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Using BIM to reflect critical project management items

Gabriela Pineda

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Escola de Engenharia

Gabriela Estefania Pineda Alvear

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Master Dissertation
European Master in Building Information Modelling

Work conducted under supervision of:
Maria Isabel Brito Valente
Jan Wium

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Gabriela Estefania Pineda Alvear

RESUMO

Durante a fase de construção é necessária uma grande troca de dados. Essa troca de informação é feita por diferentes intervenientes e está relacionada a diferentes fases desse processo. A importância e a criticidade dessa informação dependem de vários parâmetros, mas o gestor do projeto deve agir de acordo com cada troca de informações. Para isso é necessário filtrar e classificar essa informação de forma que o gestor do projeto tenha uma visão clara de todas as questões e possa decidir, acompanhar ou agilizar a decisão sobre os itens mais importantes e críticos para evitar atrasos e desperdícios de tempo. A indústria ainda carece de uma priorização adequada da informação e tarefas associadas, assim como de uma forma de materializar isso num ambiente BIM para facilitar a visualização e a condição existente do projeto em curso.

O principal objetivo deste trabalho é reduzir significativamente o tempo que os gestores de projeto gastam para priorizar os problemas que surgem durante a fase de construção. Isso é feito apresentando automaticamente os itens em causa no modelo, de forma diferenciada, com base no volume de troca de informação entre as partes interessadas. Os objetivos da tese são assim identificar uma fonte adequada de comunicação num formato que possa ser extraído e mantido numa base de dados para que possa ser usado no futuro, ter uma matriz de priorização clara que possa ser implementada e, finalmente, refletir a criticidade dos itens em o modelo BIM.

Esta pesquisa providencia uma tentativa de desenvolvimento de um modelo BIM que reflita todos os itens de acordo com sua importância e criticidade de forma rápida e fácil de entender, através de uma escala de cores identificativas: verde, amarelo e vermelho. Verde para itens que não são críticos nesse momento, amarelo para itens que devem ser verificados assim que possível para que não atinjam o valor crítico e vermelho para itens que já são críticos nesse momento.

Palavras chave: gestão de construção em BIM, gestão de projeto, itens críticos, questões de visualização, tarefa prioritária,.

ABSTRACT

During the construction phase a great exchange of data is required. That exchange of information is made by different stakeholders and related to different phases of the process. The importance and criticality of that information depends on several parameters, but the project manager must act according to each exchange of information. To that it is needed to filter and sort them in such a manner that the project manager has a clear view of all the issues and may decide, keep track or speed up the decision on the most important and critical items to avoid delays and time waste. The industry is still missing a proper prioritization of information and associated tasks and a formal way to display that in a BIM environment to facilitate the view and perspective of the existing status of the ongoing project.

The main purpose of this study is to significantly reduce the time that the project managers spend to prioritize the problems that arise during the construction phase. This is done by automatically presenting the action items in the model based on the volume of information exchange between stakeholders. The thesis objectives are to identify a proper source of communication in a format that can be extracted and kept in records so that it can be used in the future, to have a clear prioritization matrix that can be implemented and to finally reflect criticality of items on the BIM model.

This research offers an attempt to develop a BIM model that will reflect all the items according to its importance and criticality in a fast and easy to understand way such as color grading of identification: green, yellow and red. Green for items that are not currently critical, yellow for items that should be taken care soon before becoming critical and red for items that are currently critical.

Keywords: BIM construction management, critical items, issue visualization, prioritizing task, project management.

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1. INTRODUCTION

Construction is a sign of development and economic growth for a country; it is an endless activity that generates employment and income. Nowadays, advanced technologies have revolutionized this industry. Project managers are tempted to improve their competitiveness and adaptation into this fast changing technological world. The pace of transformation is quick and the project managers are required to keep up, they must handle new tools, new problems and new interconnections. The incorporation of BIM as part of the interdisciplinary solution enhances the quality of construction and reduces the probability of error occurrence. The use of BIM during the construction phase produces a transparent panorama with the purpose of decreasing the cost of modifications. There are several studies that show that BIM upgrades the quality of construction cost estimation and scheduling with the collaborative working environment and the immediate share of data among project crew members. Nevertheless, the AEC industry lacks techniques to prioritize exchanging data during the construction phase, as well as a formal way to demonstrate it on the model and deliver a smooth perception of the conditions of the project.

This work proposes the use of the tools of graphical programming and visual programming to achieve the visualization of the development of the project according to the up-to-date issues that are approaching during the construction phase. It is very common to think in the construction industry it only matters the scheduling and the cost; this study believes that the organization, direction, control of communication as well as different ways of solving issues is an important matter that must be kept and recorded for further evaluation.

1.1. Problem and subject of research

During the construction phase many issues exist at the same time that must be filtered and sorted according to the importance so that the project manager has a clear view of all the circumstances and may decide, keep track or speed up the decision on the most important and critical items to avoid delays and time wasting. Song (2004) claims that there is unfinished, imprecise or outdated information because of constant changes in site conditions. As Golparvar-Fard et al. (2017) indicate in their study that the project manager needs current information on the project in a way that is complete and easily understandable; this is obtained through programmed methods to monitor the progress of the situation. BIM during the construction phase is used at the moment for comparison among the activities that are ahead of schedule, on schedule or behind schedule. There are many studies that show the construction activities when they are behind or ahead of schedule. However, the AEC industry is still missing a proper prioritization of tasks displayed on a BIM model to simplify the view and perspective of the existing status of the project.

1.2. Purpose and Objectives

The main purpose of this study is to significantly reduce the time that the project managers spend to prioritize the problems that arise during the construction phase. This study will assume that all the communication among project managers and site supervisors, engineers, laborers, skilled laborers, architectural and structural design offices is kept and registered in an electronic format, independently of the source of contact/information.

The extraction of all calls, messages, and emails is outside the scope of this study as the focus will be on the process of prioritizing them to have a better visualization of the issues. The process would include applying a filter of word count and looking for the word “urgent” “exigent” “emergent” “serious” to have an organized view in reliance on the needs of the user. The process would also check if there is an issue with an item of the construction that is part of the critical path to be aware that requires immediate attention. The process would also involve recognizing the sender of the communication and measuring the importance of the message by the transmitter of information. Another process will take into account the ranges of criticality according to the needs of the user and display the issues according to these limits of time and volume of information. The study will propose a solution applying the mentioned processes into an example project model described in the case study section.

1.3. Dissertation Structure

The dissertation is divided into seven chapters. A brief description is provided in the following paragraphs and the connection between the chapters is shown in Figure 1.

Chapter 1: Introduction. This first chapter gives a clear outline of the study, it will explain the problem, the possible solutions aimed with the research, the significance of the topic and the structure of this dissertation work. This chapter describes briefly the process that was followed in order to reach the objectives, namely the definition of critical items by including information exchange.

Chapter 2: Literature review. This chapter reviews the current literature and studies performed on the subject so that there is an identification of missing information, it will also give background and conceptual definitions and applications.

Chapter 3: Framework application. This chapter also discusses the projected method for this dissertation, there will be an appropriate explanation of the steps until succeeding its final purpose. First, checking and defining all the sources of information; then, deciding how to quantify the database of communication, establishing limits, validating the limits with a survey and finally the application into a case study. There are four scripts developed by the author of the dissertation, one for naming convention, another one for changing the building date of the elements in the excel file and import back with the new information, another script for a creation of a 3D view with transparency of elements, and finally the script that imports the communication information, sort and classifies this to change the color of the elements according the category of criticality.

Chapter 4: Survey Methodology. This chapter covers briefly a survey made by the author of the dissertation and will address the results for classification of the criticality scenes with reference to the respondents.

Chapter 5: Case study. This chapter gives details of the selected case study with its fictitious assumed issues that will arise during the construction phase. Additionally, this chapter shows the simulated extracted information from emails, text messages and calls, the classification and the ranges that will be initially applied to the script. In this chapter, one can find the architectural, structural, plumbing, sanitary and electrical issues selected for the fictitious example.

Chapter 6: Graphical programming model and application of the visual programming script. This chapter reflects the model of the case study with its particularities and elements. This project will include structural, electrical, plumbing, sanitary and architectural models. This chapter also includes the application of the script developed by the author of the dissertation.

Chapter 7: Conclusions. This last chapter summarizes the content, the results and final contribution to the industry as well as recommendations for future research.

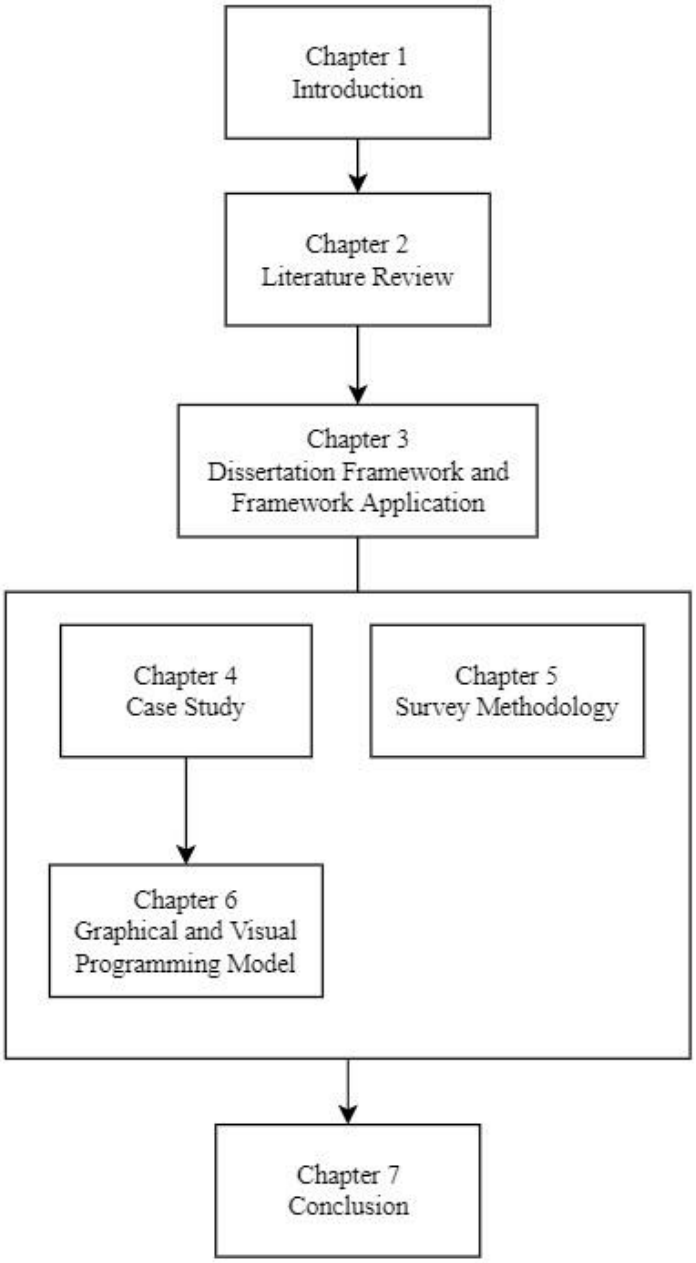

Figure 1 – Dissertation Structure

1.4. Dissertation Framework

The initial phase of this dissertation development was to determine the problem, to have a clear understanding on the topic with its properties, objectives, scope, gaps, possible solutions. The literature review contributed to this phase and allowed the author to identify many studies and researches that have aided the construction phase.

The second phase included a decision to check and define sources of information, what will be considered? In the construction site there are different ways of communication: direct approach (personal conversations), calls, text messages, and emails. For this dissertation, the direct approach will not be considered since the author perceives it as tough work to record and extract these dialogues.

The third step was to arrange a meeting with a project manager from Guayaquil, Ecuador, where the case study is situated. From this meeting many problems that take place in construction were added to the case study and the ways how the concerns are communicated to the project manager. After this, there was a quantification of the database of communication.

The fourth stage involved a definition and establishment of limits of the study and of criticality. Many of the topics like bureaucratic, legal, environmental will not be considered because of the lack of physical connection with the model, this disabled the possibility of reflection for visualization. The subsequent action was to validate these limits with a questionnaire that will obtain the insights of workers in the AEC industry and academia.

After this, the visual programming for the research was also developed by the author and several scripts were elaborated to achieve what was initially expected. Unfortunately, the author failed the attempts that included linking the data to the model with recognition of location of the item or room where the item is placed. The attempt 3 that involved the naming convention of all the elements forming the graphical model succeeded and this is how it was possible to continue with the colored visualization of the items in the model.

Next, the application of a case study is compulsory to corroborate the functionality of the proposed methodology. For the case study, the student developed the graphical programming model with the disciplines of architectural, structural, electrical, plumbing and sanitary included.

All of this is better described in Figure 2, where an illustrated summary is provided from the problem statement up to its solution.

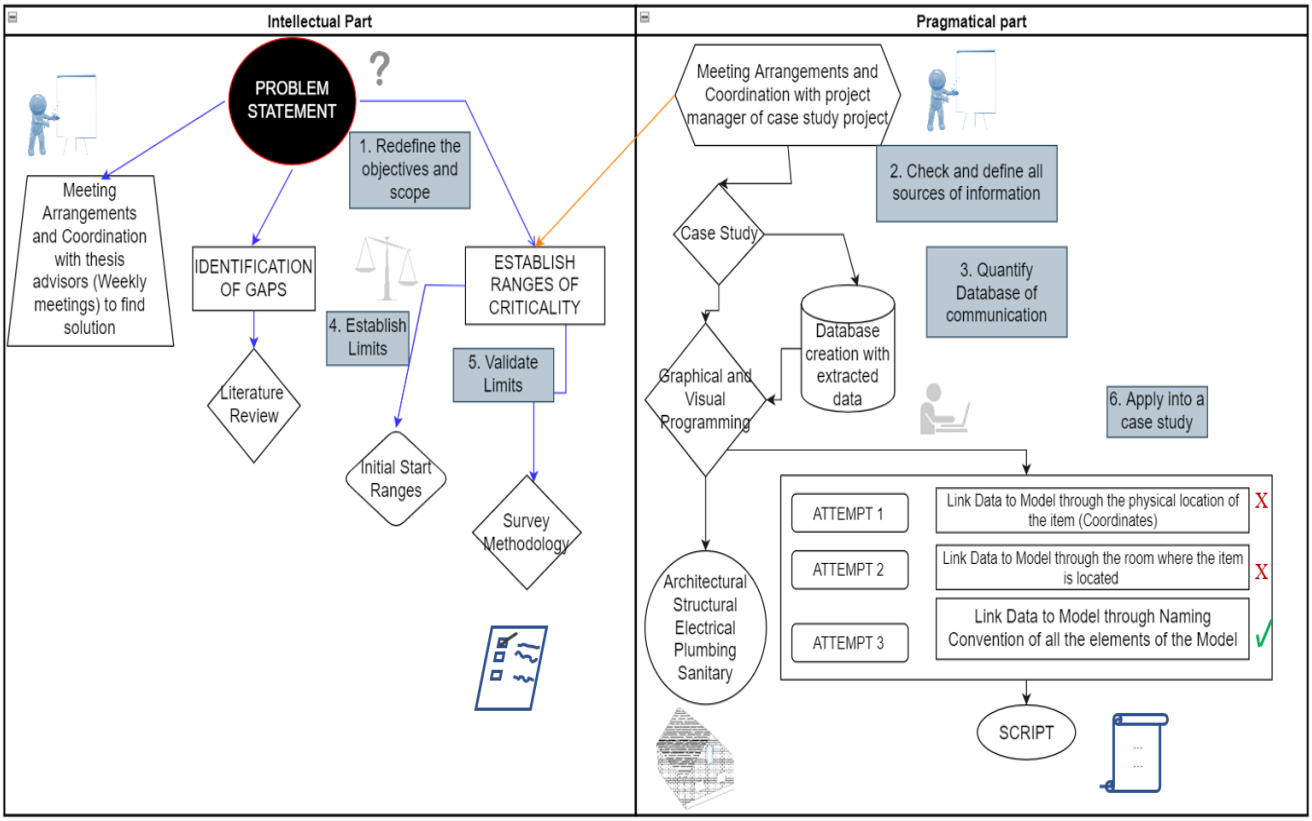

Figure 2 – Framework of dissertation

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2. LITERATURE REVIEW

2.1. BIM

There are several definitions of BIM, but the most suitable ones for this study are the following: BIM refers to all the tools and procedures related to building production (Gaspar & Ruschel, 2017). BIM is a technique of introduction of digital information into different virtual environments to succeed in the construction area (Liu et al., 2021). Therefore, the use of BIM is essential in diverse areas, it contributes to a considerable decrease in time waste which translates as well into significant cost savings due to the ease of managing, sharing and exchanging information.

2.2. Role of project manager

The project managers are the ones that are supposed to keep up-to-date track and keep the construction activities going on without stopping to avoid costly unwanted delays, the project manager needs information from various site workers (Song, 2004). Project managers are supposed to consider different approaches foreseeing possible interruptions and variations on site conditions; for this reason, they need the actual schedule, cost, design and performance information provided on time and in a way that is easy to understand (Golparvar-Fard et al., 2017). According to Song (2004) accurate methods are needed for site control and construction management. The site conditions are constantly changing and this makes the information of the drawings incomplete and inaccurate during this phase. Over time the construction stage gets more difficult and a project manager should invest more effort in order to comply with contract finishing on time, within budget (Khanzadi et al., 2020). This effort can be diminished if processes are automated to eliminate human errors, to increase efficiency in control, management and monitoring.

The management roles consist in being a leader guiding the team members, a spokesperson to express all concerns openly among stakeholders, a businessperson looking for the interest of the company, a supply allocator, the connection establishing cooperation and relationship, and an observer to monitor progress. All of these roles involve continuous information exchange that if organized properly can result in effective management. Communication is used from the beginning of the project before the construction phase, the information exchange occurs during meetings, get-togethers, emails, papers, verbal and direct communication. The important part that leads to a successful project management is to master the skills for planning, organizing and coordinating the tasks. There is a lack of competence to effectively arrange the communication in order to continue with systematized processes and positive outcomes (Karlsen et al., 2020).

2.3. BIM during the construction phase

The application of BIM for the construction phase is still in early stages at the moment, even though this stage is considered highly important and despite many academic developments, there is an absence of methodologies of BIM during the construction phase related to criticality of information exchange and how it affects the project manager decisions (Lin, 2015). The proper implementation of BIM during this phase has proved to minimize risks, track progress, improve quality and reduce costs (Tu et al., 2021). This should be considered a motivation to extend the use of BIM during the construction phase, but the

reality is that there are numerous research analyzing the implementation of BIM for several companies for the design phase and there are various studies for the use of BIM in the operational phase. It looks like the construction part is skipped; maybe due to the dynamic characteristics of the projects in this period or maybe because it requires plenty of work and support of all stakeholders. The incorporation of BIM will mean that there will be less request for information, less change orders and rework. There will be upgraded efficiency and easier data trading in a visual manner. This also means that the track and update of information can be done faster. It is imperative to fully comprehend that the BIM application does not end after the design phase (Lin, 2015). Without the use of these technological tools, the project managers are given a collection of data containing spreadsheets, bar charts, drawings, specs that would take a lot of effort and time to be able to understand, analyze and sort all this information; this surely affects the construction status instead of having proper representations in the model, this will be reflected in costs. It is true that the implementation of BIM requires investment for platform, training and defining workflow but all of this can be reflected in monetary savings avoiding issues and working faster in a more collaborative way. The suggestions for BIM adoption are to have a strong support from the firm, recognize that it requires training and effort, time and investment (Lin, 2015). The combination of BIM will ameliorate inclusively construction management leading to a higher return on investment and income (Jrade & Lessard, 2015).

It is clear that the use of BIM during this period permits enhanced communication, interaction among workers and reduces conflicts and unnecessary work. However, there is little research in this area and requires more discussion. The incorporation of BIM for the construction part concedes better identification of items, precision and quality; avoiding improvised decisions (Lorenzo et al., 2014). To stimulate better construction practices, it is advised to mix the integrated time and cost management system with BIM tools and processes. Registered updates of the model within time and costs will allow them to take major decisions, enhance communication and involve every stakeholder so that they can visualize and coordinate(Jrade & Lessard, 2015).

The change orders and schedules vary constantly, they should be adjusted based on 4-D and time-based records. The mixture of BIM and other technologies for example augmented reality significantly upgrades the quality in construction management. BIM is seen as a way to visualize and coordinate work; but using BIM tools one can also produce and preserve information beginning from the design until the maintenance stage. This data should be detailed, organized following a structure for fruitful decision making (Chen & Luo, 2014).

The limited information during this phase makes it a challenge to overcome the structural disintegration of the on site work. The main reason for BIM incorporation into this stage is the visualization of difficult four-dimensional situations for effective communication and simple manipulation of complex issues. There is a superior understanding of the materials of the elements in construction projects for the different subcontractors of various disciplines involved. BIM can help understand better the details of construction, realize independence of events (Bråthen & Moum, 2016).

During the construction phase where the structure initiates its contour, a lot of different types of data are produced and calls for input of several resources. There is a lot of information produced during the construction phase that cannot be linked to the 3D model because it is a non-figure information (Lee et al., 2018). The use of BIM during this phase will reduce or even eliminate overlapping information since

the traditional ways of construction analysis are time consuming and the integration of BIM technology will boost this step (Yang et al., 2013).

The purpose of the incorporation of BIM is centered on the all the containing data that brings to the project; BIM makes it possible to handle great capacity of data, to gather several characteristics of the different stages of the project and store it in the model so that it is easier to find construction information for further references maybe for the operational phase like in facility management of the assets. There exist several types of information that require filtering, classification and identification of value so that there is a clear understanding of the important information. The value of information is not objective; it depends a lot on the own interest for the project characteristics and future uses of data (Wijekoon et al., 2016).

2.4. Importance of visualization during the construction phase

To achieve accurate and fast decision making, project managers have to be able to visualize the problems easily. Several studies affirm that visualizations can reduce or even eliminate the smallest possibility for errors, and that decisions are made accurately and faster. (Song et al., 2005). Workers of any level of knowledge can understand the construction progress visualizations. If it is colored, it is easily represented and can be transmitted accurately (Golparvar-Fard et al., 2017). The visualization contributes to an enhanced communication among workers and project team members that can expansively observe and foresee construction problems easily. Incorporating computational processes can be a way to continuously reinforce each discipline of the project. (Fischer, 2006) The complexity of the processes during the construction point to incorporation of visualization technology to achieve a better quality assessment. (Chen & Luo, 2014)

The visualization proposed by Golparvar-Fard et al. (2017) includes color coding indicating the performance and percentage of completeness of the actual performance compared to the planned and expected one (Figure 3). This is possible through site photographs superimposed.

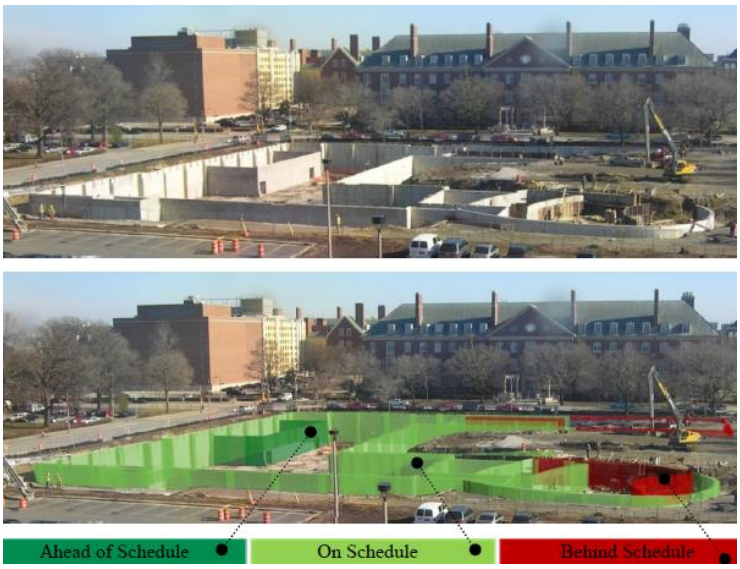

Figure 3 – Color coding visualization example of construction percentage (Golparvar-Fard et al., 2017)

Actual ways and formats of handling monitoring may not be the right ones to establish recent situations (Golparvar-Fard et al., 2017). Manual data extraction will be a time consuming practice that will distract the project managers from decision making of priorities. Automated procedures will reduce time for addressing issues and will do it more accurately. There should be more automated methods to have integration of problems into the model so it simplifies the identification of possible solutions for the numerous dilemmas. There are no standardized ways of including communication information during the construction phase into the model in practical means for diverse disciplines.

The success in the construction stage is possible with clear communication and integration among all parties (Martins et al., 2020). The AEC industry has been embracing several BIM tools but none of them are adequate for construction structure, forecasting and graphical visualization of this phase. The lack of this illustration will jeopardize the culmination of the project. There are many challenges that appear while embracing the BIM collaborative tools for the construction period. They state that BIM is not restricted to the 4,5,6 mentioned dimensions representing timescale, budget, other considerations for facility management; but, BIM Is for more integrations that can include visual aspects for planning during the construction step.

The several comments exposed previously clearly represent a shout out for paying more attention to the construction phase, considering it just as important as the design phase; equally urgently needed for development of tools in order to ameliorate the environment for this stage. Therefore, in this dissertation, the graphical and visual programming are used to develop the tool that will serve the dissertation's necessities.

2.5. Graphical Programming Interface

Graphical programming interface allows the user to customize the building information workflow, and permits an interaction with the prototype so that the visualization is a part of the workflow (Zwart & Pipe, 2015). The interface is part of the solution to many AEC problems that arise during the design phase; it is intended to offer an environment to demonstrate the pattern. Revit is a software developed by Autodesk that meets the requirements for the purpose of this study, it will be used to develop the visual issues aid. Revit is widely used globally and offers a useful extensive scope that works well with dynamo because of the developed plug-in that facilitates the interoperability between them. The use of this tool will allow the inclusion of communication information into each of the elements that have issues during the construction phase.

2.6. Visual Programming Interface

Visual programming environments are used for traditional textual languages; to envision associations among the structure of data helps to combine and elaborate program modules. Programming visually may be reachable for more users and this approach will increment the user agents that will implement it so they can reflect their particular needs into the script development until becoming inserted into the personal computing space. The visual programming tool used for this study is dynamo which is an innovative tool designed to extend the capacities of the graphical programming interference. Through the implementation of dynamo, it will be possible the organization, classification and illustration of information into the graphical programming interface.

2.7. Prioritization of activities

Numerous issues that appear during construction can be foreseen and prevented from occurring in the design phase, they can be even identified before establishing communication about the issue (Mehrbod et al., 2019). Studies indicate that more than fifty percent of the coordination mistakes have a direct influence on the budget; therefore, successful management involves cost effective projects. Mehrbod et al. (2019) claim that there are few studies on identification of issues. Project management work becomes more critical with time, mainly when the designs are sophisticated, for this reason the prioritization of tasks is crucial to enable good management and be able to focus principally on the critical tasks (Baykasoğlu et al., 2011). The resulting success of the building project goes according to the leadership style of the project managers. Many researchers believe that project managers should focus on all the activities and not only activities from critical paths as it is commonly expected; they manifest that these ignored activities could rapidly become critical activities if ignored (Heravi & Gerami Seresht, 2018).

Management of issues during construction are considered a priority and the documentation of them is considered essential and they study the possibility of keeping a record of the issues so that they can always go back to them. The research of Mehrob et al. (2019) found that there is more missing information and as-built inconsistency. The record of issues is vital to propagate useful understanding on the learning of previous projects' complications. The authors have decided to divide the issues into: multiple –systems conflict, which are issues that need to handle the connection of different systems in small spaces such as ceilings, walls, etc.; as-built inconsistency, which occur when there are last minute changes due to unexpected space or resource and missing information, when there is not enough data about project requisites and guidelines. Initial Characterization of issues were divided into design, construction and operation problems.

The construction is the resulting sum of several independent tasks; therefore, a risk assessment matrix is decidedly necessary for the identification of prioritized tasks. Another type of categorization would be: site, environmental, design and management aspects. Quite a few studies describe that many software and methodologies does not take into consideration the unique needs of the user; they do not allow an interaction with the client and the automation of the prioritization of tasks reduces the labor cost, this fact increases the value of these tools that encourage quick decision making for prioritization of activities (Sapunkov & Afanasieva, 2019; Wambeke, 2011).

2.8. Criticality

The term criticality in infrastructures has not been properly defined; there are no standards, specifications or recommended methods (Theoharidou et al., 2009). The criticality can be weighted with respect to the severity, complexity and impact. The severity relates to security, impact relates to space, complexity when talking about dependent activities and requires multiple interactions. Critical factors have an economic and environmental impact, as well as a direct influence in the dependencies of tasks.

The prioritization basis is typically taken from what the project manager believes, or from experience from previous projects. Moss and Woodhouse (1999) applied a technique for ranking probable situations by significance and also stated that the basis for prioritizing is a combination of knowledge, experience, probability and consequence. There is also a weighted score approach that is commonly applied for

determination of critical activities for each considered case with the unique conditions of a specific project. These critical activities can be measured as a subdivision of risk.

Several authors reach an agreement that criticality depends on the user impact assessment and decision criteria (Theoharidou et al., 2009). It is proved that companies prefer to base on project managers experience to manage tasks empirically rather than following a methodology for decision making or choosing criteria for criticality (Mano et al., 2020).

There are small tasks and activities not part of the critical path that must be addressed quickly because if ignored, they can delay bigger tasks that are important (Mano et al., 2020). The opposite case also happens when non important activities at a specific time should be ignored to focus on activities that have more value. Therefore, criticality is constantly changing over time inside the same project or even inside the same activity, even though it is a minor activity it may be crucial to pay attention to it at the right time.

Meng (2019) supports the idea of standardizing the construction production. The application of methods in construction vary according to the project, for example, for residential projects, it is easier to implement BIM and project managing tools than to apply this in highway projects. Time cost and quality performance are all equally considered for decision making in the construction area. There are recommendations for project managers to create rules, norms, naming conventions and other needed conditions inside a company in order to rank the criticality. There are some mixed criticality systems where there are different criticality levels according to the needed conditions of the project (Crespo et al., 2014).

The information can be categorized and classified according to the own needs of the user, they can be recognized, filtered and sorted in specific ranges or limits set previously in an automation procedure to be able to handle information in a way that the criticality of issues can be distinguished effortlessly.

2.9. BIM applied for criticality

The benefits of applying BIM for decision making are multiple such as a proper visualization of items of the critical path, clear view of the sequence of construction, all of this allows a proper monitoring of the progress. It is clear that traditional ways are limited and they require technological advances to successfully increase productivity and profit, and reduce time consuming and possible mistakes. This is the reason why Toledo et. al (2014) proposed a semi-automatic technique for color coding controller resolution in the construction phase. The proposed coloring indicates not critical, critical and highly critical (Toledo et al., 2014). Many researches used the critical path method as well to show advancements according to the planned schedule where the classification is done by checking if it is ahead or behind schedule; these researches have defined a methodology for visualization of the representation of the construction phase (Castronovo et al., 2014) (Kassem et al., 2015) (Bosche & Haas, 2008).

The goal is to have a clear understanding of the criticality which is possible due to the color visualization; this contributes to the proper prioritization of tasks and makes it easier to develop a strategy (Guevremont & Hammad, 2017). The BIM adoption in terms of criticality will allow a fluent project information exchange. The models with all the information have proven to be very fruitful for

construction management since it promotes interaction and collaboration among stakeholders. The actual studies have a common purpose to monitor the progress in construction to foresee possible problems and define a critical analysis. (Y. S. Chen et al., 2013)

2.10. Issues during the construction phase

There are many issues that arise during the construction stage that significantly alter the phase as planned and will result in a considerable cost increase, time waste and low productivity. Many of the issues occur because of the process separation, there is not a proper fluent continuity between the design and construction stage. There must be a fixed main goal among all team members to conclude the project successfully, but this idealization is far from being real. The reality is that there is poor communication, poor management, poor planning and scheduling, poor predictions of time, site conditions and techniques, poor knowledge of risks and constructability (Sepasgozar et al., 2019).

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3. FRAMEWORK APPLICATION

During the construction phase of a project, there will be records of emails, text messages and calls for the purpose of this simulation. The means on how to extract and store the information from these communication sources is not considered in this work as it is outside of its scope. Therefore, it will be assumed that all the exchange of information is already in digital format and can be stored and clustered with a given database.

To that purpose, a database file (in this case a xlsx file) contains all the information grouped in specific clusters (appendix 1). The database would contain the information shown in Table 1 shown in the next page.

The data integration into the graphical programming model is possible through the visual programming tool. The previously mentioned xlsx file can be imported and the needed information is sorted by the needs of the user.

There is a combination of the information and the model. The analysis of the data is processed through filters that would go in agreement with the desires of the project manager. In this stage, there is a requirement for the user to interact with the tool involving a real time decision making, to comply with the needs of the company or his own needs to attain an accurate visualization of the item.

After the analysis is done, the visualization of data is possible through visual and graphical programming tools; inputs would be the critical ranges or limits and the outputs would be the color changes on some of the elements and the communication information incorporated into the data of the element. As it can be seen in Figure 4, after the filter analysis, the implementation of a visual programming tool is crucial for this framework. Through the script developed it will be possible to reflect the issues in the model.

The visualization of the issues will be in line with the criticality, the respective items will present a color green when they are low in terms of criticality, yellow when medium and red when it is high.

Table 1 –Information for emails, text messages and calls extracted

Information	Emails	Text Message	Calls
Sender's email	x		
Phone Number		x	x
Caller			x
Sender		x	
Remitter	x		
Call Receiver			x
Mailbox (receiver email)	x		
Receiver		x	
Subject	x	x	x
Date	x	x	x
Due date in day	x	x	x
Item	x	x	x
Location of the item	x	x	x
Selection if it is part of critical path	x	x	x
Type of message	x	x	x
Call Duration in minutes			x
Room where item is located	x	x	x

The sequence of processes includes the proposed naming convention that can be used in any model once it is ready with the elements of the various disciplines such as architectural, structural, electrical, plumbing and sanitary. The use of a visual programming tool is required to name all the elements that will be taken into consideration for the ongoing communication during the construction phase.

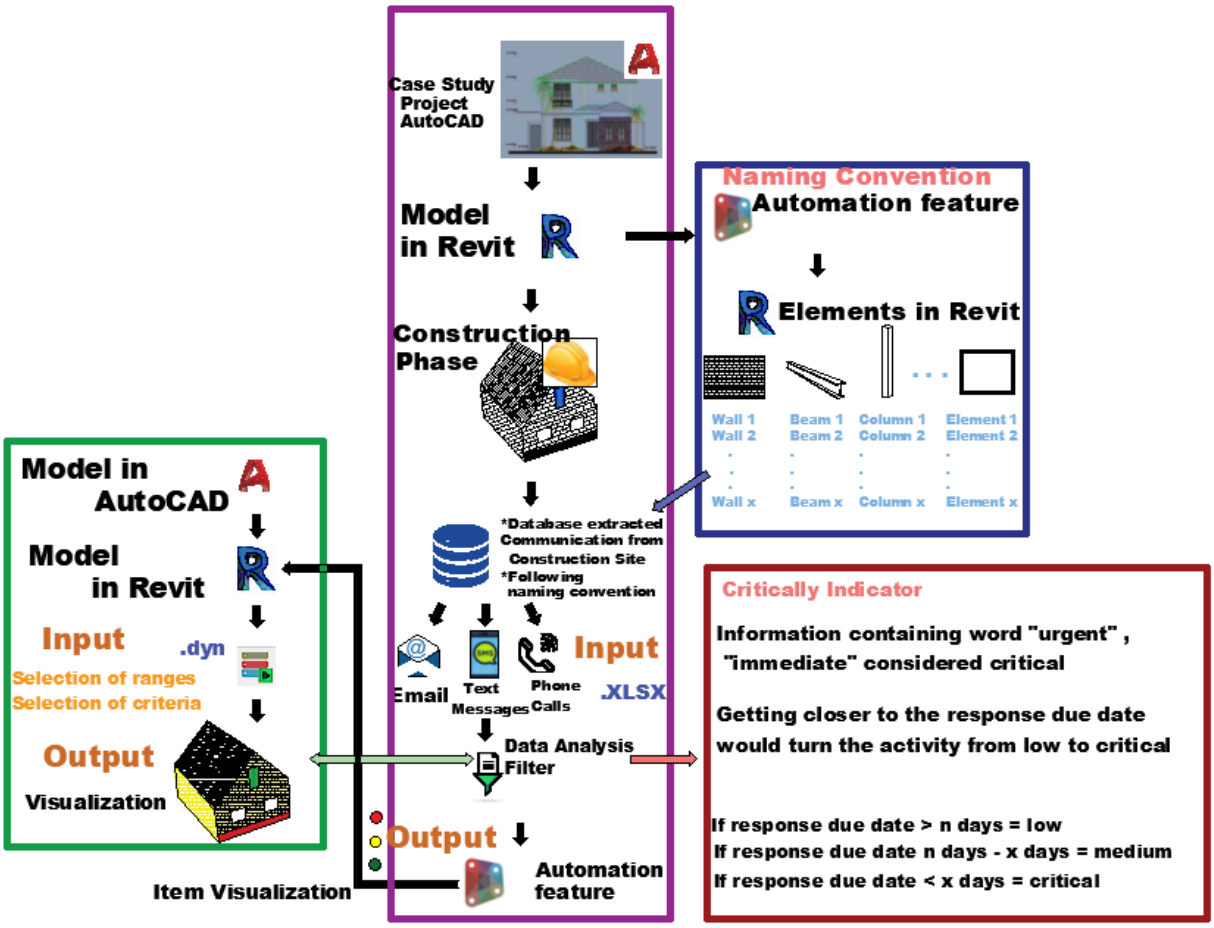


Figure 4 – Applied sequence of process.

For the critical indicator part, the script was developed according to the due date, volume of information, sender of information, matrix of volume and due date, and if the mentioned item in the communication is part of the critical path or urgent as it is illustrated below (Figure 5 to Figure 8).

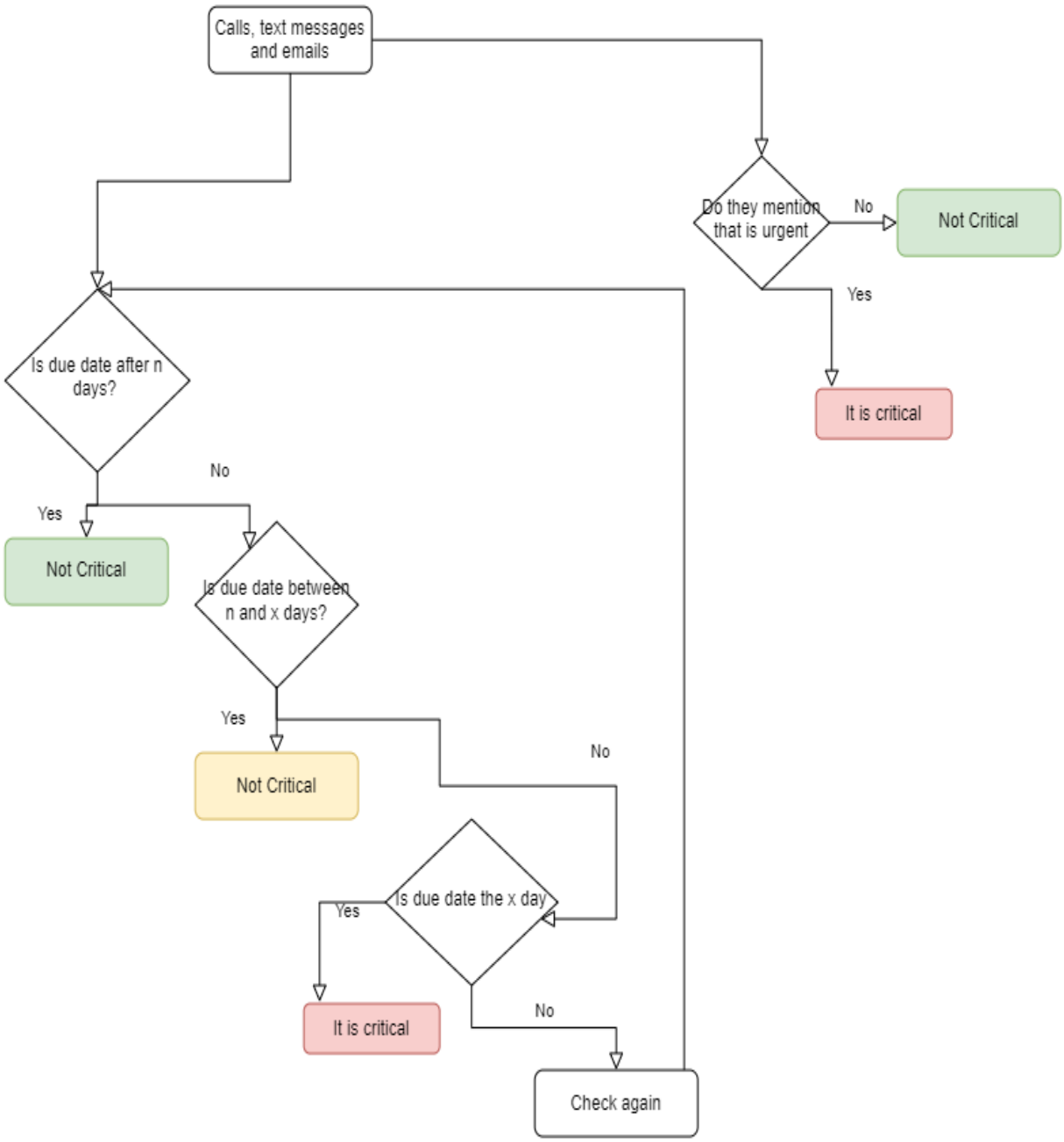


Figure 5 – Sorting of communication according to the due date

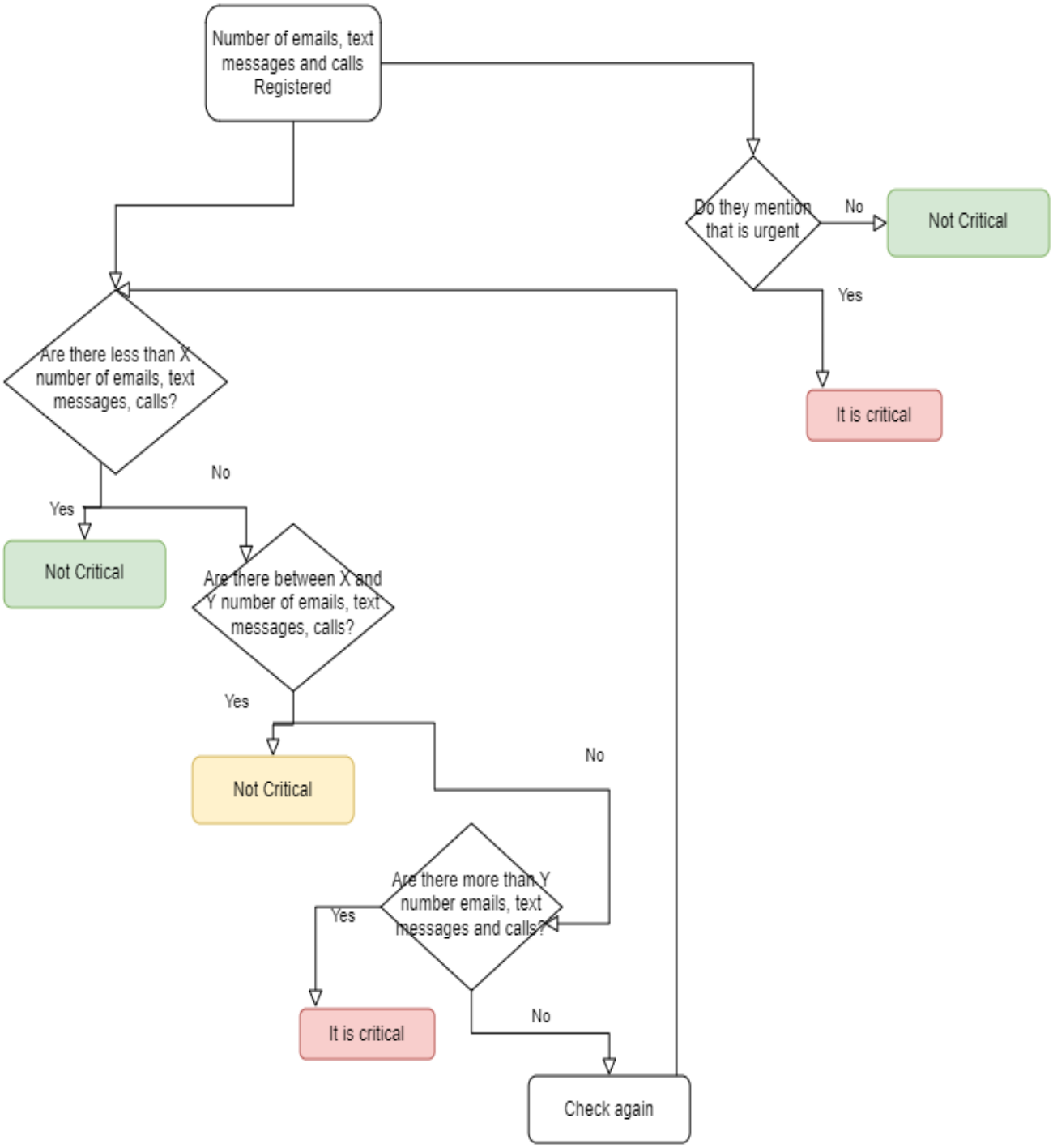


Figure 6 – Sorting of communication according to the volume of information

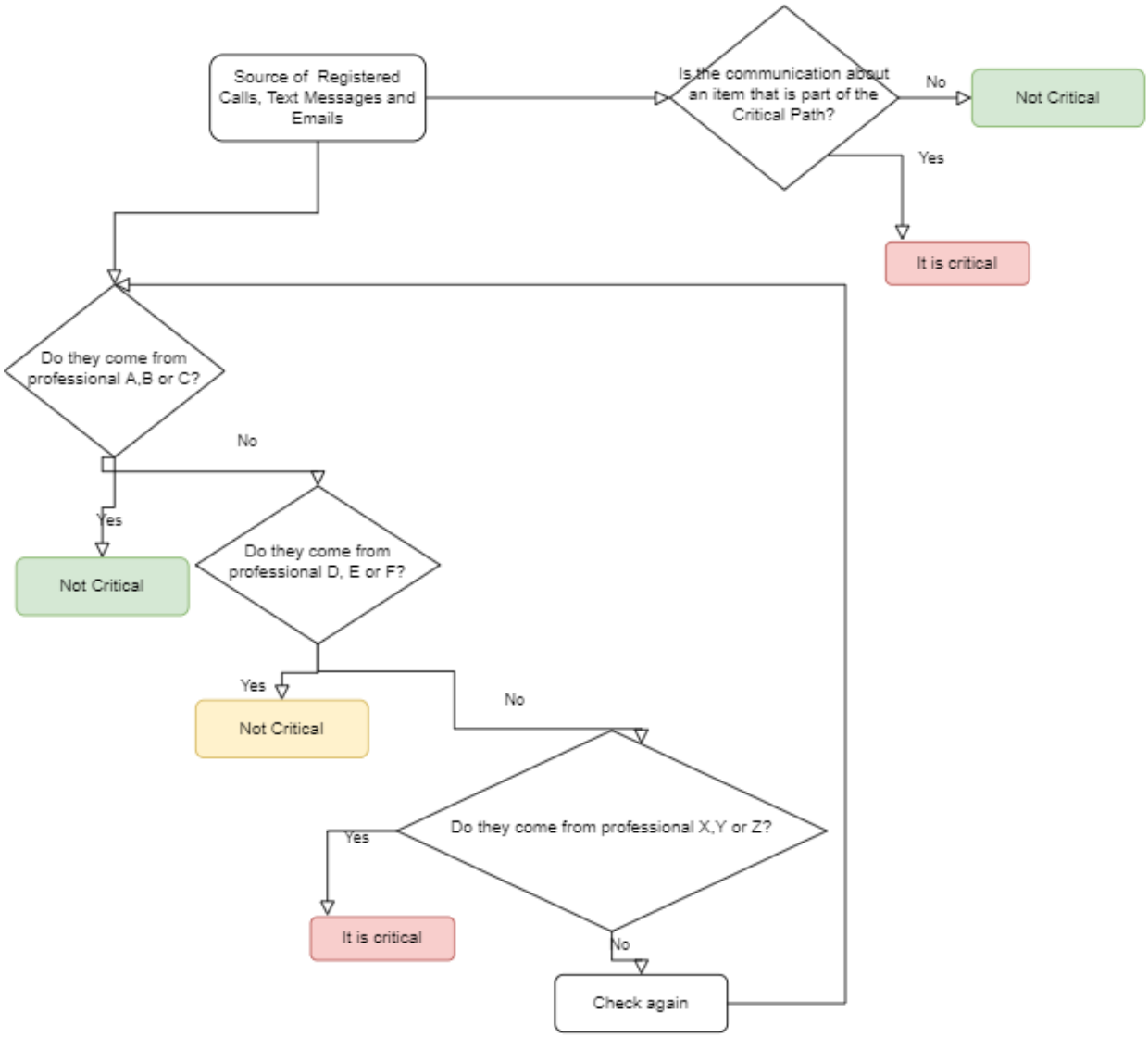


Figure 7 – Sorting of communication according to the sender of information

Volume							Time
Registered Emails, text messages and Calls	**m days**	**n days**	**o days**	**p days**	**q days**	**r days**	due date
more than x	not critical	medium	medium	medium	Critical	Critical	
between x-y	not critical	not critical	medium	medium	Critical	Critical	
less than y	not critical	not critical	not critical	medium	medium	Critical	

Figure 8 – Sorting of communication according to the matrix of volume of information and due date

3.1. Script development for incorporation and classification of data

The process of organizing and classifying the communication database is done in the visual programming tool Dynamo 2.10.1.3976. The dynamo scripts developed can run in the automatic or manual form; for this study, this is set as manually to avoid loading the process after changes.

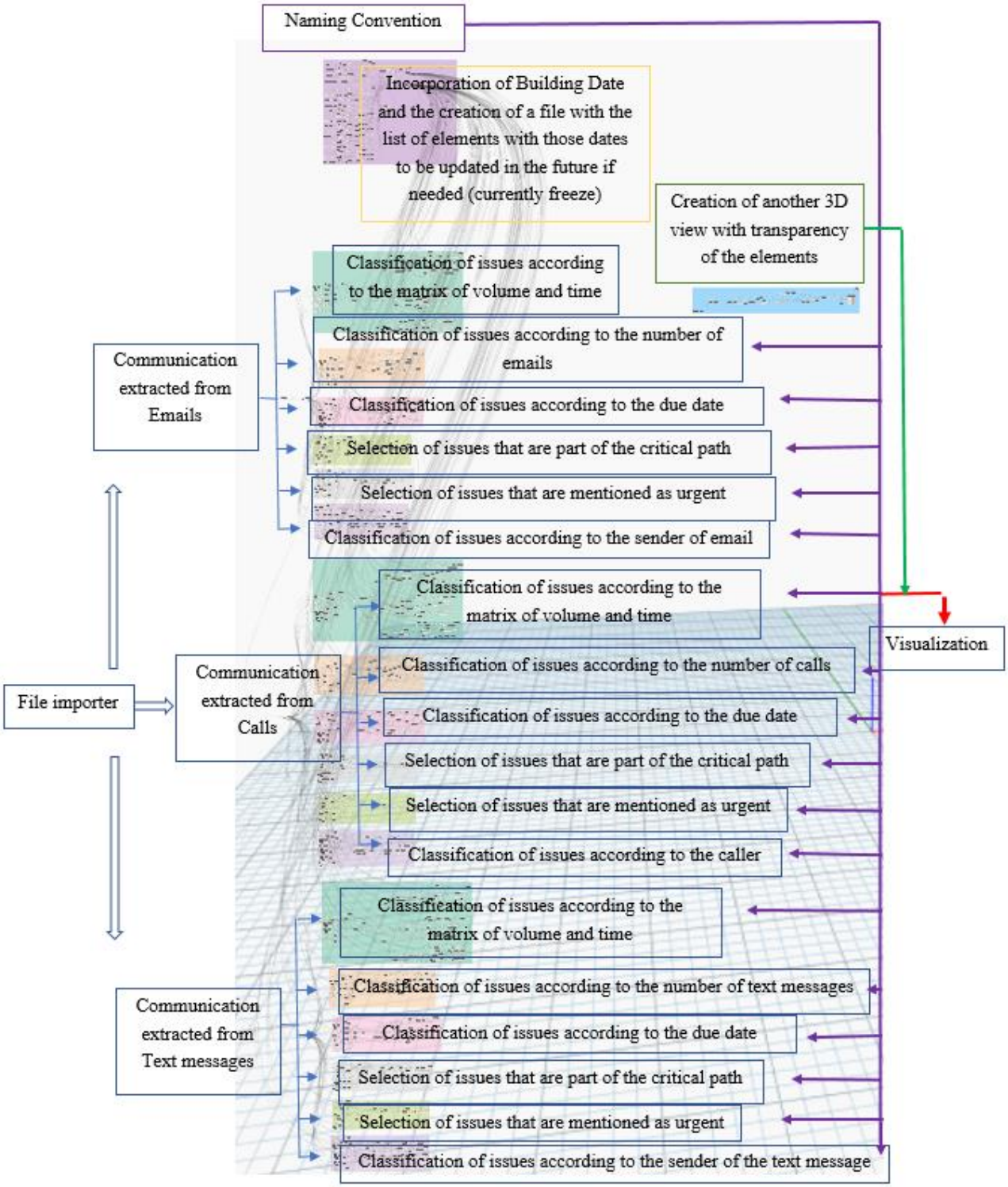


Figure 9 – Global sketch of the scripts

The global sketch of the scripts (Figure 9) shows the connection that exists with the naming convention as a previous step to achieve the visualization. The creation of another 3D view is also part of the visualization process. The next preceding steps of the script will be explained in detail in the next paragraphs.

To accomplish the incorporation of information, it is needed to import this data to dynamo through File path and File from Path nodes that can be seen in the next Figure 10.

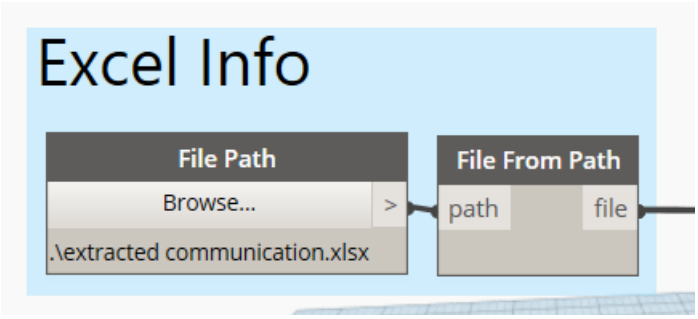
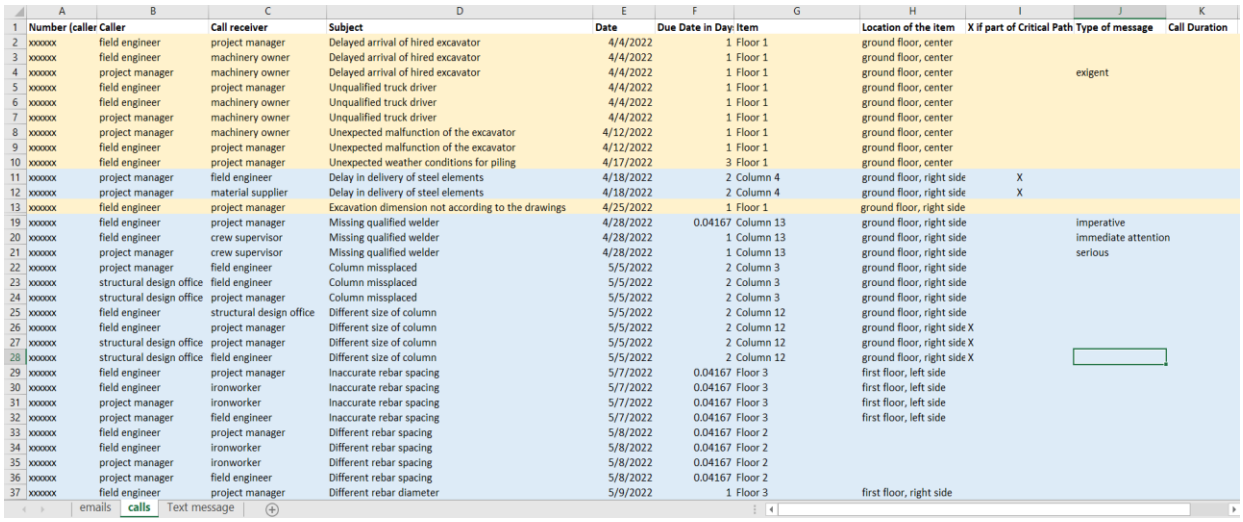


Figure 10 – Dynamo script for importing communication database



	A	B	C	D	E	F	G	H	I	J	K
1	Number (caller	Caller	Call receiver	Subject	Date	Due Date in Day	Item	Location of the item	X if part of Critical Path	Type of message	Call Duration
2	xxxxxx	field engineer	project manager	Delayed arrival of hired excavator	4/4/2022	1	Floor 1	ground floor, center			
3	xxxxxx	field engineer	machinery owner	Delayed arrival of hired excavator	4/4/2022	1	Floor 1	ground floor, center			
4	xxxxxx	project manager	machinery owner	Delayed arrival of hired excavator	4/4/2022	1	Floor 1	ground floor, center		exigent	
5	xxxxxx	field engineer	project manager	Unqualified truck driver	4/4/2022	1	Floor 1	ground floor, center			
6	xxxxxx	field engineer	machinery owner	Unqualified truck driver	4/4/2022	1	Floor 1	ground floor, center			
7	xxxxxx	project manager	machinery owner	Unqualified truck driver	4/4/2022	1	Floor 1	ground floor, center			
8	xxxxxx	project manager	machinery owner	Unexpected malfunction of the excavator	4/12/2022	1	Floor 1	ground floor, center			
9	xxxxxx	field engineer	project manager	Unexpected malfunction of the excavator	4/12/2022	1	Floor 1	ground floor, center			
10	xxxxxx	field engineer	project manager	Unexpected weather conditions for piling	4/17/2022	3	Floor 1	ground floor, center			
11	xxxxxx	project manager	field engineer	Delay in delivery of steel elements	4/18/2022	2	Column 4	ground floor, right side	X		
12	xxxxxx	project manager	material supplier	Delay in delivery of steel elements	4/18/2022	2	Column 4	ground floor, right side	X		
13	xxxxxx	field engineer	project manager	Excavation dimension not according to the drawings	4/25/2022	1	Floor 1	ground floor, right side			
19	xxxxxx	field engineer	project manager	Missing qualified welder	4/28/2022	0.04167	Column 13	ground floor, right side		imperative	
20	xxxxxx	field engineer	crew supervisor	Missing qualified welder	4/28/2022	1	Column 13	ground floor, right side		immediate attention	
21	xxxxxx	project manager	crew supervisor	Missing qualified welder	4/28/2022	1	Column 13	ground floor, right side		serious	
22	xxxxxx	project manager	field engineer	Column missplaced	5/5/2022	2	Column 3	ground floor, right side			
23	xxxxxx	structural design office	field engineer	Column missplaced	5/5/2022	2	Column 3	ground floor, right side			
24	xxxxxx	structural design office	project manager	Column missplaced	5/5/2022	2	Column 3	ground floor, right side			
25	xxxxxx	field engineer	structural design office	Different size of column	5/5/2022	2	Column 12	ground floor, right side			
26	xxxxxx	field engineer	project manager	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X		
27	xxxxxx	structural design office	project manager	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X		
28	xxxxxx	structural design office	field engineer	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X		
29	xxxxxx	field engineer	project manager	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side			
30	xxxxxx	field engineer	ironworker	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side			
31	xxxxxx	project manager	ironworker	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side			
32	xxxxxx	project manager	field engineer	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side			
33	xxxxxx	field engineer	project manager	Different rebar spacing	5/8/2022	0.04167	Floor 2				
34	xxxxxx	field engineer	ironworker	Different rebar spacing	5/8/2022	0.04167	Floor 2				
35	xxxxxx	project manager	ironworker	Different rebar spacing	5/8/2022	0.04167	Floor 2				
36	xxxxxx	project manager	field engineer	Different rebar spacing	5/8/2022	0.04167	Floor 2				
37	xxxxxx	field engineer	project manager	Different rebar diameter	5/9/2022	1	Floor 3	first floor, right side			

emails | calls | Text message

Figure 11 – Extracted communication xlsx file

The complete file that is being imported can be found in the annex 1. There is a print screen of the document (Figure 11) to explain that the document has the sheets of emails, calls and text messages with all the information.

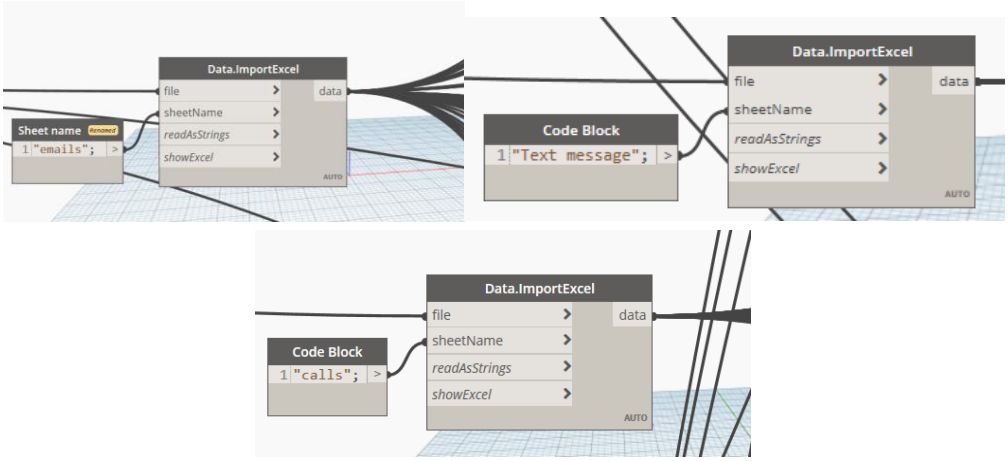


Figure 12 – Dynamo script for importing the sheets of the xlsx file

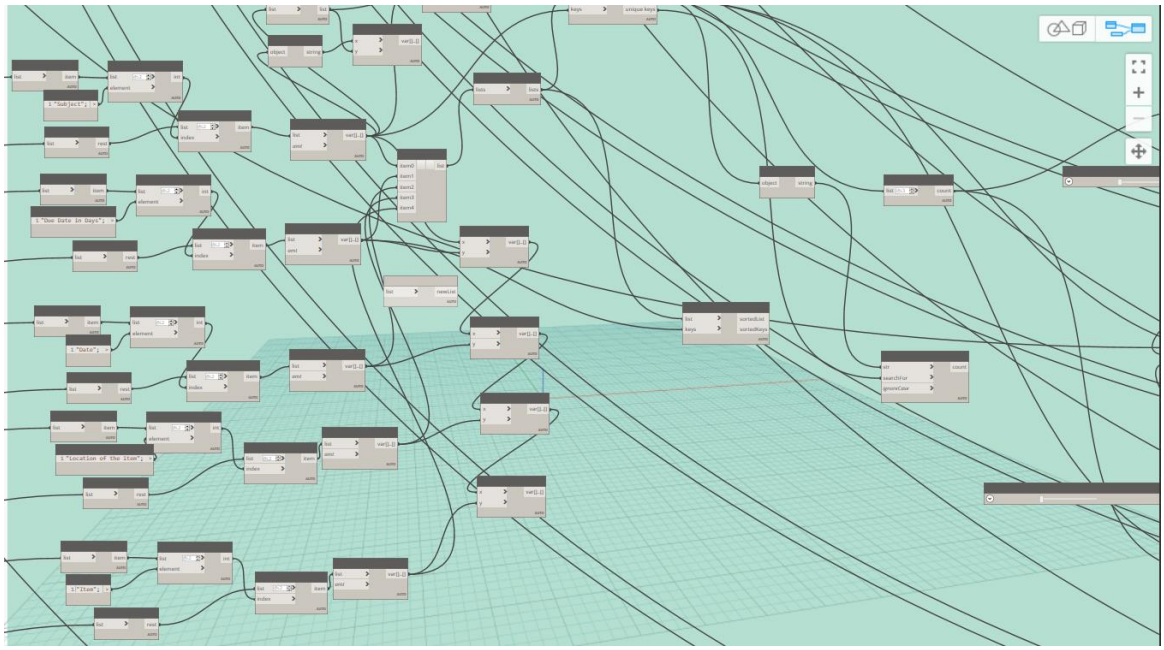


Figure 13 – Dynamo script for importing the information inside each of the sheets of the xlsx file

After importing the sheets of emails, text messages and calls, it is necessary to import the information inside these sheets that is possible with the nodes of List.IndexOf, List.FirstItem, List.RestOfItems ,List.GetItemAtIndex, List.Flatten to compress the lists and the List.Create to have a new list with all the information from the sheets. (Figure 12 and Figure 13)

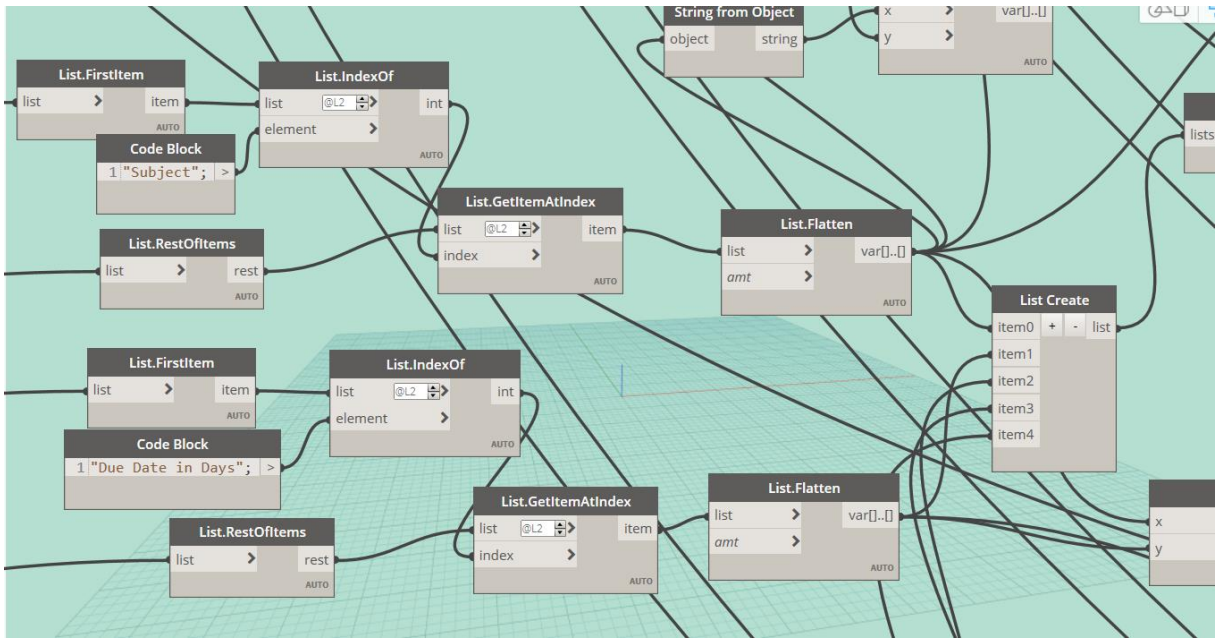


Figure 14 – Dynamo script for importing the information

Afterwards, the node List.Transpose is chosen to create sub lists of content according to the subject (Figure 14). Later, the node List.SortByKey and List.GroupByKey is applied to be able to count the number of emails or text messages or calls that there exist regarding that specific subject. The counting is possible with the node List.Count (Figure 15).

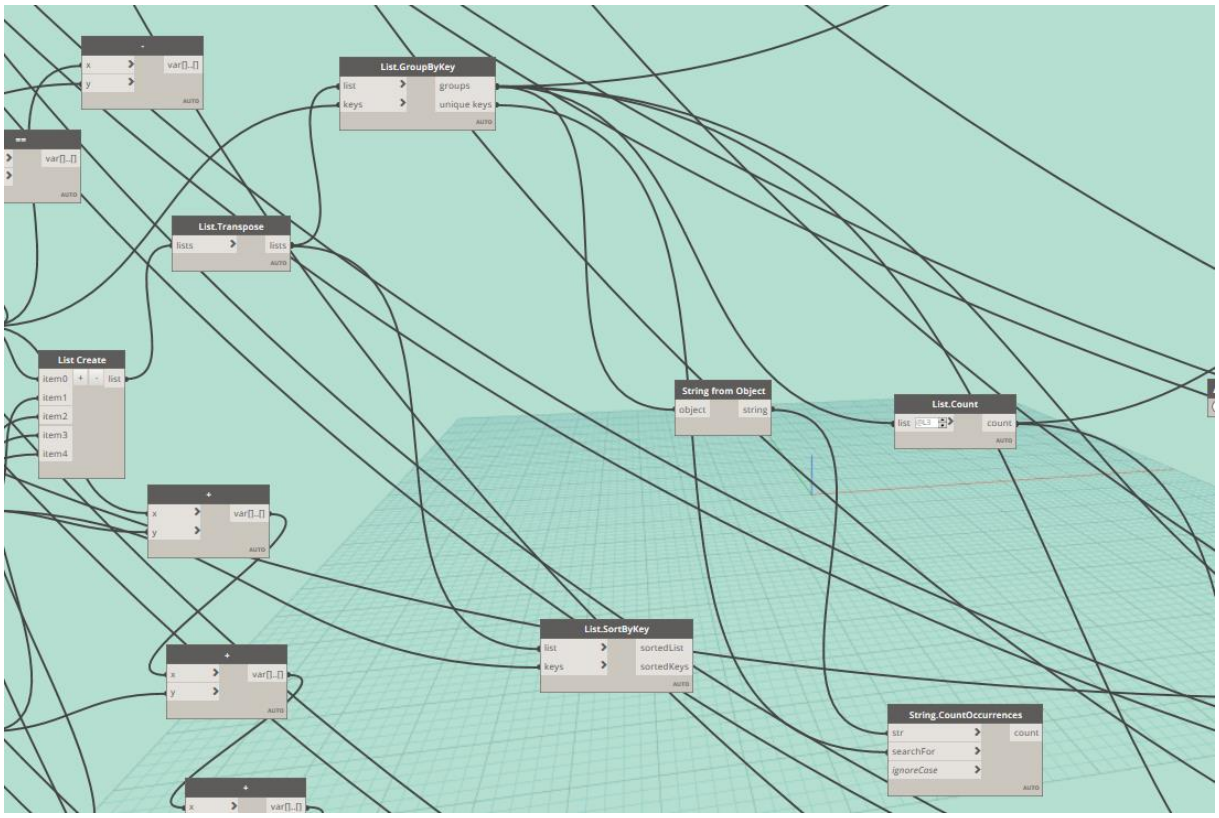


Figure 15 – Dynamo script for sorting and grouping the information

Subsequently, the user criteria are added through the node number slider and establish these sliders as inputs. These number sliders are the ranges that can be changed later by the user. The same is applied in Figure 16 for limits of due date to be able to sort the information according to the matrix of volume and due date. These will separate the information into the low, medium and high criticality.

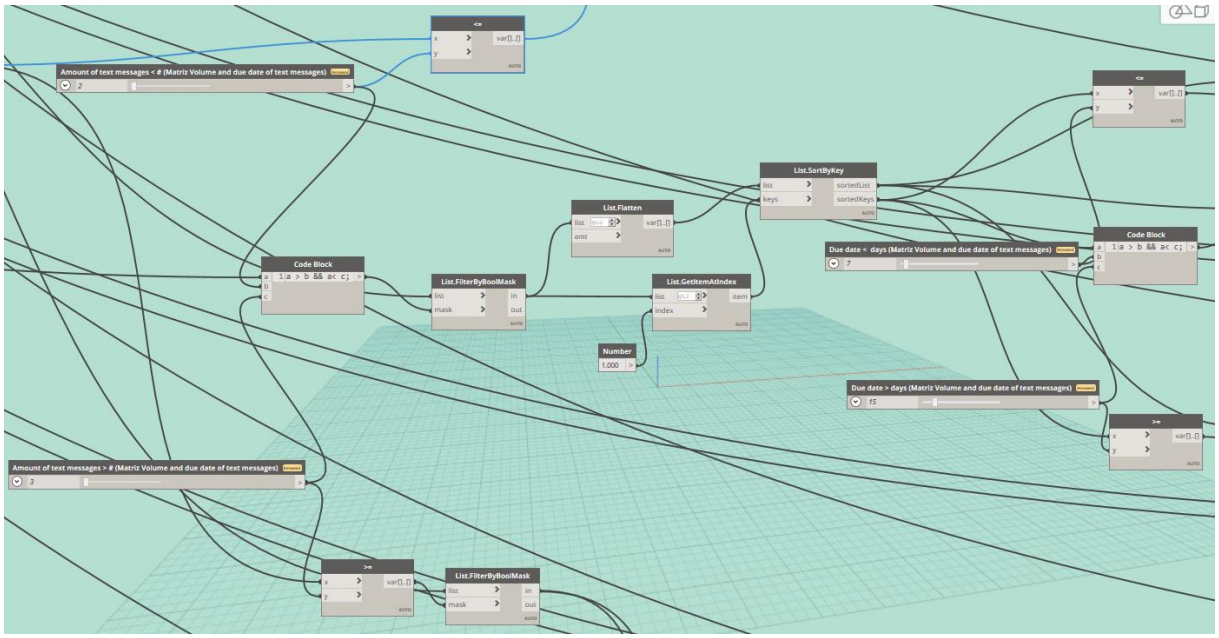


Figure 16 – Dynamo script for classification of amount of information and due date

Lastly, after the classification, visualization is possible through the nodes of List.SetIntersection, List.Contains, Element.GetParameterValueByName, List.FilterByBoolMask, Element.OverrideColorInView. The script is getting first all the elements of the model and through a filter only choosing the ones that have the mark in the low, medium and high and coloring them green if low, yellow if medium and red if high. The node used Element.OverrideColorInView will change the color of the element in the view that is active at the moment of running the script (Figure 17). Therefore, the author has developed a script mentioned later in this chapter to generate another 3D view with a transparency of the items so that it is possible to view all the elements with their changed colors. The other 3D view was created so that the script does not make changes to the original 3D of the model.

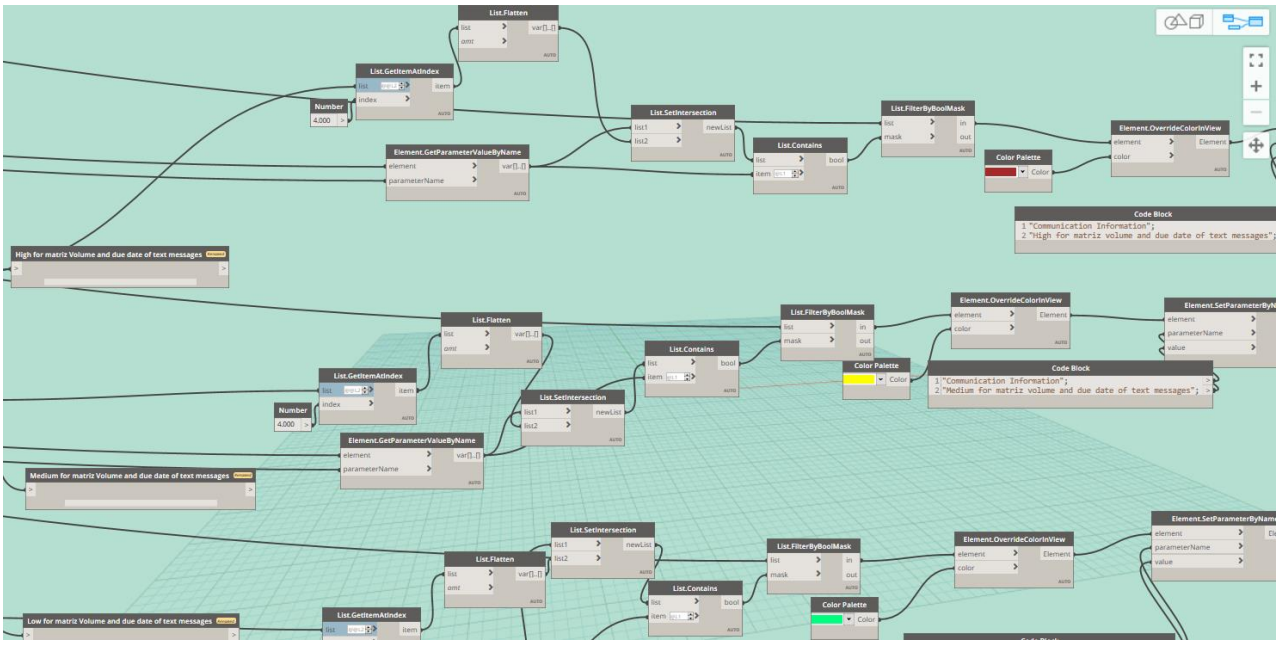


Figure 17 – Dynamo script to override the color of the elements in the current active view

Similar steps were followed for the development of the script for choosing the criteria only for volume of information (Figure 18) or only for information according to the due date.

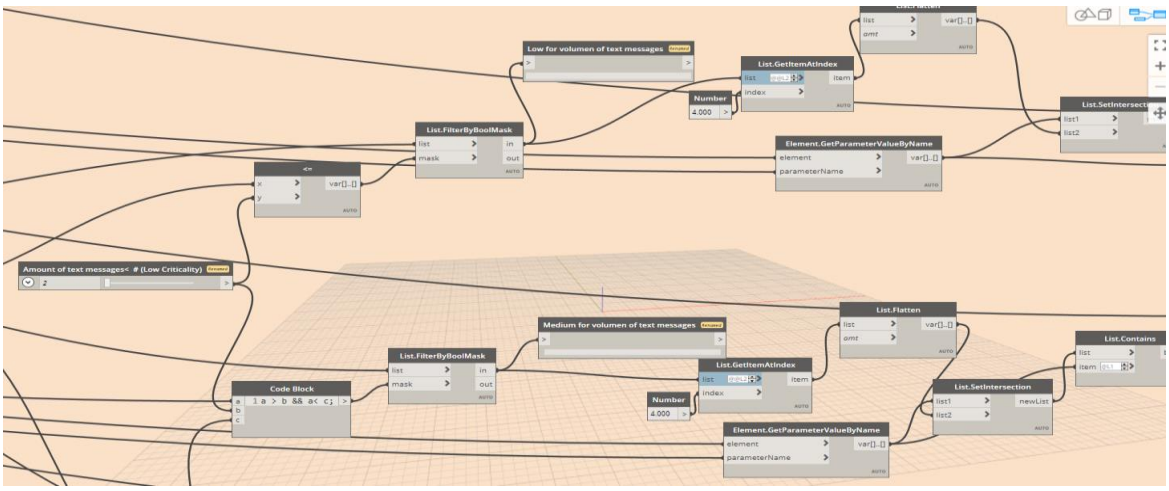


Figure 18 – Dynamo script for classification of text messages according to the amount of them

For items that are considered critical because it is mentioned as urgent, the same steps are followed until the list creation with the information. After this step, there is a creation of a new list with possible keywords such as urgent, vital, exigent, imperative, immediate attention, serious, important, major, instant, critical. The script shown in Figure 19 checks if one of these words is mentioned in the type of message and then that mentioned item would be displayed as red in the new 3D view.

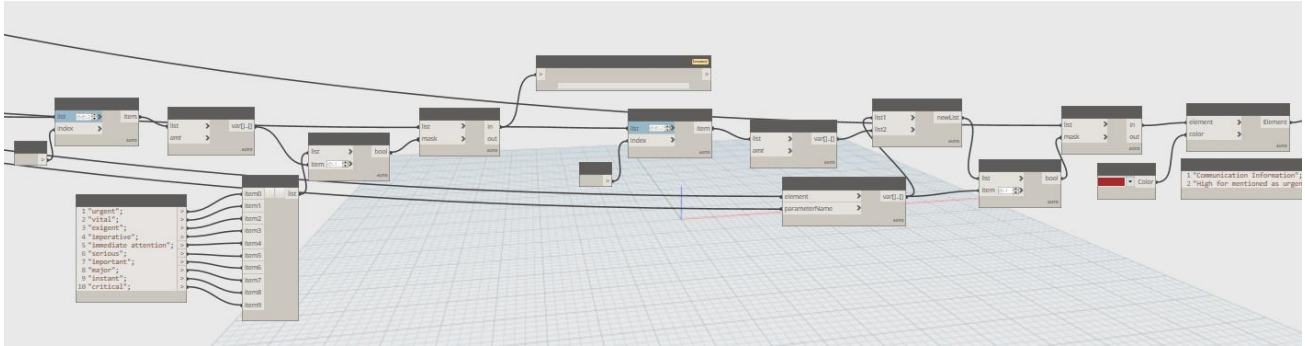


Figure 19 – Dynamo script for looking for keywords into the type of message of the communication

The script illustrated in Figure 20 for checking if an item is from the critical path is very similar to the one checking the keywords because instead of looking for those words, it only checks for the X mark. This part was thought and developed manually like that because the user can have the construction schedule in other tools like Bexel or Naviswork or Project Manager or Primavera or many other existing tools. If it was connected to one of these tools, then the script would not work if another user has the information in another tool.

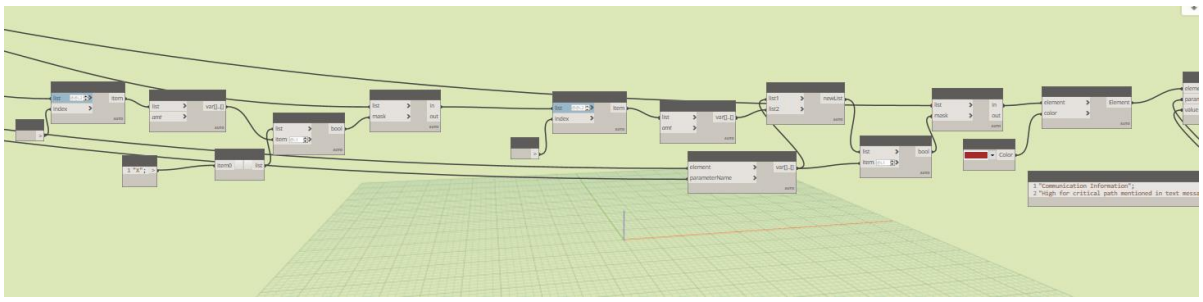


Figure 20 – Dynamo script for looking if a mentioned item is part of the critical path

The script for sorting the information according to the sender is possible due to the nodes List.Contains, List.Create, List.Flatten, List.FilterByBoolMask that checks and filters the information according to a specific name of a professional (Figure 21). This can be modified by the user, but this can only be possible only through managing the dynamo script; not through the dynamo player.

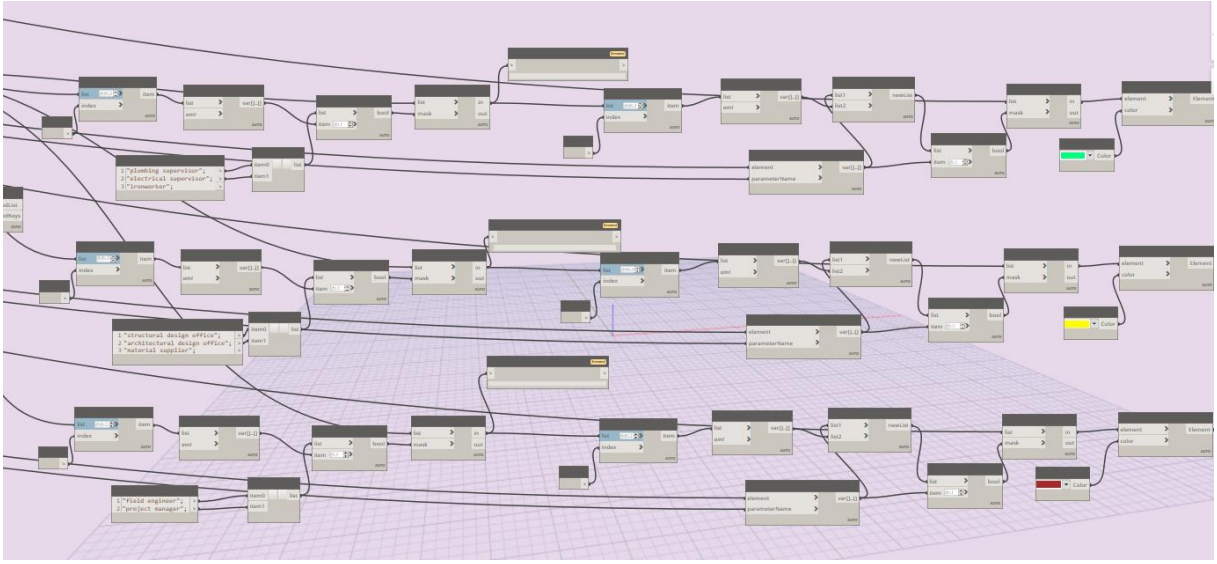


Figure 21 – Dynamo script for classifying the information according to the sender

After the sorting, the visualization is possible as explained before for other types of classification. The script calls all the elements of the model and then selects only the mentioned ones as low criticality and colors them as green, medium criticality and colors them as yellow and high criticality and colors them as red.

The user has access to the script through dynamo or dynamo player. In dynamo, the script was developed and the user can change the names of the professionals according to the ranges of classification due to the sender of information and with the player, there is a simpler way to run the script and to adjust the limits. However, since there are many ranges and other types of criteria integers that can be modified according to the project manager needs, it is suggested to do it through the dynamo tool itself and not the player to avoid possible confusions.

3.2. Script development for naming convention

The naming convention of all elements of the model as a function of the categories shown in Figure 22 and mentioned previously will be explained in detail in this section. The identification will be numbering them; for example, we will have column 1, column 2, until reaching column x. The proposal is to include this into the communication phase. It is suggested that workers on field start addressing issues mentioning the exact item that requires attention in order to avoid misunderstandings. There will be only one column 1 in the model so there is no room for misperception. The script first calls all items according to the category that can be roofs, ceilings, walls, doors, etc. Then, through List.Count, it counts how many elements of that category exist in the model. After this, a code block is used to create a list starting from 1 and finishing in the number obtained from the count. This name is placed in the element as a mark by the node Element.SetParameterByName. The user of the script that wants to apply the naming convention to a model needs to have a complete knowledge of its elements or the user can work directly with the team that developed the graphical model and give a list of elements used for each discipline. These elements need to be checked if they are already listed in the script, if it is not included, the user must add the ones that are missing. Since the naming convention was done for a specific case

study of a house, there will be some elements that are missing if wanted to apply this for high rise buildings.

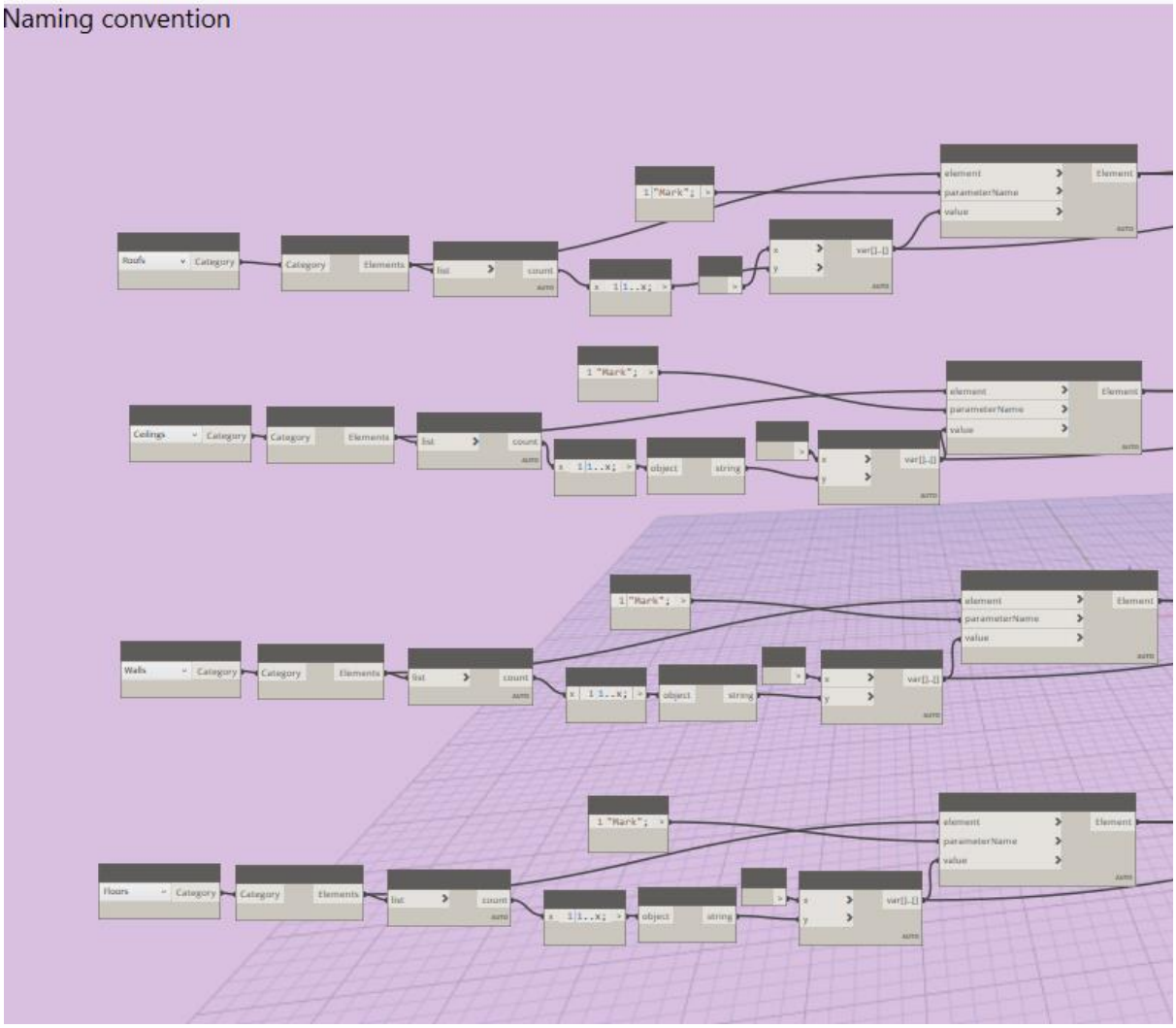


Figure 22 – Dynamo script for naming the items

3.3. Script development for incorporation of a building date

There is a script created for the inclusion of the building date into the elements. This was done for further reference and can also be applied for maybe a 4D simulation of appearance of the elements according to this date. The building date can be added manually by element in the model or in the excel file which is simpler to add or maybe if needed to change many of the dates it is easier this way. Though the node Element.GetParameterValueByName the data can go to an exported excel sheet and then after making the changes can be implemented in the elements by importing the data and the node Element.SetParameterValueByName that will add the information. This script is currently frozen as shown in Figure 23. If needed can be unfrozen partially so that it works correctly. First, to be able to work with it, the user will need an empty excel document stored where the user wants. The document must be chosen through the node File Path and after this the Data.ExportExcel can be unfreezed so that it fills with the information of the model. After this, one can modify and save. To import the information

into the elements, the user needs to unfreeze the Data.ImportExcel and run the script so that the information will be added directly to the elements.

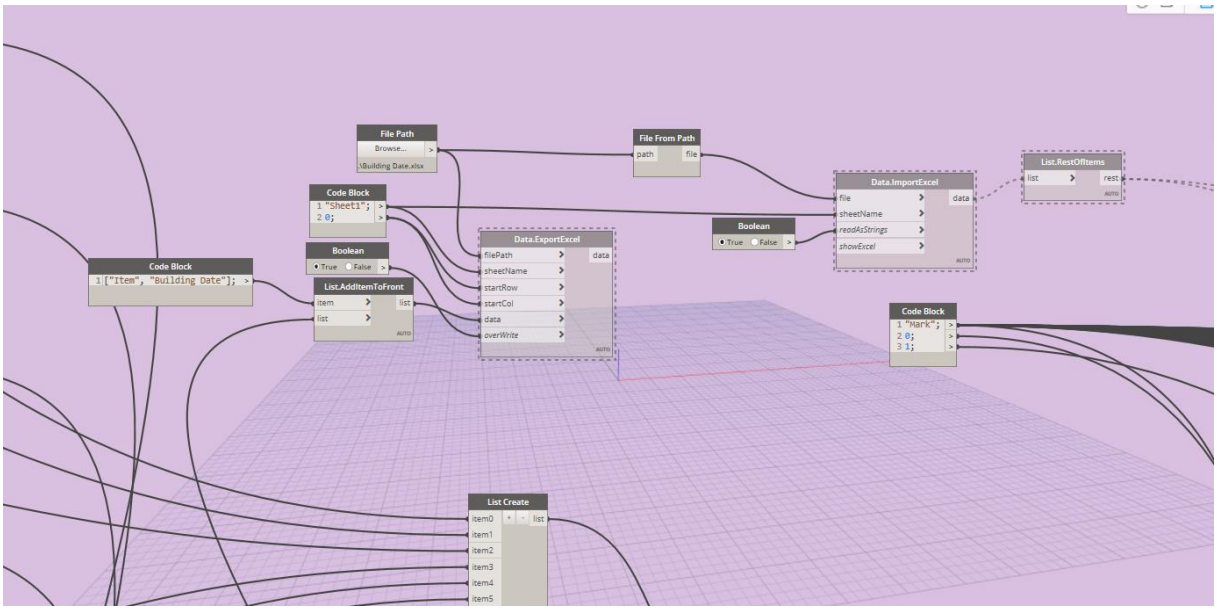


Figure 23 – Dynamo script for modifying and adding building date to the elements

3.4. Script development for creating a new 3D view

To avoid interference with the existing 3D view of the model, a script shown in Figure 24 was developed to create a new 3D view through the nodes of Create Override Graphic Settings and View Set Elements Override to set the view with a transparency of the elements of 30. The Dynamo tool has many useful packages and one of them is GeniusLoci. The nodes Create Override Graphic Settings and View Set Elements Override are nodes of this package used in this script.

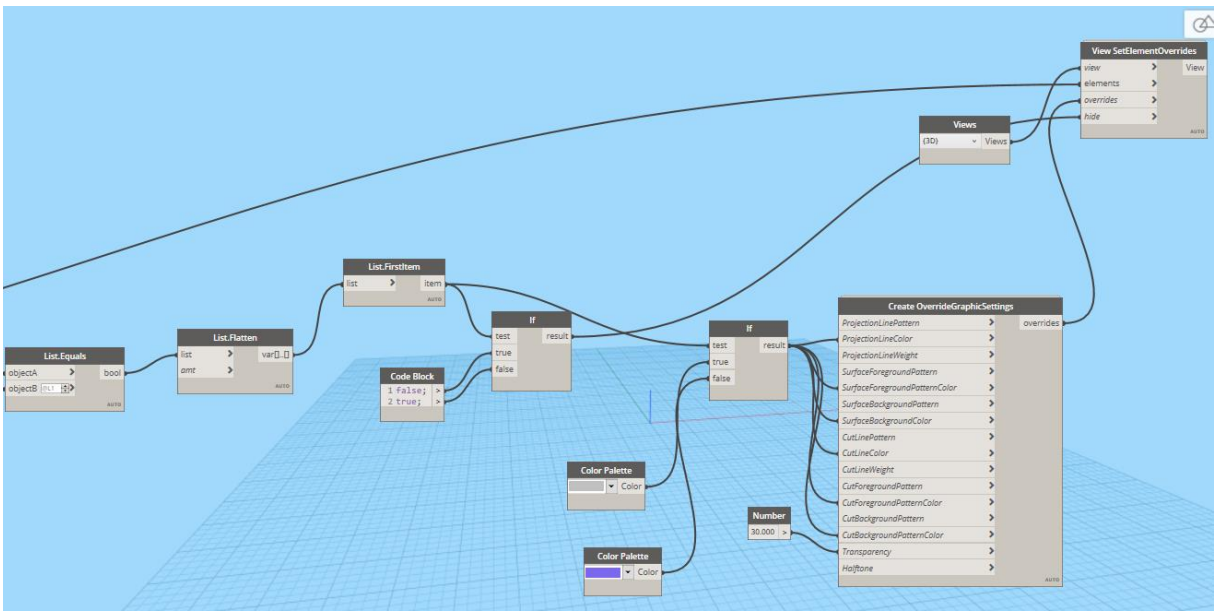


Figure 24 – Dynamo script for adding another 3D view with transparency of the elements

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4. SURVEY METHODOLOGY

In the previous chapter it was mentioned that a questionnaire was done in order to obtain the insights from contractors, owners, project manager and A/E firms. The survey was made possible by the support of José Carlos Lino, a board member and an implementation strategist of the company BIM MS and owner of the Engineering Consultant company Newton. The objective of the survey is to define possible ranges for the value of the information obtained during a construction process. To this aim, the previously described framework is adaptable and updatable with this information allowing it to be used within different situations and work strategies.

The survey can be found in annex 2, it was prepared through the online app Smart Survey from the UK. The questionnaire deals with questions regarding the quality and quantity of communication information; it was distributed to participants involved in the industry and academia of the AEC production. The questionnaire is composed of thirteen questions and divided by sections coinciding with the mean of communication. The first question is about the working area of the participants, whether they are from academia or from industry. After this comes the first section is related to calls where all the questions about calls are found; the second section is text messages, and the third one is about emails; after this, questions with other classifications considering content of the message begin, for example, the sender of the communication, and the ranking of communication methods and lastly, there is an open question in case someone wants to clarify their answers or to include a suggestion for the study. The questions inside the sections involve the classification of medium, low and high when having a certain number of calls, text messages and emails during a specific range of time. Other questions ask about criticality according to the quantity of calls, text messages and emails. Finally, the responses were stored to proceed with the data analysis of the results.

4.1. Responses

The questionnaire was answered by three people from academia and four people from the industry. The results obtained from the responses of the questionnaire are very different according to the needs of the user. The first answer was from the industry of South Africa and they considered that three to six calls were already critical to consider regarding one issue. Not critical for them would only be one call. They would consider it critical starting from one email. This response is very similar to the other respondent of the industry of South Africa, while the participant of the industry of Portugal has similar responses than the participant of the industry of Ecuador. For both of the participants from the industry of South Africa, they do not consider the calls critical, they leave them for last. They consider the emails medium and high and text messages only as medium. In terms of the sender of the communication, participants are between medium and high in the classification of information coming from field engineers and architectural and structural design offices. The participants agree that the communication coming from the electrical and plumbing supervisor would be classified as medium. For the rest of the senders, the tendency is not clear.

Participants from the industry of South Africa consider emails and text messages where the context of information is more important and they consider it important to keep record of it by email. Most people

here use the methodology of getting things done as soon as they receive the issue, so for them even 1 call is priority.

A different answer came from a participant from industry of South Africa that would consider two and three calls not critical but more than three already critical. Same for text messages one to three text messages not considered critical and more than six text messages would be considered critical. In the case of emails, less than 6 emails would not be critical and more than 7 would be considered critical. For them any type of communication is either medium or high critical but there is not low.

Another answer from the industry in Portugal considers that two to four calls would not be considered important, they would consider it as critical having more than six calls which is similar to the response of the participant of the industry of Ecuador. Three to five text messages regarding one topic would not be considered critical but from six to ten would be considered critical. For them less than 7 emails are not critical, while having more than seven would be considered critical.

Another response from the academia in Portugal has decided that one to two calls are not considered critical, while having more than three calls would be critical. The same for messages, three to five text messages would be considered not critical and more than six would be considered critical. Not critical would be to receive less than seven emails and more than seven would be critical. They consider the calls and emails as high in order of criticality and text messages are considered medium. A different response from another participant from academia in Portugal states that one call would not be critical but more than two would be critical, one text message would not be critical and more than two would be critical. One to five emails would be considered critical. So, they consider that communication coming from calls and emails are highly important and when it comes from text messages are medium; nothing would be low.

4.2. Results Summary Analysis

The results were collected and they can be found summarized in this section.

For the first question, following results are obtained:

Table 2 –Working area of the participants

Academia		40%	3
Industry		60%	4

4 participants were from the industry and 3 participants were from academia. (Table 2)

For the second question, the results can be summarized and seen better in the Table 3

Table 3 –Classification of low(1), medium(2) and high(3) when having a certain amount of calls during a specific range of time

1 -3 days	**1**	**2**	**3**
Less than 3 calls	42.9%	28.6%	28.6%
3-7 Calls	28.6%	14.3%	57.1%
More than 7 Calls	14.3%	28.6%	57.1%
3 -7 days			
Less than 3 calls	28.6%	57.1%	14.3%
3-7 Calls	28.6%	28.6%	42.9%
More than 7 Calls	14.3%	14.3%	71.4%
7-14 days			
Less than 3 calls	42.9%	42.9%	14.3%
3-7 Calls	28.6%	42.9%	28.6%
More than 7 Calls	14.3%	0.0%	85.7%
14-28 days			
Less than 3 calls	42.9%	28.6%	28.6%
3-7 Calls	28.6%	42.9%	28.6%
More than 7 Calls	14.3%	28.6%	57.1%
28 days or more			
Less than 3 calls	57.1%	0.0%	42.9%
3-7 Calls	28.6%	42.9%	28.6%
More than 7 Calls	28.6%	14.3%	57.1%

These results demonstrate that 43% of the participants consider low criticality to receive less than three calls in one to three days; 57% consider it critical to receive more than three calls in one to three days. While 57% consider medium to have less than three calls in three to seven days and 57% consider it critical to receive three to seven calls in three to seven days. In seven to fourteen days, participants are

mainly divided into medium and low to have less than three calls; 43% consider it medium to have three to seven calls and 86% consider it critical to have more than seven calls. For fourteen to twenty-eight days: 43% consider it as low to have less than three calls; 43% consider it as medium to have three to seven calls; 57% consider it critical to have more than seven calls. In the range of twenty-eight days and more, 57% of the participants consider it as low to have less than three calls; 43% consider it as medium to have three to seven calls; 57% consider it as critical to have more than seven calls.

The results of the third question can be found in the next Table 4 where one can see that 43% consider it critical to have from three to six calls.

Table 4 – Number of calls to consider critical

1-3 calls	**28.57%**	**2**
3-6 calls	42.86%	3
6-7 calls	28.57%	2
7-10 calls	0.00%	0
Other (please specify):	0.00%	0

The results of the fourth question can be found in the next Table 5 where one can see that 57% consider it not critical at all to have from one to two calls.

Table 5 – Number of calls not to consider critical

1-2 calls	**57.14%**	**4**
2-4 calls	42.86%	3
4-7 calls	0.00%	0
Other (please specify):	0.00%	0

These results demonstrated in Table 6 express that 71% of the participants consider medium criticality to receive less than five text messages in one to three days; 57% consider it critical to receive more than five text messages in one to three days. While 57% consider it as low to have less than five messages in three to seven days and forty-three percent consider it critical to receive five to ten text messages in three to seven days. In seven to fourteen days, 71% consider it as medium to have less than five text messages; 43% consider it critical to have five to ten text messages and 71% consider it critical to have more than ten text messages. For fourteen to twenty-eight days: 43% consider it as low to have less than five text messages; 43% consider it as medium to have five to ten text messages; 71% consider it critical to have more than ten text messages. In the range of twenty-eight days and more, 43% of the participants

considered it low to have less than five text messages; 43% consider it as critical to have five to ten text messages; 57% consider it as critical to have more than ten text messages.

Table 6 – Classification of low(1), medium(2) and high(3) when having a certain amount of text messages during a specific range of time

1-3 days	**1**	**2**	**3**
Less than 5 text messages	28.6%	71.4%	0.0%
5-10 text messages	28.6%	14.3%	57.1%
more than 10 text messages	28.6%	14.3%	57.1%
3-7 days			
Less than 5 text messages	57.1%	42.9%	0.0%
5-10 text messages	28.6%	28.6%	42.9%
more than 10 text messages	14.3%	14.3%	71.4%
7-14 days			
Less than 5 text messages	28.6%	71.4%	0.0%
5-10 text messages	28.6%	28.6%	42.9%
more than 10 text messages	14.3%	14.3%	71.4%
14-28 days			
Less than 5 text messages	42.9%	28.6%	28.6%
5-10 text messages	28.6%	42.9%	28.6%
more than 10 text messages	14.3%	14.3%	71.4%
28 days or more			
Less than 5 text messages	42.9%	14.3%	42.9%
5-10 text messages	28.6%	28.6%	42.9%
more than 10 text messages	14.3%	28.6%	57.1%

The results of the sixth question can be found in the next Table 7 where one can see that forty-three percent consider it critical to have from six to ten text messages.

Table 7 – Number of text messages to consider critical

1-3 text messages	**28.57%**	**2**
3-6 text messages	28.57%	2
6-10 text messages	42.86%	3
10-20 text messages	0.00%	0
Other (please specify):	0.00%	0

The results of the seventh question can be found in the next Table 8 where one can see that 57% consider it not critical at all to have from one to three text messages about a subject.

Table 8 –Number of text messages not to consider critical

1-3 text messages	**57.14%**	**4**
3-5 text messages	42.86%	3
5-7 text messages	0.00%	0
Other (please specify):	0.00%	0

These results in Table 9 demonstrate that 71% of the participants consider medium criticality to receive less than seven emails in one to three days; 43% consider it critical to receive seven to fifteen emails in one to three days. While 57% consider it as medium to have less than seven emails in three to seven days and 57% consider it critical to receive seven to fifteen emails in three to seven days. In seven to fourteen days, 86% consider it as medium to have less than seven emails; 57% consider it critical to have seven to fifteen emails and 86% consider it critical to have more than fifteen emails. For fourteen to twenty-eight days: 43% consider it as low to have less than seven emails; 43% consider it as critical to have seven to fifteen emails; 71% consider it critical to have more than fifteen emails. In the range of twenty-eight days and more, 57% percent consider it as low to have less than 7 emails, while 43% of the participants consider as critical to have less than seven emails; 57% consider as medium to have seven to fifteen emails; 57% consider as critical to have more than fifteen emails.

Table 9 –Classification of low(1), medium(2) and high(3) when having a certain amount of emails during a specific range of time

1-3 days	**1**	**2**	**3**
less than 7 emails	28.6%	71.4%	0.0%
7-15 emails	28.6%	28.6%	42.9%
more than 15 emails	14.3%	14.3%	71.4%
3-7 days			
less than 7 emails	42.9%	57.1%	0.0%
7-15 emails	14.3%	28.6%	57.1%
more than 15 emails	14.3%	14.3%	71.4%
7-14 days			
less than 7 emails	14.3%	85.7%	0.0%
7-15 emails	14.3%	28.6%	57.1%
more than 15 emails	14.3%	0.0%	85.7%
14-28 days			
less than 7 emails	42.9%	28.6%	28.6%
7-15 emails	28.6%	28.6%	42.9%
more than 15 emails	14.3%	14.3%	71.4%
28 days or more			
less than 7 emails	57.1%	0.0%	42.9%
7-15 emails	14.3%	57.1%	28.6%
more than 15 emails	14.3%	28.6%	57.1%

The results of the ninth question can be found in the next Table 10 where one can see that 57% consider it critical to have from one to five emails.

Table 10 – Number of emails to consider critical

1-5 emails		**57.14%**	**4**
5-9 emails		42.86%	3
9-10 emails		0.00%	0
10-15 emails		0.00%	0
more than 15 emails		0.00%	0
Other (please specify):		0.00%	0

The results of the tenth question can be found in the next Table 11 where one can see that 85% consider it not critical at all to have less than seven emails about a subject.

Table 11 – Number of emails not to consider critical

less than 7 emails		**85.71%**	**6**
7-15 emails		0.00%	0
more than 15 emails		0.00%	0
Other (please specify):	any mail more than 1 I would regard as critical	14.29%	1

The resulting summary from Table 12 is that participants consider as high criticality when the communication comes from structural design office (71%), architectural design office (43%), field engineer (57%), material supplier (43%); as medium when the communication comes from architectural design office (57%), field engineer (43%), skilled laborer, ironworker, electrical and plumbing supervisor (all of these 57%); as low when the communication comes from skilled laborer and ironworker (both 43%).

As the resulting Table 13 shows, 75% consider that the emails are ranked as high criticality, one hundred percent consider the text messages as medium and 57% consider the calls high.

Table 12 – Criticality according to the sender of information

Answer Choices	1 Low Criticality	2 Medium Criticality	3 High Criticality
Structural Design Office	0.00%	28.57%	71.43%
Architecture Design Office	0.00%	57.14%	42.86%
Field Engineer	0.00%	42.86%	57.14%
Electrical Supervisor	28.57%	57.14%	14.29%
Plumbing Supervisor	28.57%	57.14%	14.29%
Skilled Laborer	42.86%	57.14%	0.00%
Ironworker	42.86%	57.14%	0.00%
Material Supplier	14.29%	42.86%	42.86%

Table 13 – Ranking of the communication methods

Answer Choices	1 Low	2 Medium	3 High
Emails	12.50%	12.50%	75.00%
Text messages	0.00%	100.00%	0.00%
Calls	28.57%	14.29%	57.14%

The conclusion of the performed questionnaire is that there must be more participants to be able to see an evident tendency. The sample is very small and does not necessarily reflect the opinion of the industry. It is clear that every participant has their own ranges or limits of criticality and this is considered while developing the script. The ranges are set as inputs so that they can be modified according to the users' needs. One can notice resemblances between the answers of the participants from industry in Portugal and Ecuador. Also, the answers from the participants of the industry of South Africa were very similar and the ones from academia of Portugal were alike.

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5. CASE STUDY

The case study is used to show how there is an exchange of information and what is extracted from the communication during the construction phase. It will also be useful to show how the issues are classified and visualized in the model. This case study will serve as an example of the proposed methodology of this dissertation.

The proposed case study is a project with various disciplines such as architecture, structure, plumbing, electrical and sanitary. For the purpose of this dissertation, it was assumed that all the drawings and specs are well designed to avoid issues during construction made following a mistake in the drawings or in the designs. As an example the house for this study will be of 140m^2 of construction in a land of 190m^2. The proposed case study initiates its process by obtaining all the architectural, plumbing, electrical and structural drawings of the case study house in AutoCAD format (DWG). Since this is a house that was built by the writer of this dissertation, this step was immediate and eliminated any bureaucratic procedure to comply. The next step is to convert all the information of the drawings into the graphical programming model that will be described in chapter 6.

5.1. Description of the Case study

The example house will be 2 stories; in the ground floor there will be an office, a dining room, a kitchen, 1 guest bedroom, 1 bathroom for guest bedroom, 1 general guest restroom, 1 laundry room, 1 living room and outside will be the parking area and halls. In the first floor, the main bedroom will be located with its closet and bathroom, as well as 2 bedrooms with their own closet and bathroom. For the structural part, the house has a foundation slab standard of 20cm and columns of 250x350, and 250x250; the first floor with main beams, secondary beams (floor beams) and columns of 250x150x4mm, 250x150x3mm, 150x100x3mm. For the Architectural part, the design will include walls of bricks with plaster on each side. The floor will be of concrete slab and a finish of ceramics. Figure 25 and Figure 26 show the example house, the architectural façade and the distribution of the ground floor.

Figure 25 – Example of the 2 story house

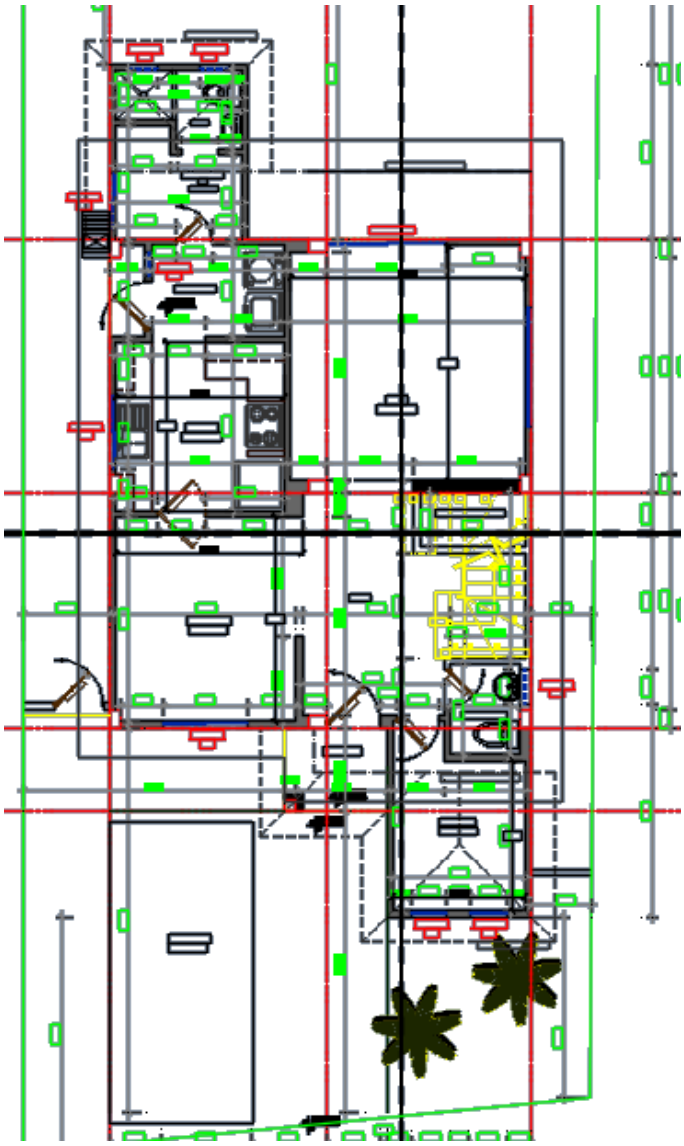

Figure 26 – Drawing of the distribution of the ground floor

5.2. Assumed issues during the construction phase

During this phase there are several problems mentioned in the meeting with the project manager that are described in this chapter and can be seen in Figure 27.

5.2.1. Excavation Issues

For the excavation part the main issue would be that the hired excavators do not arrive on time to start the activity or not having a qualified truck or driver to remove the material faster. Another main issue would be to suddenly find that there is a different type of material (maybe a harder type of soil) in one specific location requiring more time and effort to remove it. Secondary issues would be that the excavator suddenly stops working and that time is needed to fix it and replace it. Another secondary issue would be that the excavation dimension is not correct and needs adjustment.

Inadequate weather conditions can also be a problem that can limit the construction activity and will slow down the process.

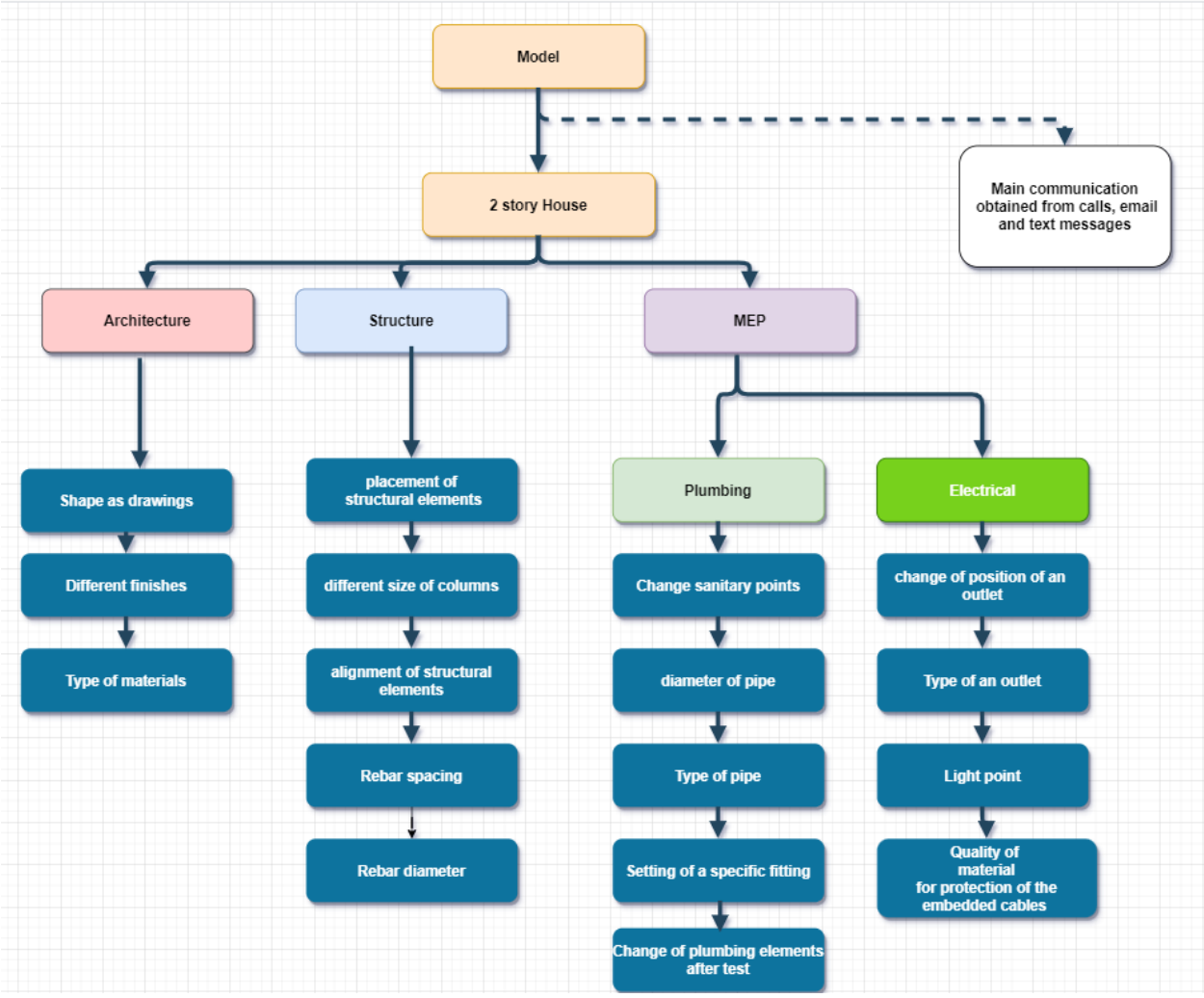

Figure 27 –Distribution of the project management issues

5.2.2. Architectural Issues

One main issue would be that the finishing of the facade is not as designed and specified in the drawings. Another main issue would be that the construction is not following the required shape shown in the drawings. A secondary issue for the architectural part would be the selection of the type of floor tiles for each room or other finishing material. The type of windows available in the market is different from the one designed in the architectural drawings.

5.2.3. Structural Issues

The main problems with structural parts during construction assumed for the purpose of this project would be: placing these structural elements in the incorrect spot, not having qualified personnel for steel structures installation, having columns not of the size as it was designed and columns that are not correctly aligned. Steel supplier delays the delivery of the steel elements. Another secondary issue would be that the spacing of the rebar is not as specified and that the diameter of the rebar is not accurate.

5.2.4. MEP Issues

The issues with MEP considered as the purpose of this project are the ones described as plumbing, sanitary and electrical issues. The main plumbing and sanitary issues would be that after placing the concrete to form the walls, changes to the sanitary points must be done so part of the wall must be destroyed in order to modify the sanitary point. Another main issue would be after the pressure test, one of the plumbing elements fails and needs to be replaced. Another main issue after the first use of the restroom for the test would be realizing that the drain was not connected to the box. Secondary plumbing and sanitary issues would be placing the wrong type of material of the pipe and wrong type of diameter, placing wrong quality pipes. The improper setting of a specific fitting. This can be changed during this phase so it is easy to make the modifications while they have not been covered.

Electrical Main issues would be the incorrect placement of an outlet, incorrect type of outlet (instead of a 220v, one of 110v has been installed), light point is not in the exact place as shown in the drawings, or to place a simple switch instead of a three-way switch. Secondary issues would be that there are not specific items in the stores and one should make the decision to choose another one. Another secondary issue would be that the quality of the material for protection of the embedded cables is not a good one or the installation is incorrect and damaged after the concrete slab casting.

5.2.5. Other Issues during construction

There are several other issues that arise during the construction period that unfortunately are not possible to be included and shown in the visualization model because it lacks a direct connection with an element of the model. They are mentioned in this chapter since the study recognizes these problems exist and occur occasionally and it is clear that there must be a way to include them in the visual aid but it will be left for further research purposes.

5.2.5.1. Legal Issues

- The paycheck of a laborer was altered and cashed out like that. Informed by the accounting department of the company to the project manager and legal department through an email. The laborer continues working for the company so there must be a decision within 2 weeks.
- Crew found out stealing construction elements communicated from site supervisor to project manager through a phone call. The project manager calls the legal department to find an immediate solution.
- A laborer that suddenly stopped coming for 1 week and appears the following week communicated through a text message from site supervisor to project manager. This is informed to the legal department from the project manager by a call.

5.2.5.2. Bureaucratic Issues

- A laborer that suddenly stopped coming for 1 week and appears the following week communicated through

- Changes that have not been properly requested through the company process, requesting signatures and approval from administrative offices. This is stated in an email from site supervisor to project manager.

- Material requires approval to be taken into the construction site communicated through emails from site supervisor to project manager.

- The site supervisor does not allow entrance of the excavator to the site because the subcontracted heavy machinery company sent another type of equipment with another driver (not the one reported in the email). This was informed in a call from the site supervisor to the sales and rent offices of the mentioned company requiring immediate clarification. After the proper explanation, the call goes from site supervisor to project manager to request an immediate approval for this issue.

5.2.5.3. Safety Issues

- Not enough water in the construction site may be communicated by email from the safety manager to the site supervisor and project manager giving 3 days to solve the problem.

- Electrical conductors on surfaces with water reported in a call from the safety manager to the site supervisor and project manager expected to be solved immediately.

- Scaffolding without guardrails communicated in a call from the safety manager to the site supervisor and project manager to be solved immediately.

- Workers not wearing the appropriate safety implements stated by text message from the safety manager to the site supervisor and project manager having 2 weeks to solve the issue completely.

5.3. Selection of Issues

The selection of issues for the simulation are the ones that can be seen in the following images (Figure 29 - Figure 33, the labeling description is in Figure 28). It has been divided conforming to the stages of site preparation, foundation, steel structure, external, floor slab, brickwork, plumbing, electrical and finishes.

Figure 28 –Labelling of the next figures about issue selection

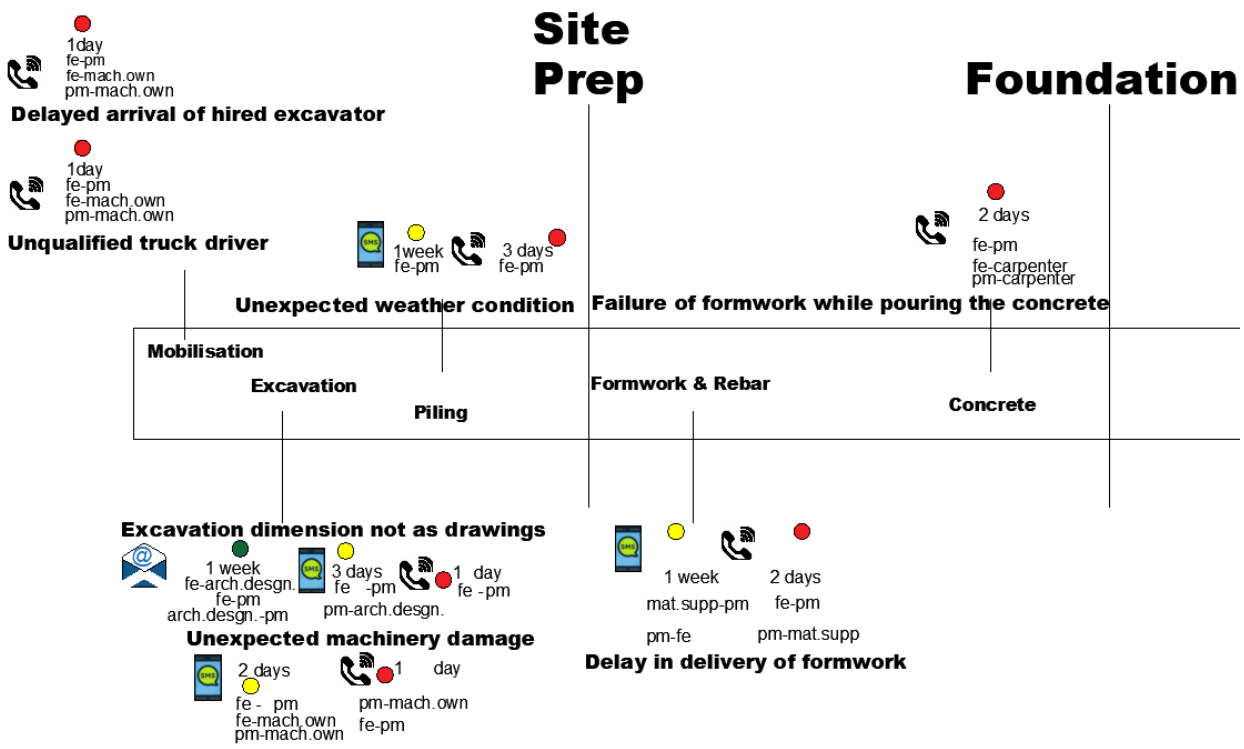

Figure 29 –Issue selection of Site preparation and Foundation.

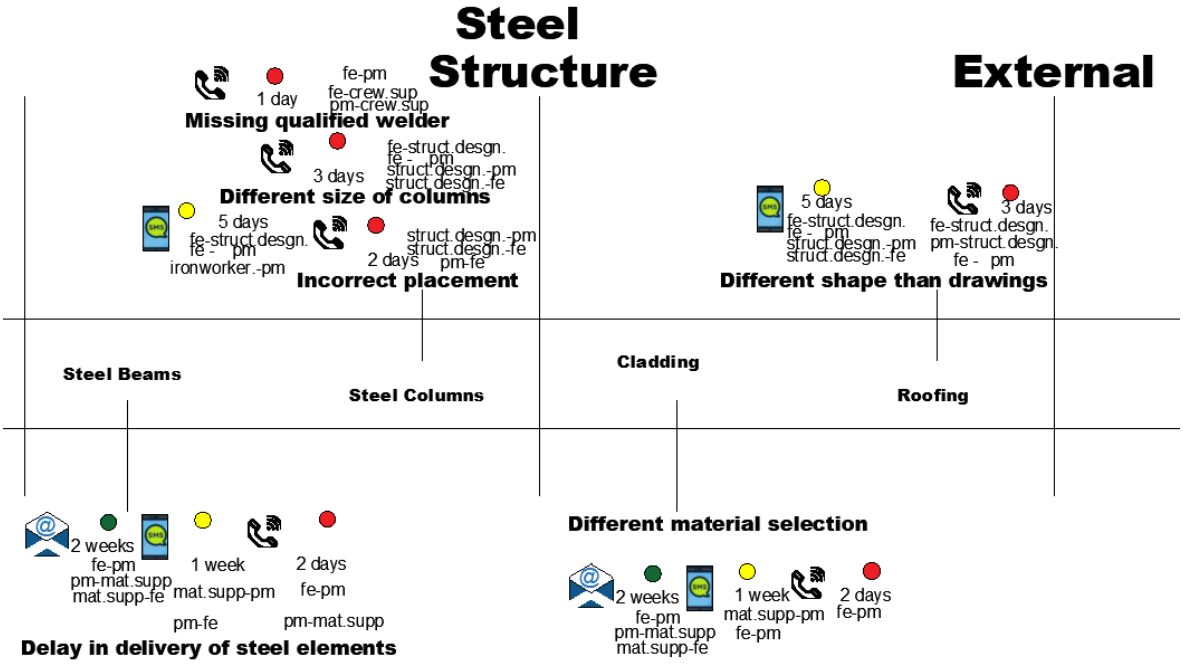

Figure 30 –Issue selection of Steel Structure and External.

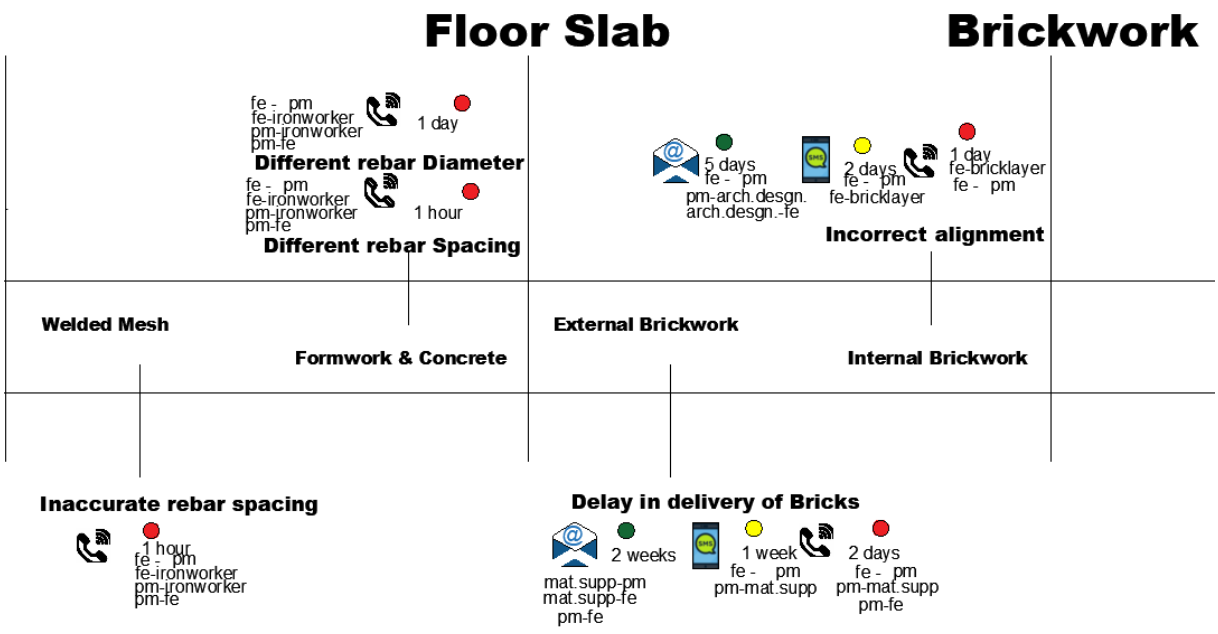

Figure 31 –Issue selection of Floor Slab and Brickwork

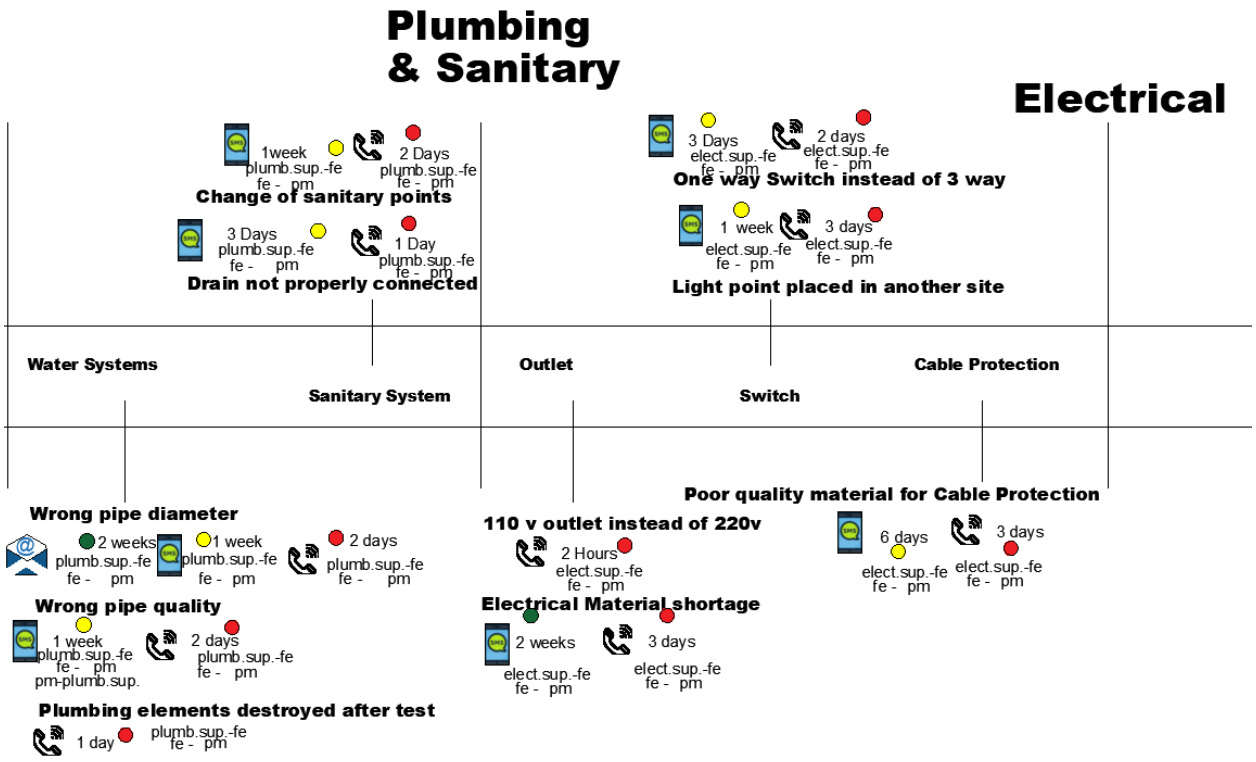

Figure 32 –Issue selection of Plumbing, Sanitary and Electrical

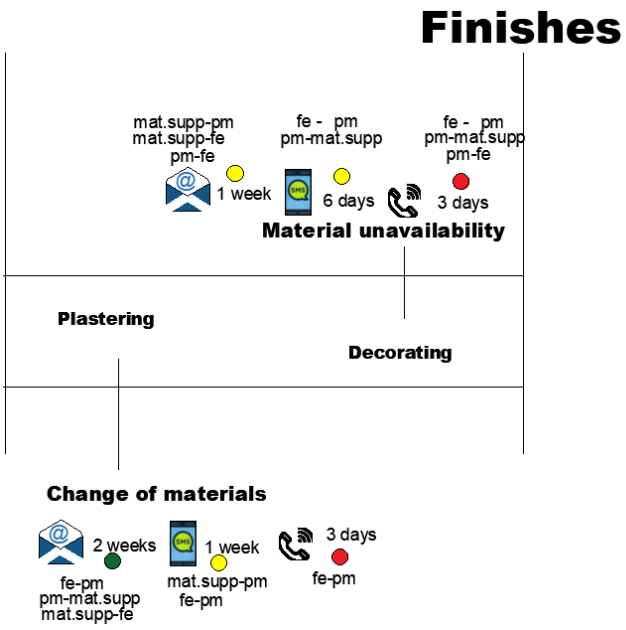

Figure 33 –Issue Selection of Finishes

5.4. Extracted information

It is mentioned in the previous chapters that many possible issues were selected for the purpose of this case study. The way of expressing these issues was briefly illustrated from Figure 29 to Figure 33, but it is described in detail in this section. Basically for the purpose of this research after checking the answers of the questionnaire, it is assumed that calls occur when something is urgent and when the deadline is very close, emails would be the initial and bureaucratically way of indicating these issues, and text messages would be used when something is medium in terms of criticality or if it is in the middle of the deadline.

5.4.1. Information exchange for architectural issues

The architectural issues were assumed that were communicated in the following ways:

- Different finishing of façade: The skilled laborer would send an email to the project manager regarding this issue, asking for a response within 1 week. There will be many ongoing emails among the designers' team, the project manager, site supervisor and the material supplier. A change order would be needed if they decide to change the actual material.

- Section that has different shape than drawings: The site supervisor would communicate the issue initially through email to the project manager and the designer office and will expect their reply within 5 days. A phone call regarding this issue is registered after the second day that it was initially requested.

- Last minute material selection due to unavailability of the initially chosen ones would be notified from the material provider to the project manager through email, having a chance to make changes for 1 week

5.4.2. Information exchange for structural issues

The structural issues were assumed that were communicated as follows:

- Column placed in another spot: Site supervisor would communicate this issue to the project manager and structural design office through messages needing an answer within 4 days. After 2 days, a phone call was registered regarding this issue.
- Missing qualified personnel for structural steel elements installation would be reported through 1 phone call to the project manager from the site supervisor and solved immediately.
- Different size columns stated through a phone call from the site supervisor to the project manager necessitating a response within 2 days.
- Incorrect alignment of the columns was told through a phone call from site engineer to the project manager, who gave an immediate response to modify that and have it aligned based on the respective drawings.
- Delay of the delivery of the steel elements would be informed through email from the steel supplier to the site engineer and project manager. This issue was informed 1 week before so it can be planned.
- Rebar spacing not done as stated on the drawings would be expressed in a phone call to the project manager from the site supervisor requiring immediate response.
- Rebar diameter not respected would be expressed in a phone call to the project manager from the site engineer requiring immediate response.

5.4.3. Information exchange for plumbing and sanitary issues

The plumbing and sanitary issues were assumed to be communicated as follows:

- Change of sanitary points would be requested through text message from plumbing supervisor from site supervisor to project manager having 1 week to reply.
- Plumbing elements destroyed after test would be professed through a text message from plumbing supervisor to site supervisor and project manager followed by a phone call to the project manager expecting an approval to replace the damaged plumbing components
- Having drain not properly connected in the main restroom would be proclaimed through a text message with an expected response of 3 days.
- Placing pipe with the wrong diameter would be communicated by email from the site supervisor to the project manager
- Placing pipe with the wrong quality would be expressed by a text message and expected to be solved in 1 week from site supervisor to project manager

5.4.4. Information exchange for electrical issues

The electrical issues were assumed to be communicated as follows:

- To place a 110v outlet instead of a 220v outlet would be communicated in a phone call from electrical supervisor to site supervisor and project manager requiring an immediate answer within 2 hours to make the changes.

- Light point placed in another spot would be communicated through a text message from the electrical supervisor to the site supervisor and would be able to be changed in 3 days.

- To place a simple switch instead of a 3-way switch would be stated in a text message from the electrical supervisor to the site supervisor; the site supervisor would address the issue to the project manager that will have 3 days to make the change.

- Another type of outlet due to material shortage in storage of a specific brand would be notified from the sales department of the supplier office through email to electrical supervisor 2 weeks before the scheduled delivery. Then, the electrical supervisor would consult this issue through text message with the site supervisor and project manager to be able to solve this issue during those 2 weeks.

- Poor quality of material for cable protection would be communicated from the sales department of the supplier office through email to the electrical supervisor 2 weeks before the scheduled delivery. Then, the electrical supervisor would consult this issue with the site supervisor and project manager and would solve this issue during those 2 weeks.

5.5. Summary of extracted information

The following figures (Figure 34 - Figure 36) are the zoom out example of the xlsx file with the extracted information of the specific chosen case study, this can be better seen in annex 1. The content of the database was already described in chapter 3.

Email (sender)	Remitter	Mailbox (addressee)	Receiver	Subject	Date	Due Date in Days	Item	Location of the item	X if part of Critical Path	X if urgent	Room
steel.supplier@xmail.com	Steel Supplier	project.manager@xmail.com	Project Manager	Delay of delivery of steel elements	4/11/2022	8	column	ground floor, right side			office
fieldeng@xmail.com	field engineer	project.manager@xmail.com	Project Manager	Excavation dimension not according the drawi	4/18/2022	8	Wall 17	ground floor, right side			office
fieldeng@xmail.com	field engineer	project.manager@xmail.com	Project Manager	A section with a different shape	5/10/2022	5	Wall 16	ground floor, right side	X	X	dining room
designoffice@xmail.com	Designer Office	project.manager@xmail.com	Project Manager	A section with a different shape	5/10/2022	5	Wall 16	ground floor, right side	X	X	dining room
plumbing.supervisor@xmail.co	Plumbing Supervisor	project.manager@xmail.com	Project Manager	Wrong mpa requirements	6/3/2022	8	pipe	ground floor, left side			laundry room
plumbing.supervisor@xmail.co	Plumbing Supervisor	project.manager@xmail.com	Project Manager	wrong pipe diameter	6/10/2022	8	pipe	ground floor, left side			laundry room
salesdpt@xmail.com	Supplier Office	electrical.supervisor@xmail.con	Electrical Supervisor	electrical material shortage	6/13/2022	16	cable	ground floor, left side			kitchen
electrical.supervisor@xmail.co	Electrical Supervisor	project.manager@xmail.com	Project Manager	electrical material shortage	6/13/2022	16	cable	ground floor, left side			kitchen
salesdpt@xmail.com	Supplier Office	electrical.supervisor@xmail.con	Electrical Supervisor	Poor quality material for cable protection	6/20/2022	16	cable	ground floor, right side			pump room
electrical.supervisor@xmail.co	Electrical Supervisor	project.manager@xmail.com	Project Manager	Poor quality material for cable protection	6/20/2022	16	cable	ground floor, right side			pump room
material.supplier@xmail.com	material supplier	project.manager@xmail.com	Project Manager	Material unavailable	8/1/2022	7	Wall 37	first floor, right side	X		main bedroom
skilledlaborer@xmail.com	Skilled laborer	project.manager@xmail.com	Project Manager	Different finishing of façade	8/1/2022	7	Floor 3	first floor, right side			main bedroom
designers@xmail.com	Designer team	project.manager@xmail.com	Project Manager	Different finishing of façade	8/2/2022	7	Floor 3	first floor, right side			main bedroom
fieldeng@xmail.com	field engineer	project.manager@xmail.com	Project Manager	Different finishing of façade	8/2/2022	7	Floor 3	first floor, right side			main bedroom
finish.matsupp@xmail.com	Finishing Material Supplie	project.manager@xmail.com	Project Manager	Different finishing of façade	8/3/2022	6	Floor 3	first floor, right side			main bedroom

Figure 34 – Emails extracted

Number (caller	Caller	Call receiver	Subject	Date	Due Date in Day	Item	Location of the item	X if part of Critical Path	X if urgent	Call Duration	Room
xxxxxx	Site supervisor	project manager	Hired excavator missing	4/4/2022	1	fundation	ground floor, center		X		
xxxxxx	Site supervisor	project manager	Not Qualified truck driver	4/4/2022	1	fundation	ground floor, center				
xxxxxx	Site supervisor	project manager	Missing qualified ironworker	4/28/2022	0.04167	column	ground floor, right side		X		living room
xxxxxx	Site supervisor	structural design office	Column missplaced	5/4/2022	2	column	ground floor, right side				living room
xxxxxx	structural design office	project manager	Different size of columns	5/5/2022	2	column	ground floor, right side	X			living room
xxxxxx	Site supervisor	project manager	Column not aligned	5/6/2022	0.04167	column	ground floor, right side	X			living room
xxxxxx	Site supervisor	structural design office	Different rebar spacing	5/7/2022	0.04167	floor	first floor, left side				bedroom
xxxxxx	Site supervisor	project manager	Different rebar spacing	5/7/2022	0.04167	floor	first floor, left side				bedroom
xxxxxx	Site supervisor	structural design office	Different rebar diameter	5/9/2022	0.04167	floor	first floor, right side				bedroom
xxxxxx	Site supervisor	project manager	Different rebar diameter	5/9/2022	0.04167	floor	first floor, right side				bedroom
xxxxxx	Site supervisor	project manager	A section with a different shape	5/12/2022	3	wall	first floor, right side				main bedroom
xxxxxx	plumbing supervisor	project manager	request for approval to change damaged plumbing elemer	6/7/2022	1	pipe	ground floor, right side		X		guest restroom
xxxxxx	Electrical Supervisor	Site supervisor	Placement of 110v instead of 220v	6/15/2022	0.083333	electrical fixture	ground floor, left side				laundry room
xxxxxx	Electrical Supervisor	project manager	Placement of 110v instead of 220v	6/15/2022	0.083333	electrical fixture	ground floor, left side				laundry room

Figure 35 – Calls extracted

Receiver	Subject	Date	Due Date in Days	Item	Location of the item	X if part of Critical Path	X if urgent	Room
project manager	unexpected type of soil	4/5/2022	14	foundation	ground floor, center		X	
project manager	unexpected malfunction of the excavator	4/11/2022	1	foundation	ground floor, center			
project manager	unexpected weather conditions	4/13/2022	14	foundation	ground floor, center			
project manager	Column missplaced	5/2/2022	4	column	ground floor, left side	X		dinning room
structural design office	Column missplaced	5/2/2022	4	column	ground floor, left side	X		dinning room
project manager	Wrong pipe quality	6/1/2022	7	pipe	first floor, left side			restroom 1
site supervisor	Plumbing components damaged after test	6/7/2022	4	plumbing fixtures	first floor, right side		X	restroom 2
site supervisor	Missconnection of drain from main restroom	6/10/2022	3	plumbing fixtures	first floor, right side			main restroom
site supervisor	electrical material shortage	6/14/2022	14	electrical fixture	ground floor, left side			kitchen
project manager	electrical material shortage	6/14/2022	14	electrical fixture	ground floor, left side			kitchen
site supervisor	Simple switch instead of a 3way switch	6/19/2022	3	electrical equipmer	ground floor, left side			laundry room
project manager	Simple switch instead of a 3way switch	6/19/2022	3	electrical equipmer	ground floor, left side			laundry room
site supervisor	Poor quality material for cable protection	6/20/2022	14	conduit	ground floor, right side			pump room
project manager	Poor quality material for cable protection	6/20/2022	14	conduit	ground floor, right side			pump room
site supervisor	Change of sanitary point	7/4/2022	7	plumbing fixtures	ground floor, right side			guest restroom
project manager	Change of sanitary point	7/4/2022	7	plumbing fixtures	ground floor, right side			guest restroom

Figure 36 –Text messages extracted

5.6. Ranges for classification of information

The subsequent illustrations (Figure 37- Figure 42) indicate the chosen ranges in terms of criticality coming from due date, volume of information, source of information and combination of volume of information and the due date. These ranges can be modified according to the needs of the project manager using the script.

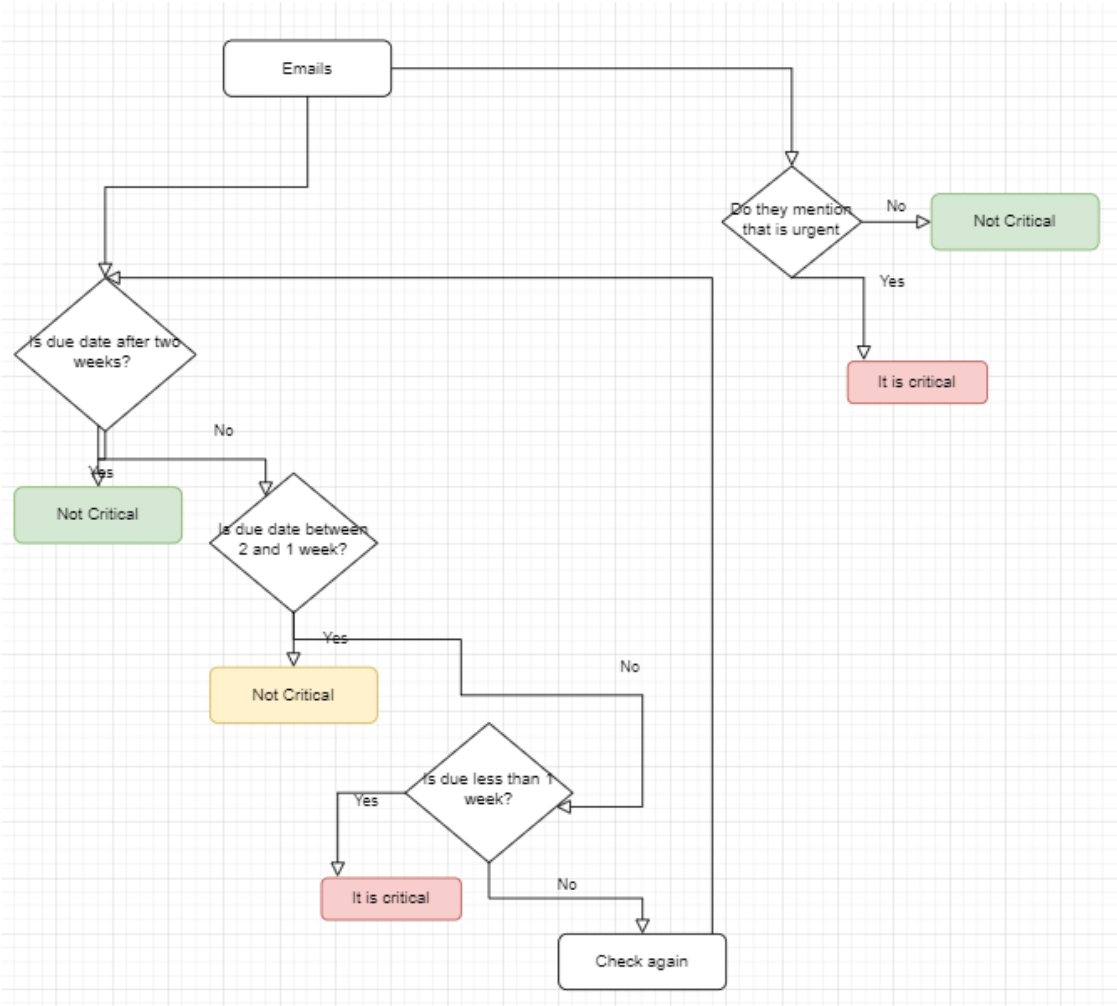

Figure 37 –Diagram of emails according the due date

The initial range for emails and text messages would be as follows: it would be considered critical if the due date is less than a week, medium if due date is between 1 and 2 weeks and not critical at all when due date is after two weeks.

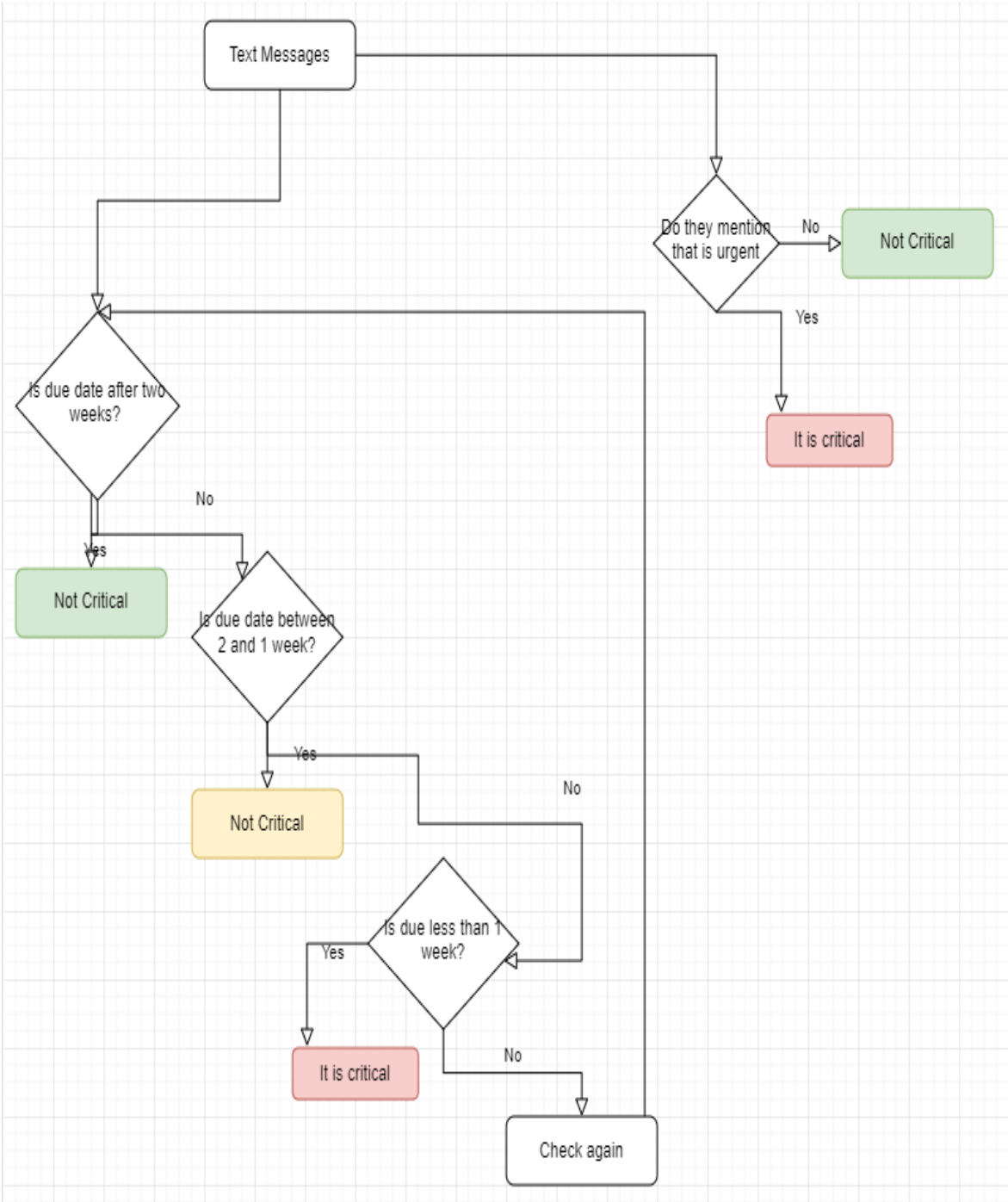

Figure 38 –Diagram of text messages according the due date

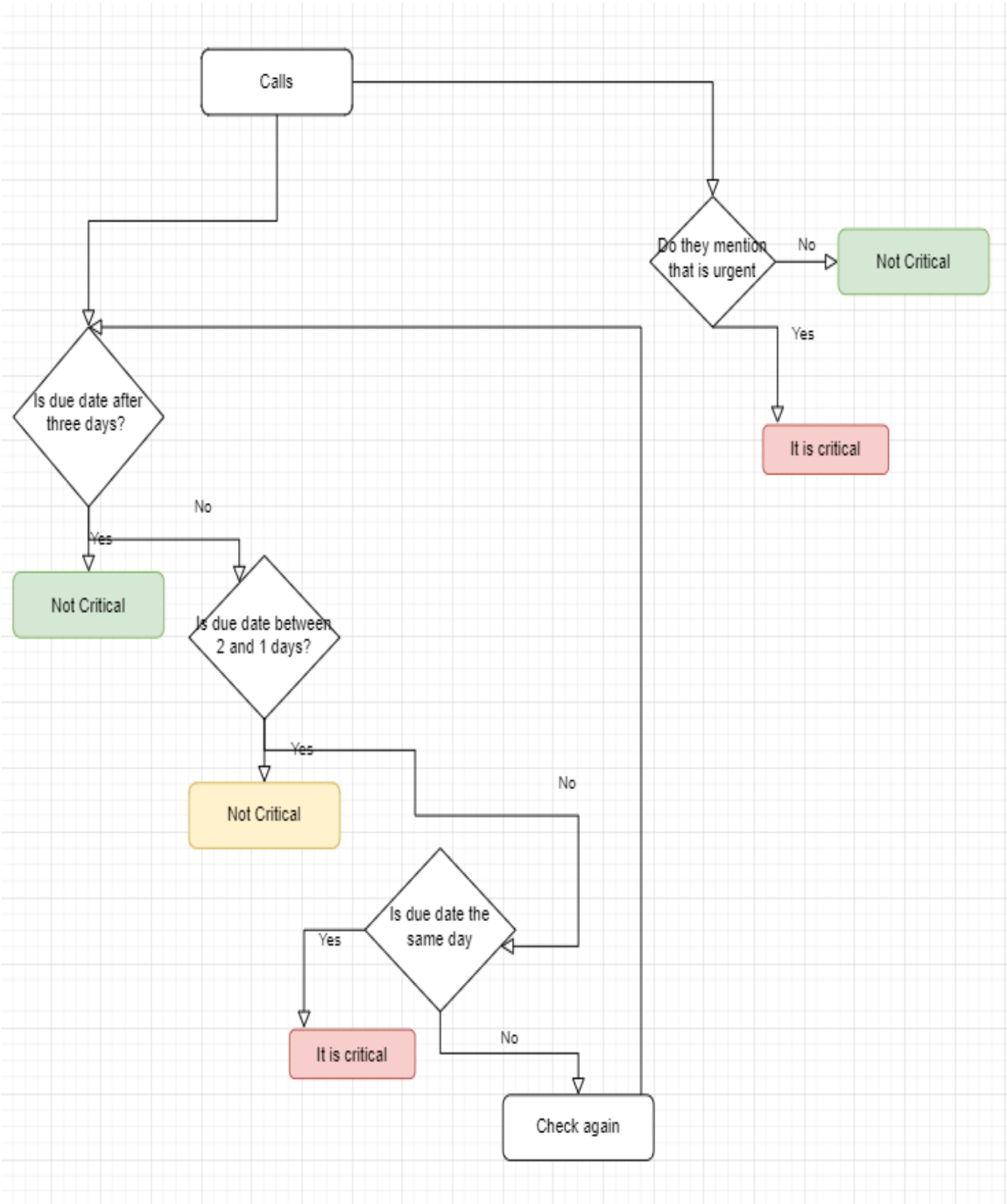

Figure 39 –Diagram of calls according the due date

The diagram of calls indicates that if there is a due date after more than three days, then it is not critical at all; if there is a due date between 1 and 2 days, then it would be medium and if the due date is on the same date, then it would be critical.

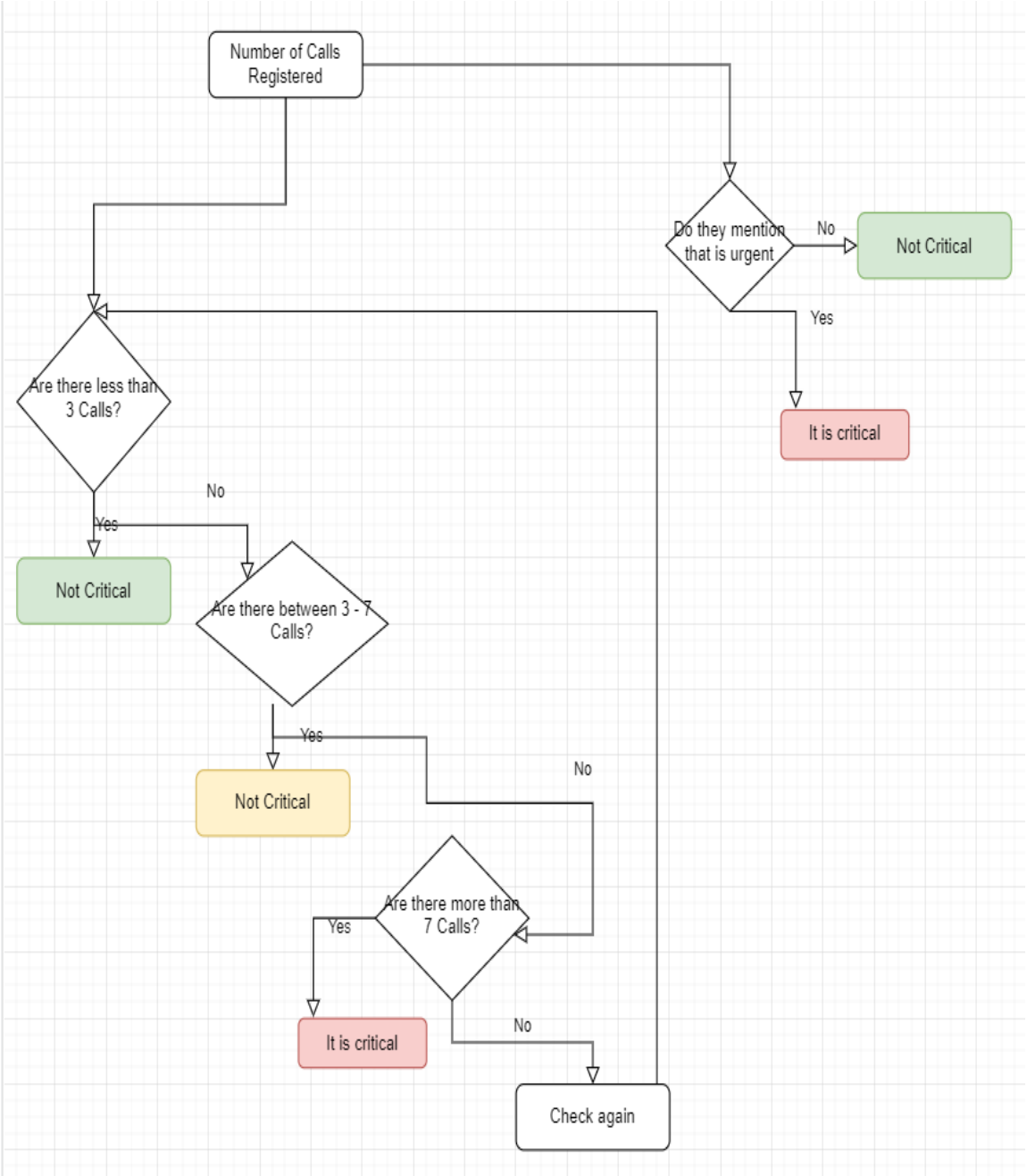

Figure 40 – Diagram of calls according the Volume of information

If there are less than three calls registered over the same topic, then it would be considered not critical at all; if there are between 3 and 7 calls regarding one topic, then it would be considered medium in terms of criticality and if there are more than 7 calls regarding one specific topic, then it would be considered critical immediately.

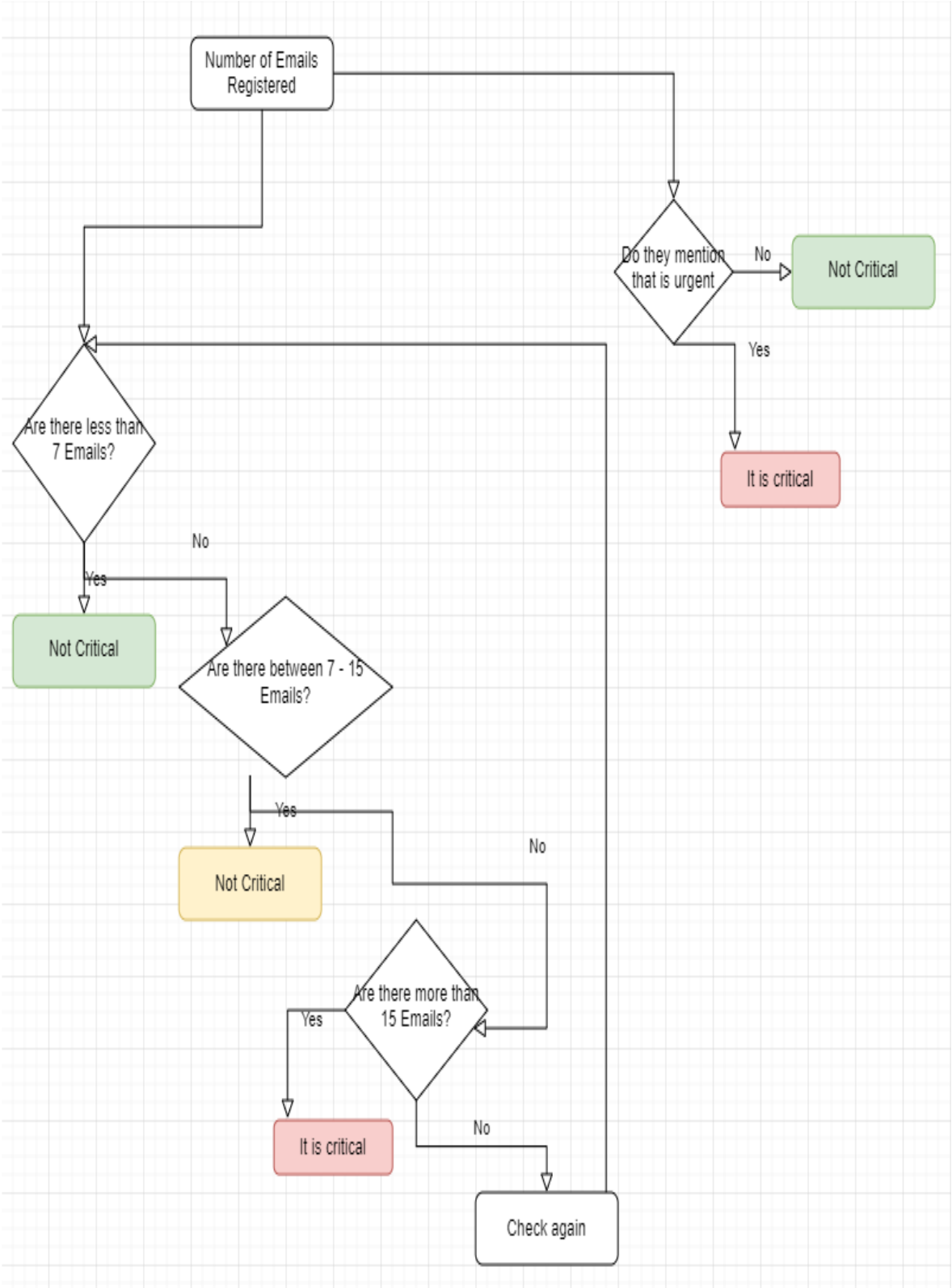

Figure 41 – Diagram of emails according the Volume of information

If there are less than 7 emails it would be considered not critical at all; if there are between 7-15 emails, then, it would be considered medium in terms of criticality and if there are more than 15 emails regarding one specific topic, then it would be considered critical immediately.

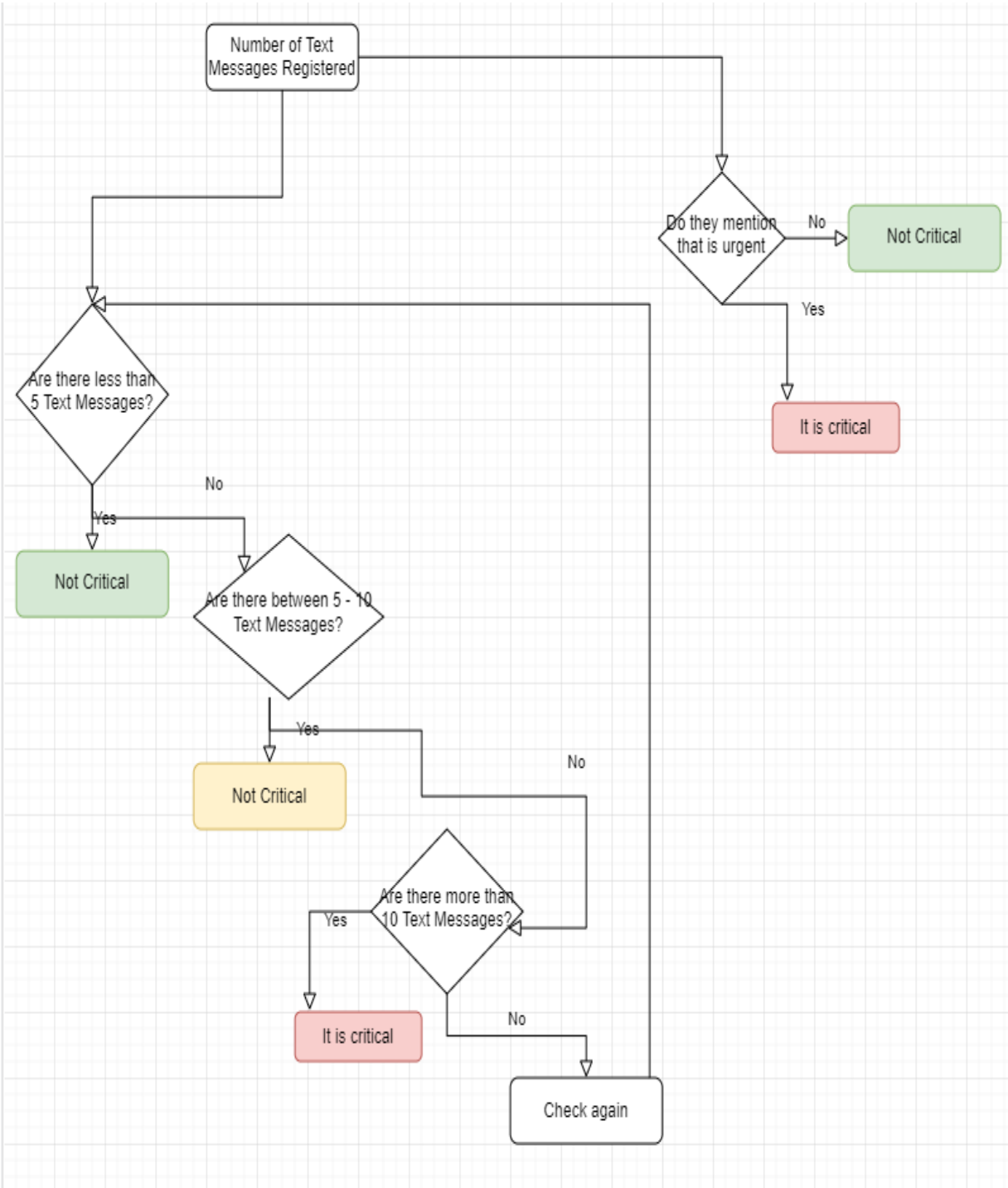

Figure 42 – Diagram of text messages according the Volume of information

If there are less than 5 text messages it would be considered not critical at all; if there are between 5-10 text messages, then, it would be considered medium in terms of criticality and if there are more than 10 text messages regarding one specific topic, then it would be considered critical immediately.

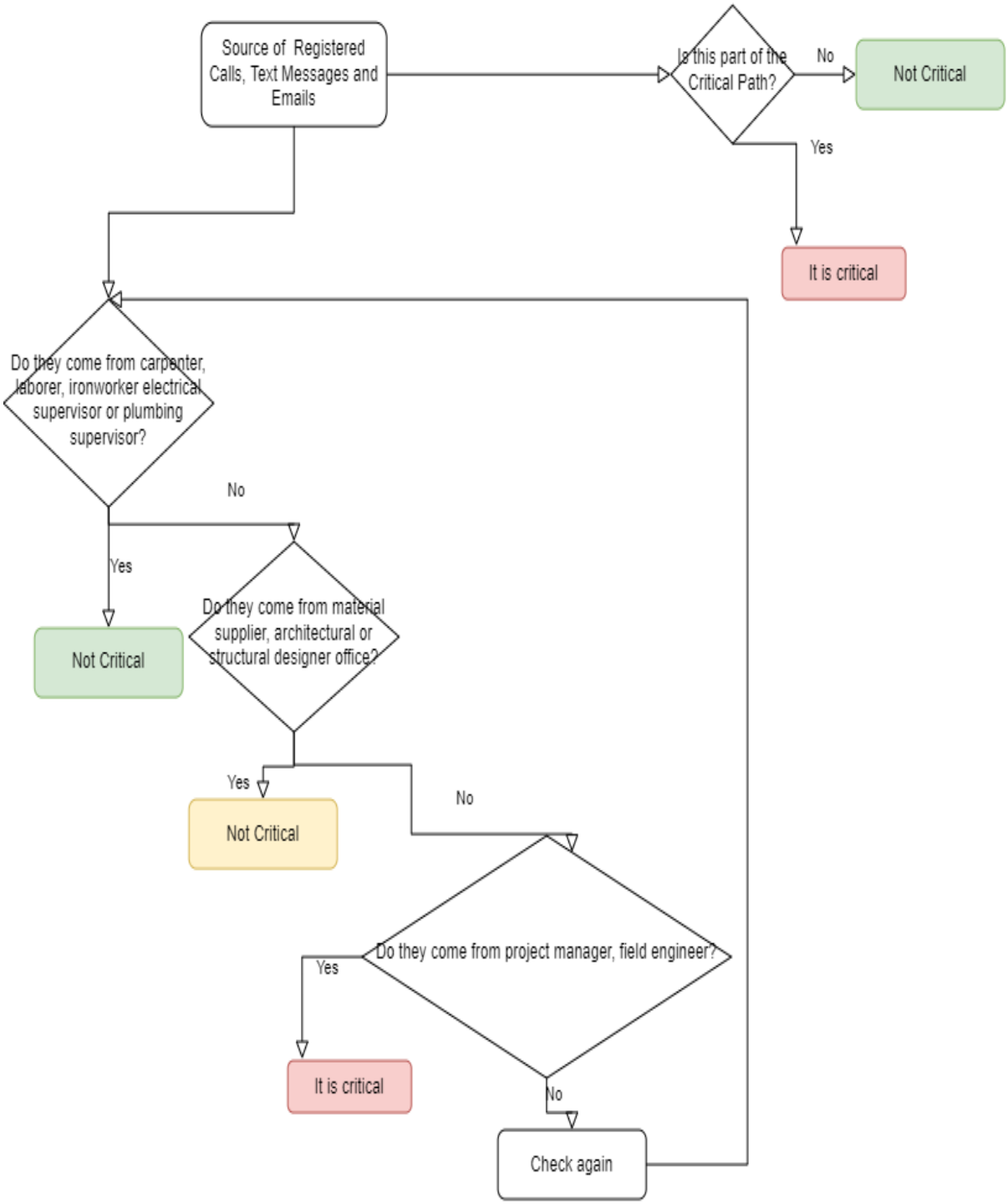

Figure 43 – Text Messages, Emails and Calls according source of information

The Figure 43 clearly states that it would not be considered critical at all if the communication comes from laborer, carpenter or material supplier; the message would be considered medium in terms of criticality if it comes from architectural or structural design office; the information would be considered critical if it comes from project manager, field engineer, electrical supervisor or plumbing supervisor.

Volume						Time
Registered Calls	**28 days or mor**	**14-28 days**	**7-14 days**	**3-7 days**	**1-3 days**	due date
more than 7	not critical	medium	medium	Critical	Critical	
between 3-7	not critical	medium	medium	Critical	Critical	
less than 3	not critical	not critical	medium	medium	Critical	

Volume						Time
Registered Text Messages	**28 days or mor**	**14-28 days**	**7-14 days**	**3-7 days**	**1-3 days**	due date
more than 10	not critical	medium	medium	Critical	Critical	
between 5-10	not critical	not critical	medium	Critical	Critical	
less than 5	not critical	not critical	medium	medium	Critical	

Volume						Time
Registered Emails	**28 days or mor**	**14-28 days**	**7-14 days**	**3-7 days**	**1-3 days**	due date
more than 15	not critical	medium	medium	Critical	Critical	
between 7-15	not critical	not critical	medium	Critical	Critical	
less than 7	not critical	not critical	medium	medium	Critical	

Figure 44 – Initial ranges of volume of information according due date

Volume				*		Time
Registered Calls	**28 days or more**	**14-28 days**	**7-14 days**	**3- 7days**	**1-3 days**	due date
more than 7	critical	critical	critical	critical	critical	
between 3-7	medium	medium	medium	not critical medium	critical	
less than 3	not critical	not critical	not critical/ medium	medium	medium /critical	

Volume						Time
Registered Text Mes	**28 days or more**	**14-28 days**	**7-14 days**	**3- 7 days**	**1-3 days**	due date
more than 10	critical	critical	critical	critical	critical	
between 5-10	not critical/ medium	not critical/ critical	not critical/ medium	not critical/ medium	critical	
less than 5	not critical/ critical	medium critical	medium	not critical	medium	

Volume						Time
Registered Emails	**28 days or more**	**14-28 days**	**7-14 days**	**3- 7 days**	**1-3 days**	due date
more than 15	critical	critical	critical	critical	critical	
between 7-15	medium	not critical/ medium	critical	critical	not critical/ medium	
less than 7	not critical/	medium critical	medium	medium	medium	

Figure 45 – Ranges of volume of information according due date resulting from questionnaire

The Figure 44 combines the amount of information received according to the due date resulting from the questionnaire. When there are two classifications like in less than 3 calls received in 1-3 days, the participants were divided in the classification between medium and critical. Among all of these considerations, there is the mark when it is an item from the critical path or when it is mentioned as urgent in the conversation, this means that the item is immediately considered as critical when this happens. All of these initial ranges and defined criteria (Figure 45) will be applied in the script of the visual programming tool defined in chapter 3.

6. GRAPHICAL PROGRAMMING MODEL AND APPLICATION OF THE VISUAL PROGRAMMING SCRIPT

In this chapter there is a detailed description of the graphical programming model of the case study and the application of the script described in chapter 3 into the model. The results are shown and there are indications on how to modify the inputs of the script according to the user. The graphical programming tool used for this dissertation was the Revit 22.0.2.392 and the tool for visual programming used for this study is the up-to-date Dynamo 2.10.1.3976.

6.1. Graphical Programming Model

The Revit model was done following the mentioned drawings (Chapter 5); each discipline was based on the sketches. The drawings were temporarily imported into the Revit file according the need.

The model was done through the phases of site preparation, foundation, steel structure, external, floor slab, brickwork, plumbing and sanitary, electrical and finishes as illustrated in Figure 46.

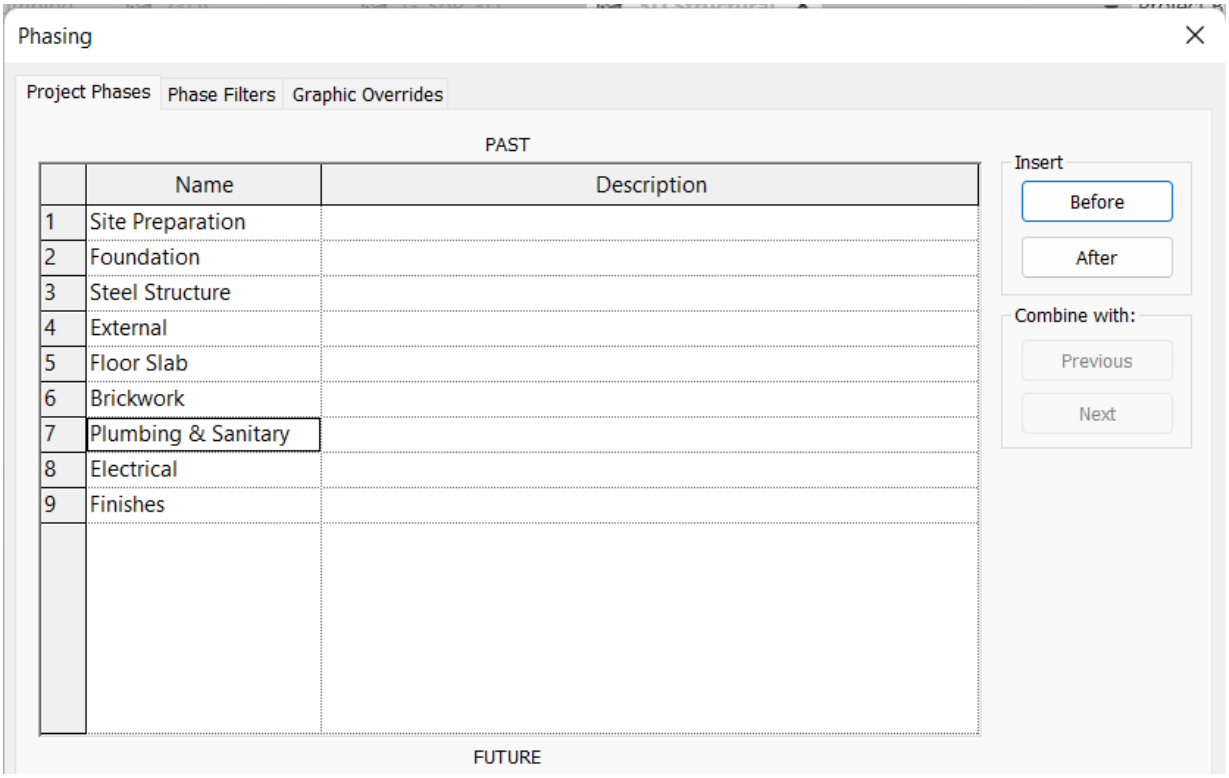

Figure 46 – Phases of Revit model

Each item in the Revit model will have the information of building date, mark and communication information as it can be appreciated in Figure 47.

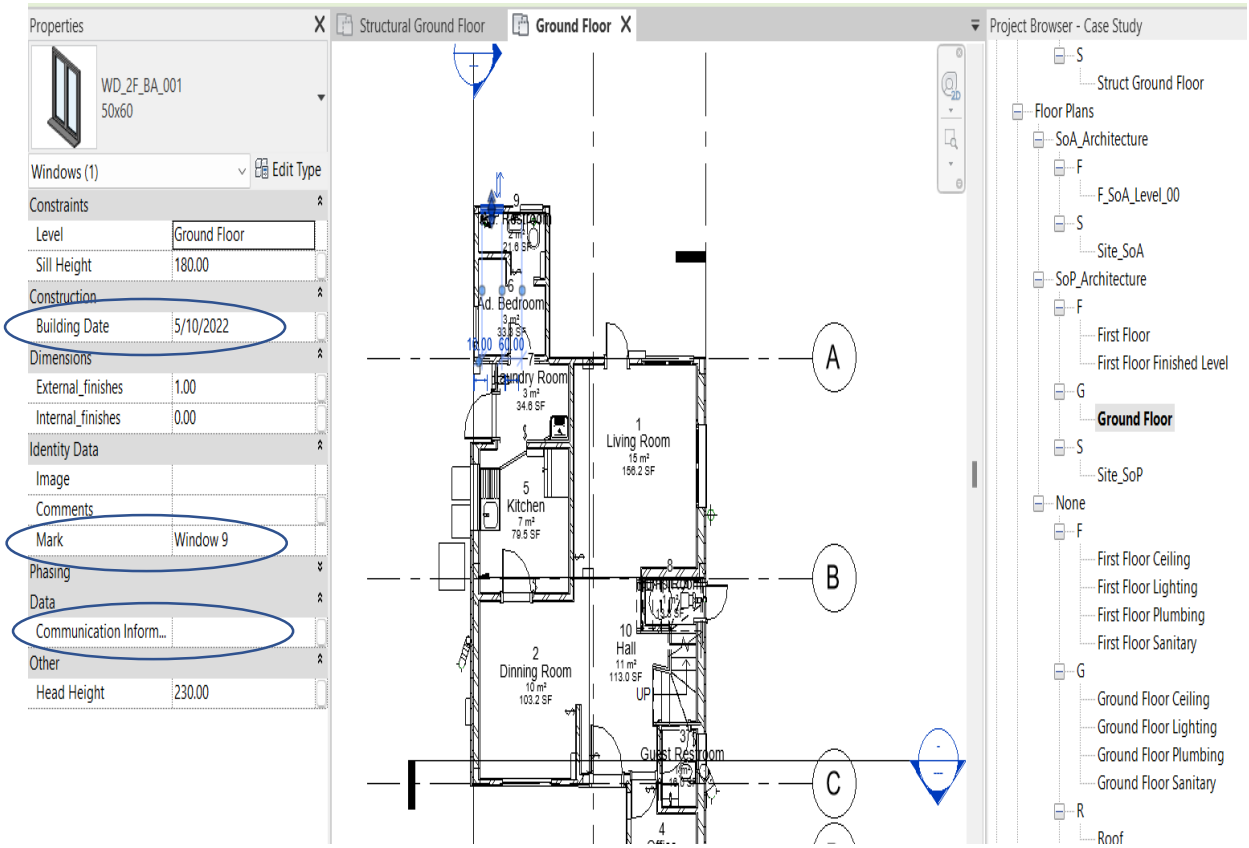

Figure 47 – Elements in Revit

The building date will be used to have a reference of the dates when they are built or installed during the construction phase; also, all the issues are represented in the items in conformity with the dates they are notified.

The mark will be used from the beginning of the model so that during the communication of the construction phase, the number of item is mentioned to identify which item someone is talking about; for example, the model will have column 1, 2, 3, so on and so forth until reaching the total amount of columns that the house has, the same would go for walls, doors, and all items part of the house. This can be later modified by the user or company that decides to change the naming convention and maybe separate the internal walls with external walls, among others.

The communication information will be filled after running the script with the low, medium or high criticality information so that the project manager can immediately know the reason for the color of the element in the resulting output. These parameters were added though managing project parameters and were set as instance parameters.

The case study contains the elements per model shown in Table 14. The images (Figure 48 - Figure 50) are representative of the case study house Revit architectural model (3D view, ground and first floors plans).

Table 14 –Architectural, structural, electrical, plumbing and sanitary elements in model

Element	Architectural	Structural	Electrical	Plumbing	Sanitary
Walls	x				
Doors	x				
Windows	x				
Stairs	x				
Rails	x				
Columns		x			
Beams		x			
Foundations		x			
Floors		x			
Water Components				x	
Pipes				x	x
Fittings				x	x
Plumbing Fixtures				x	x
Plumbing Components				x	x
Electrical Fixtures			x		
Lighting Devices			x		
Electrical Components			x		
Lighting Fixtures			x		
Wires			x		
Switches			x		
Transformers			x		
Panels			x		

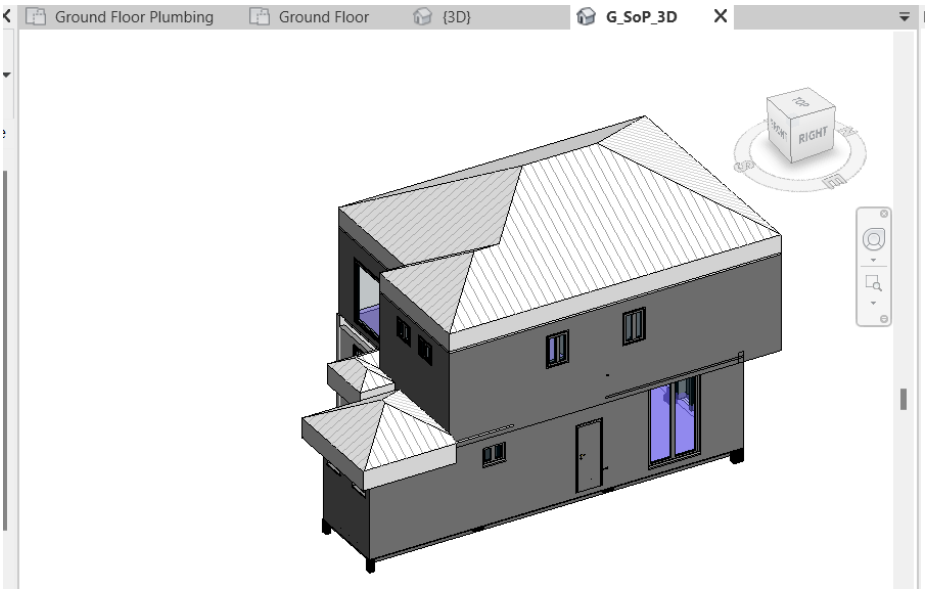

Figure 48 – 3D view in Revit of the case study house

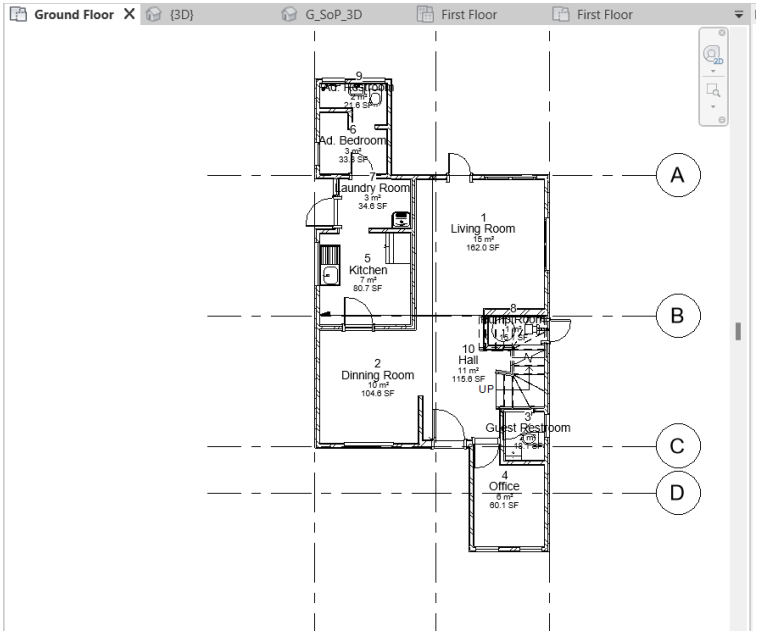

Figure 49 – Ground floor view in Revit of the case study house

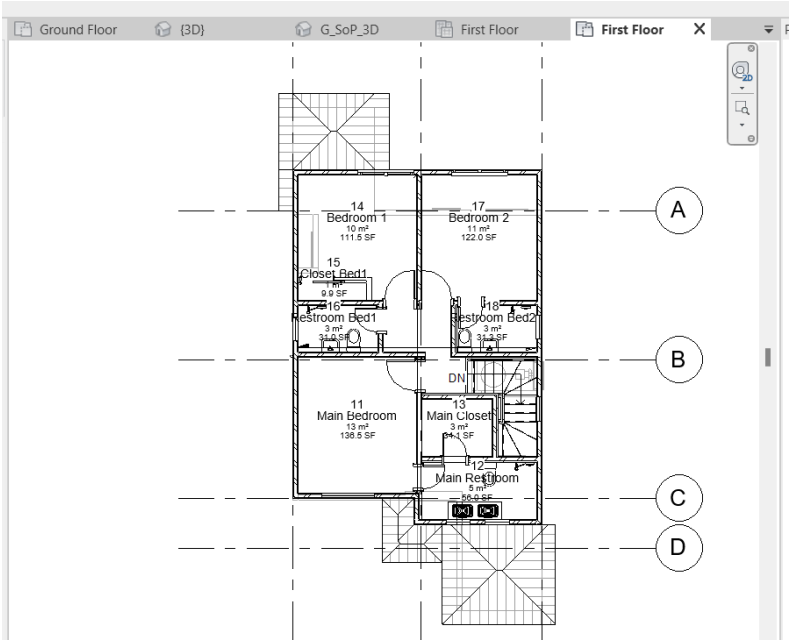

Figure 50 – First floor view in Revit of the case study house

The structural part of the case study is defined by a foundation slab standard of 20cm and columns of 250x350, and 250x250; the first floor with main beams, secondary beams (floor beams) and columns of 250x150x4mm, 250x150x3mm, 150x100x3mm. The following images (Figure 51 and Figure 52) are of the structural model of the case study.

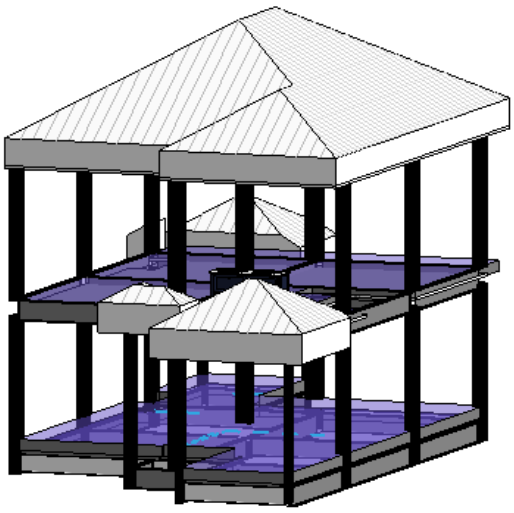

Figure 51 – 3D view of the structural part of the case study

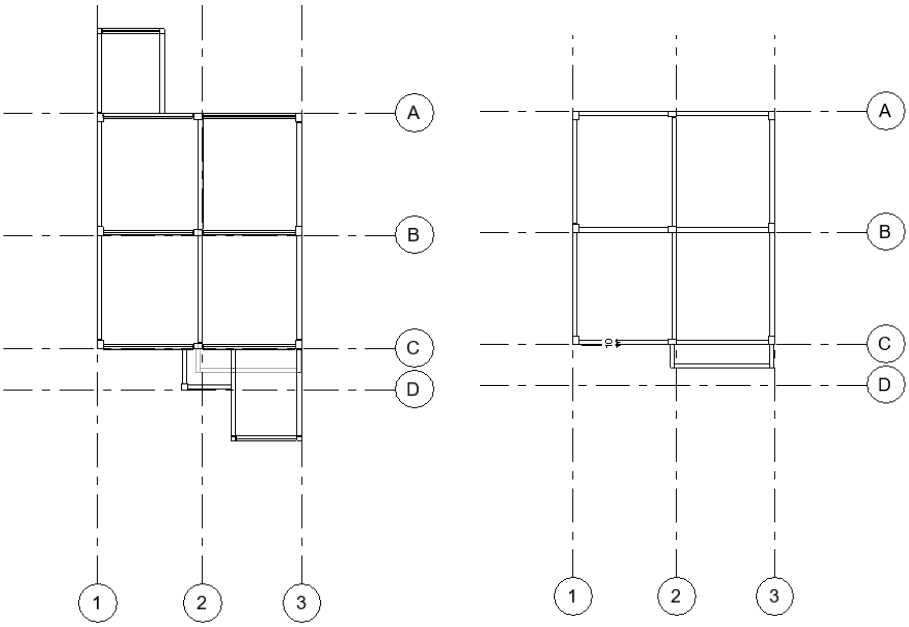

Figure 52 – Ground and first floor view of the structural part of the case study house

The electrical model of the case study house can be seen in Figure 53 and Figure 54 where you can notice that all lighting devices and fixtures are connected through the same system into electrical panel boards per floor. The switches, outputs are connected to other electrical panel boards also per floor that are connected to a transformer and then to a circuit breaker switchboard located on the ground floor.

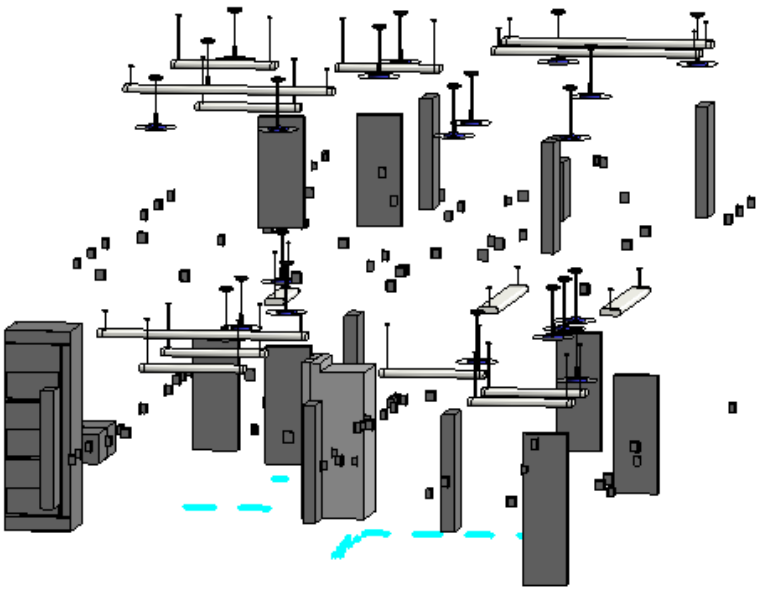

Figure 53 – 3D view of the electrical design

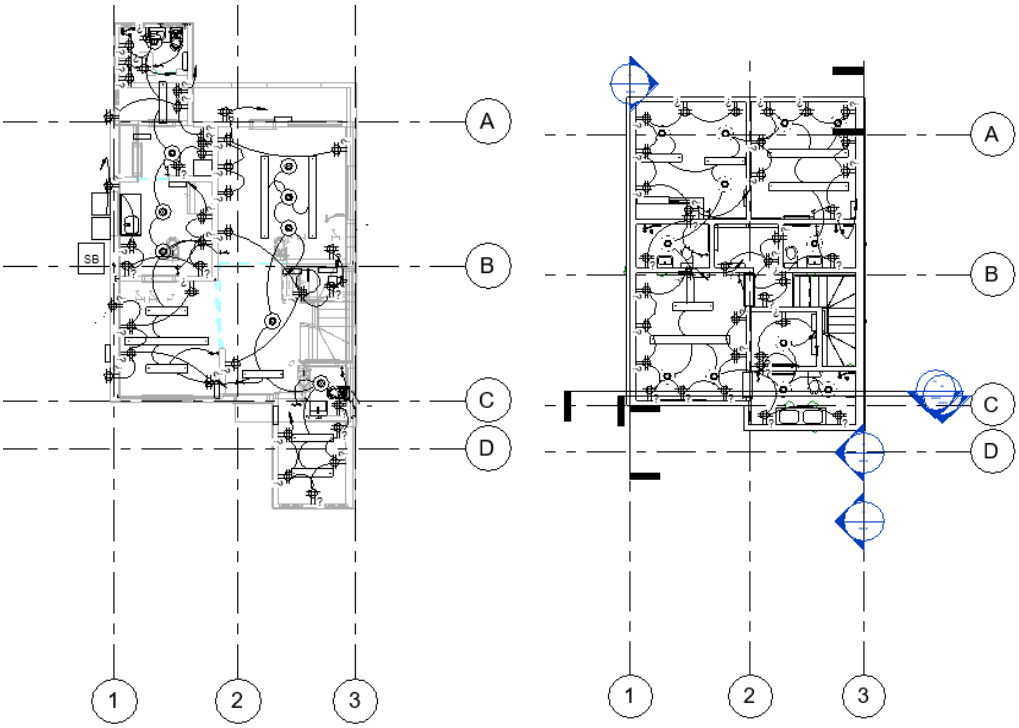

Figure 54 – Ground and first floor view of the electrical design of the case study house

The plumbing and sanitary model of the case study house can be appreciated in Figure 55 and Figure 56 where you can notice that all plumbing and sanitary devices and plumbing fixtures are connected through pipes and pipe fittings. The plumbing system starts in the house on the ground floor in the pump room located under the stairs. The sanitary design goes through all the connected sewage boxes that go to the main sewage collector of the neighborhood.

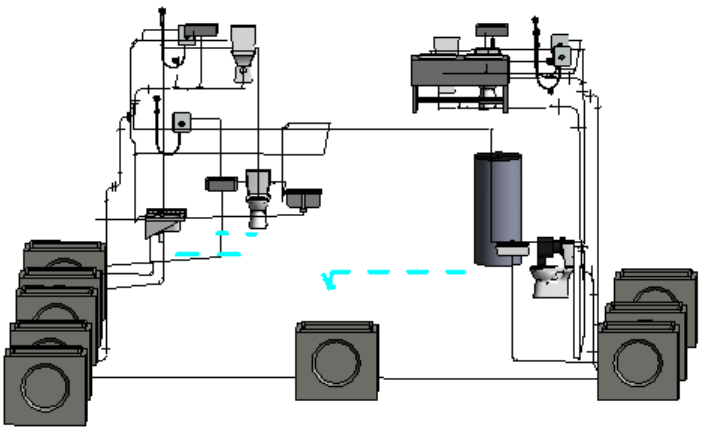

Figure 55 – 3D view of the plumbing and sanitary design of the case study house

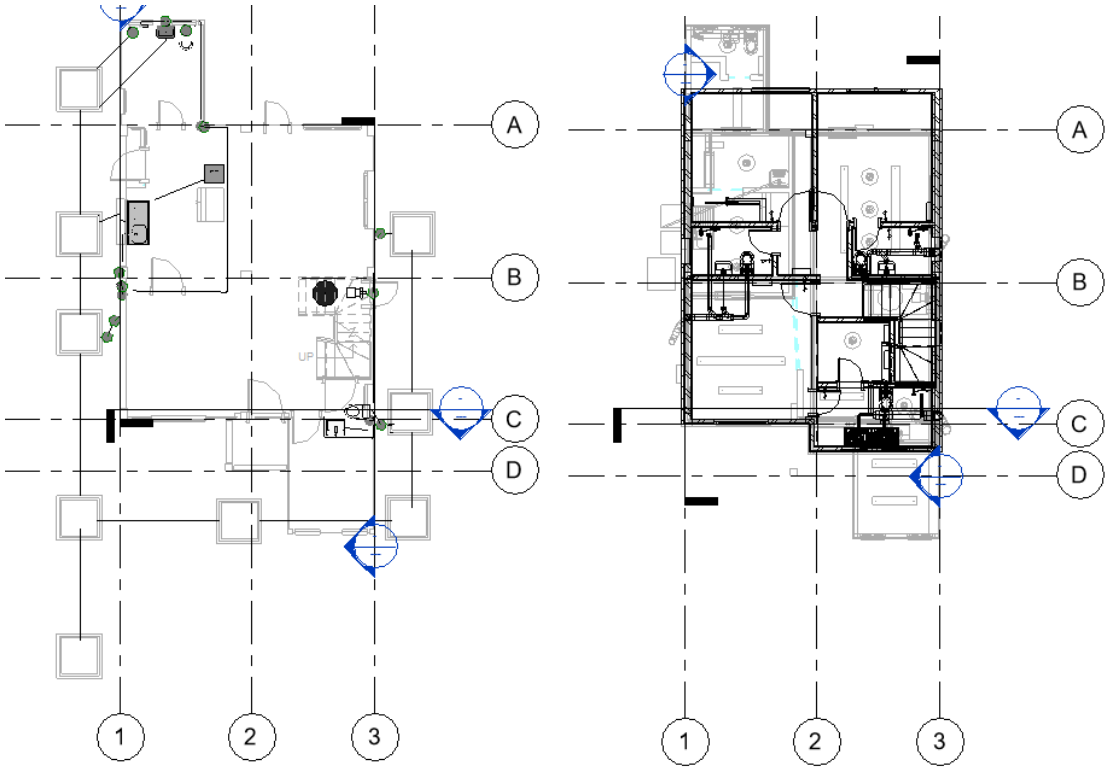

Figure 56 – Ground and first floor view of the plumbing and sanitary design of the case study house

The purpose of the study is to visualize all the elements and to have all the elements of the diverse disciplines loaded in the model to reflect on them the communication information. It is true that before proceeding to the construction phase a scrutinized clash detection examination is needed to be able to foresee some of the construction issues and avoid them; however, for the purpose of this fictitious case study, the clash detection part was skipped due to the limited time. Of course, any model that comes to be analyzed is suggested to go through clash detection to accomplish a better visualization.

6.2. Visual Programming Script Result

As the previous chapters' state, there is a script that will contribute to the achievement of the visual aid for project managers. The dynamo script is shown in detail in Chapter 3. This script is played through the Dynamo Player option available in Revit-Manage. The .dyn file is selected and played. After a while, this image appears with all the intervals and limits to be changed if wanted or needed. (Figure 57 and Figure 58)

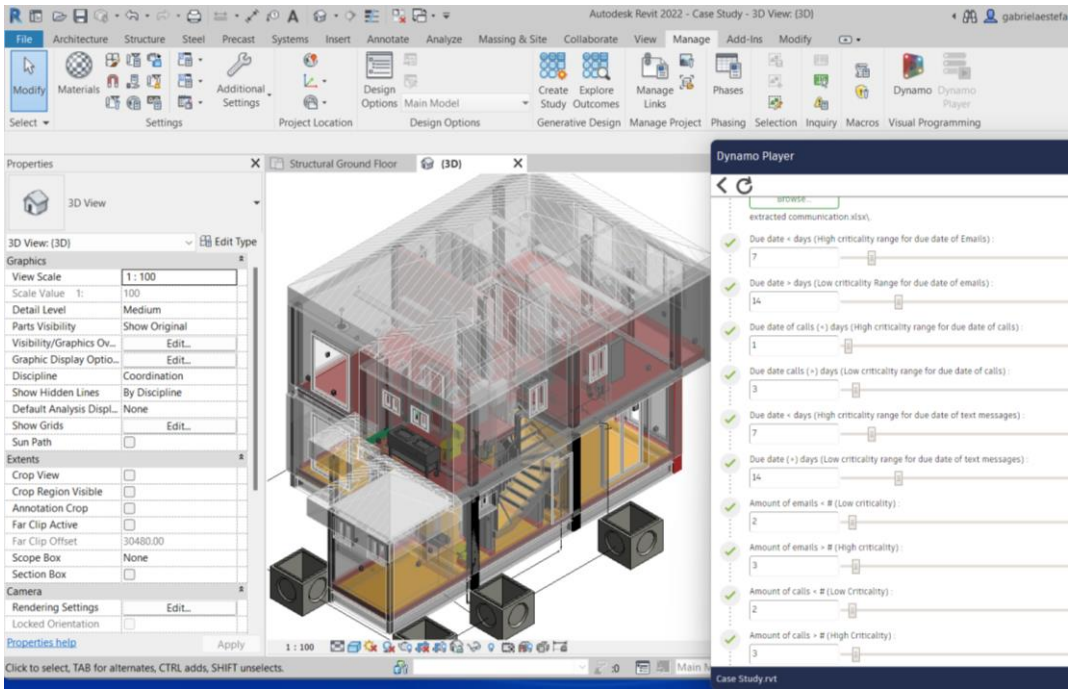

Figure 57 – Ranges that can be changed

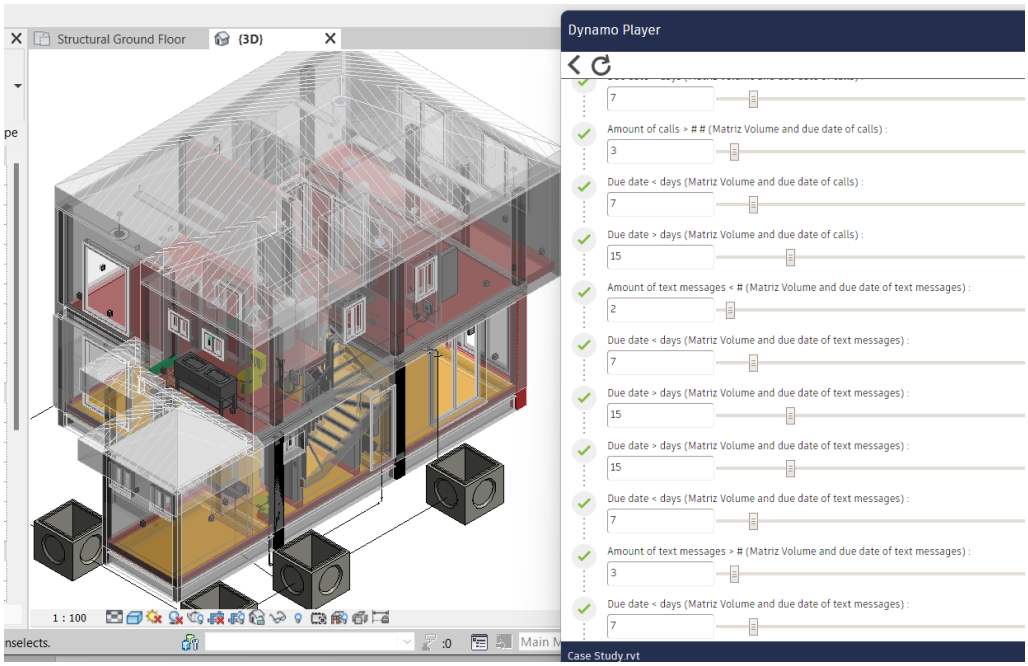

Figure 58 – More ranges that can be changed

According to these changes, the user can obtain a list of the issues sorted by criticality. There will be a list for low, medium, and high criticality of emails, text messages and calls, classified by due date, volume, matrix and sender of information. The information seen is the subject of the issue, the due date to answer, the date when the issue was presented, the location of the item and the mark of the item. (Figure 59, Figure 60 and Figure 61)

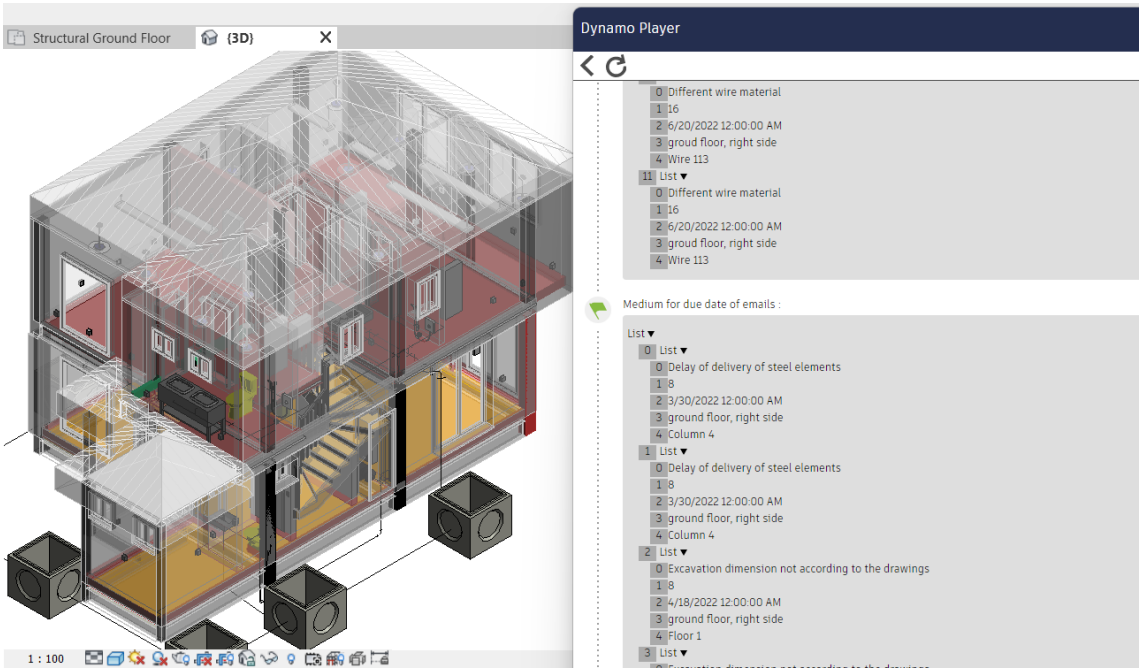

Figure 59 – List of issues according to the classification of criticality

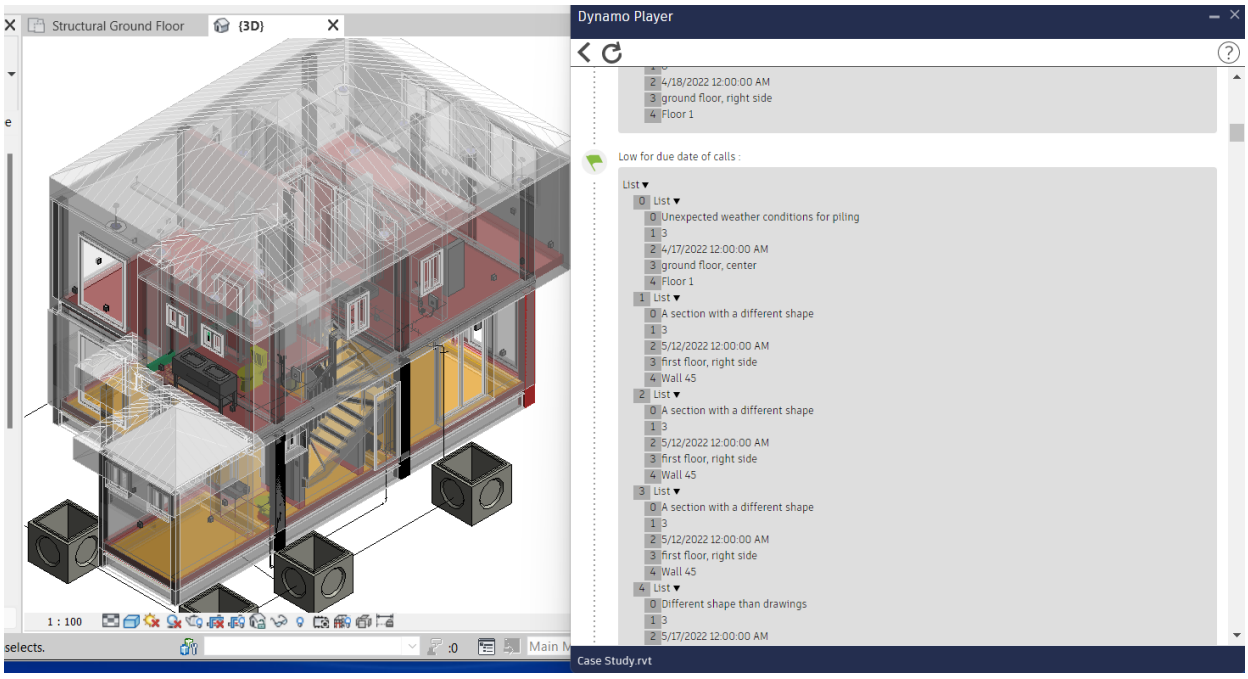

Figure 60 – List of more issues according to the classification of criticality

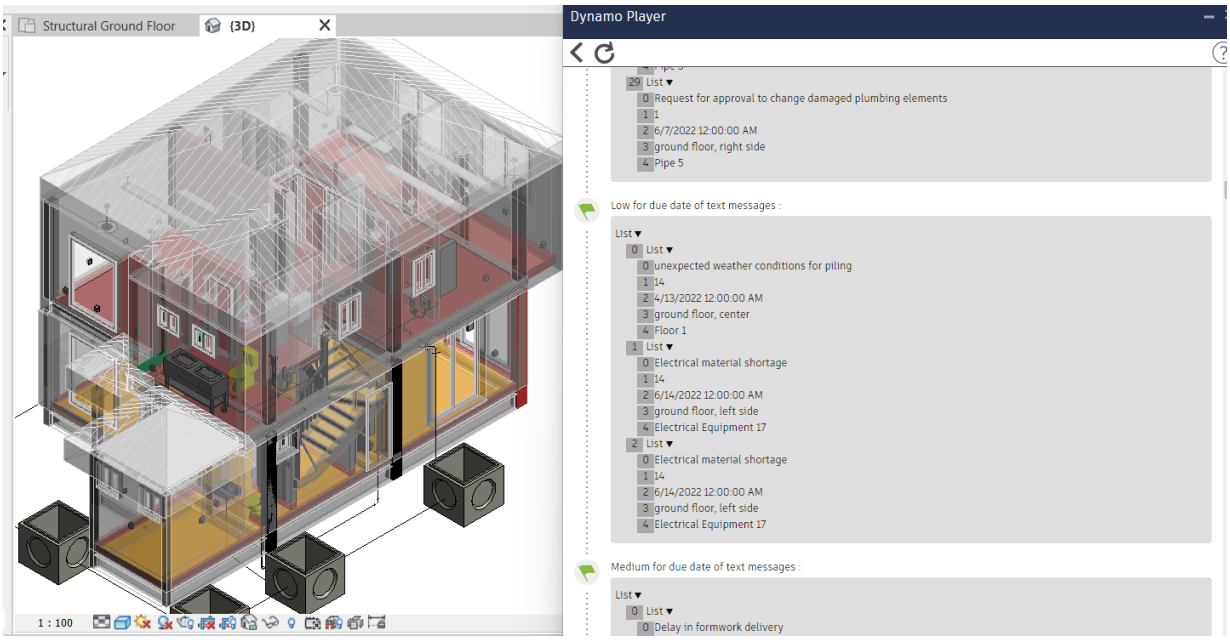

Figure 61 – List of other issues according to the classification of criticality

In the following Figure 62, one can see that there are items low (green), medium(yellow) and high (red).

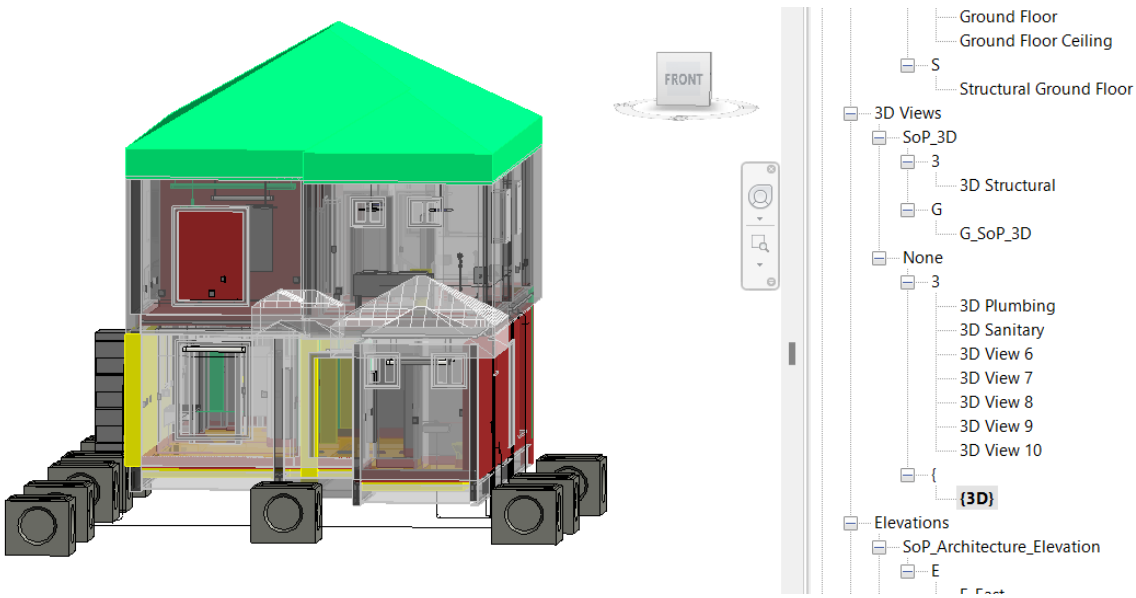

Figure 62 – Resulting visualization of the items of the case study in the 3D view according to the criticality

After clicking the yellow column, one can notice the reason why the element is yellow. It was classified as medium for the due date of emails. This can be found in the communication information of the item. (Figure 63)

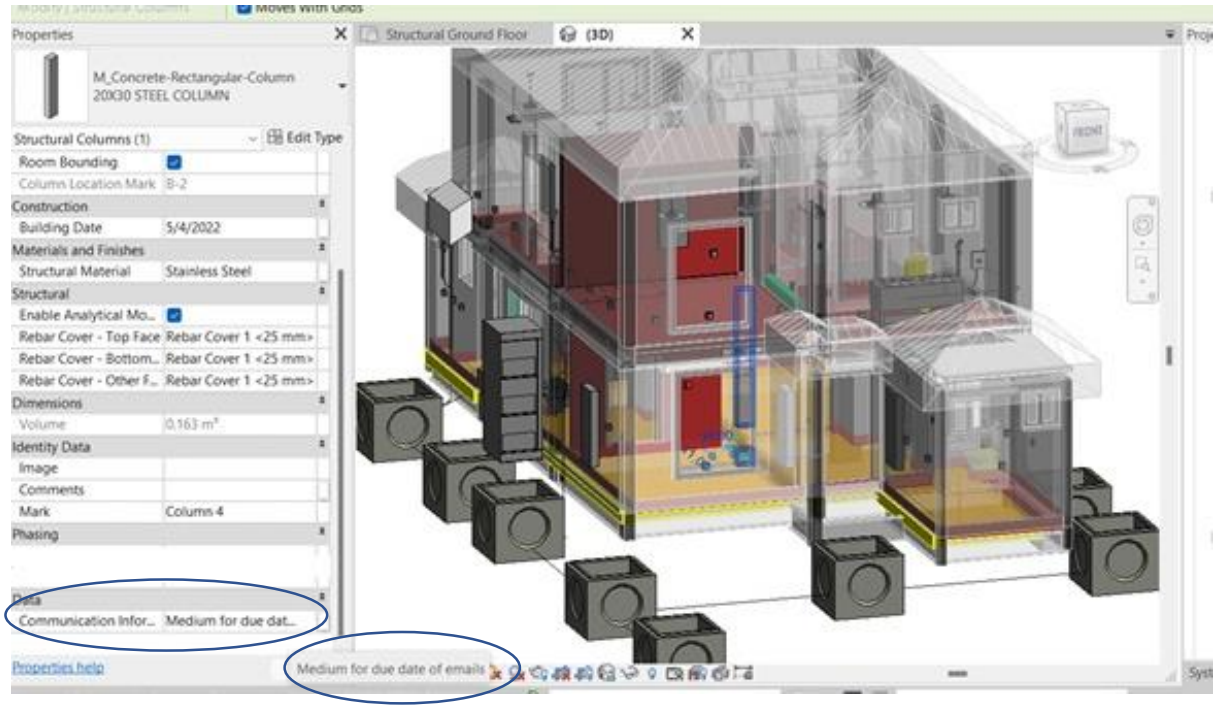

Figure 63 – Communication information of the yellow column 4

After clicking on the green wall, one can notice the reason why the element is green. It was classified as low for the due date of calls. This can be found in the communication information of the item. (Figure 64)

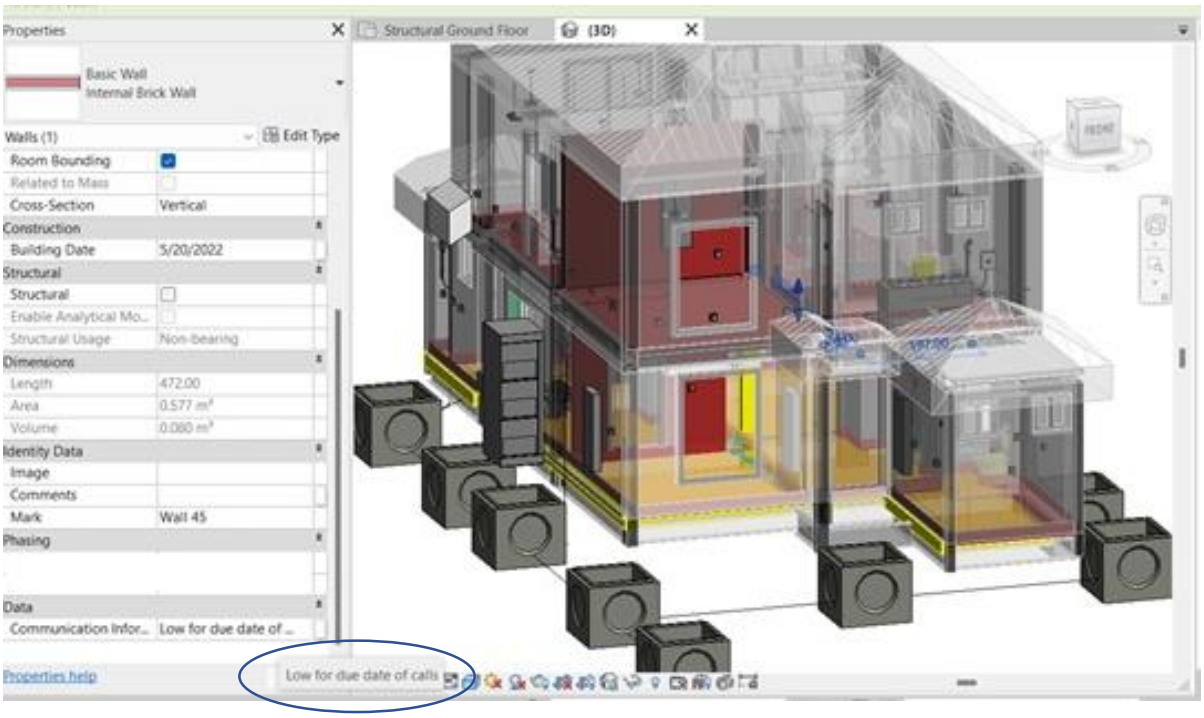

Figure 64 – Communication information of the green wall 45

After clicking on the red wall, one can notice the reason why the element is red. It was classified as high for the due date of emails. This can be found in the communication information of the item. (Figure 65)

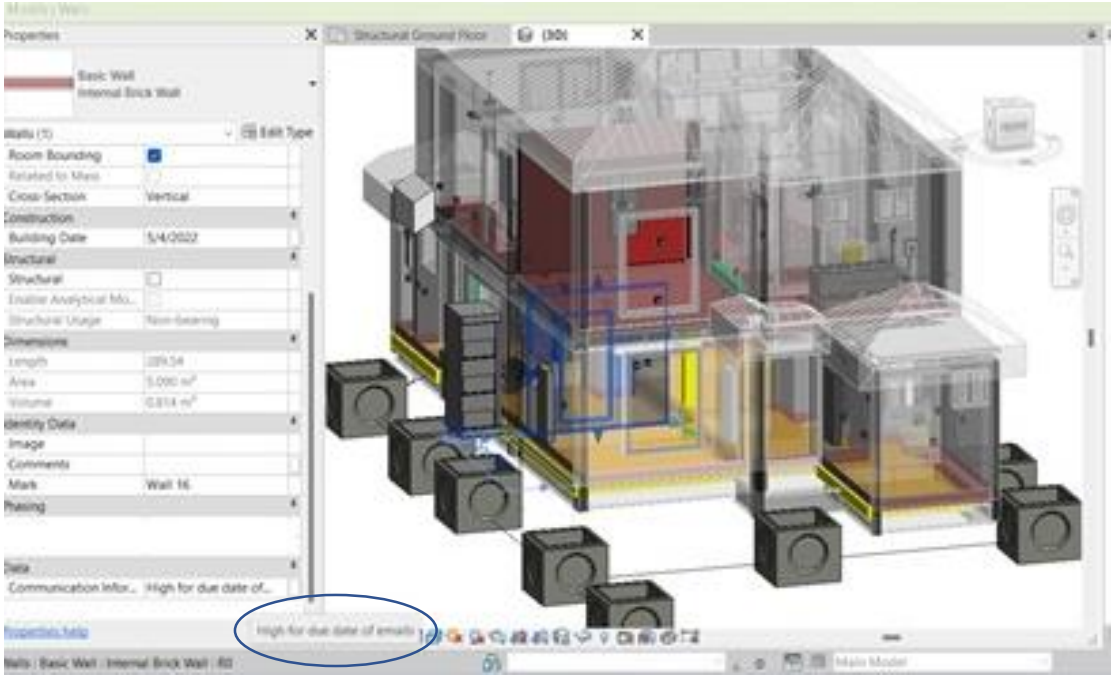

Figure 65 – Communication information of the red wall 16

There is another angle of view of the case study house and from this side (Figure 66), one can notice that also have colored items that will be seen in the following images.

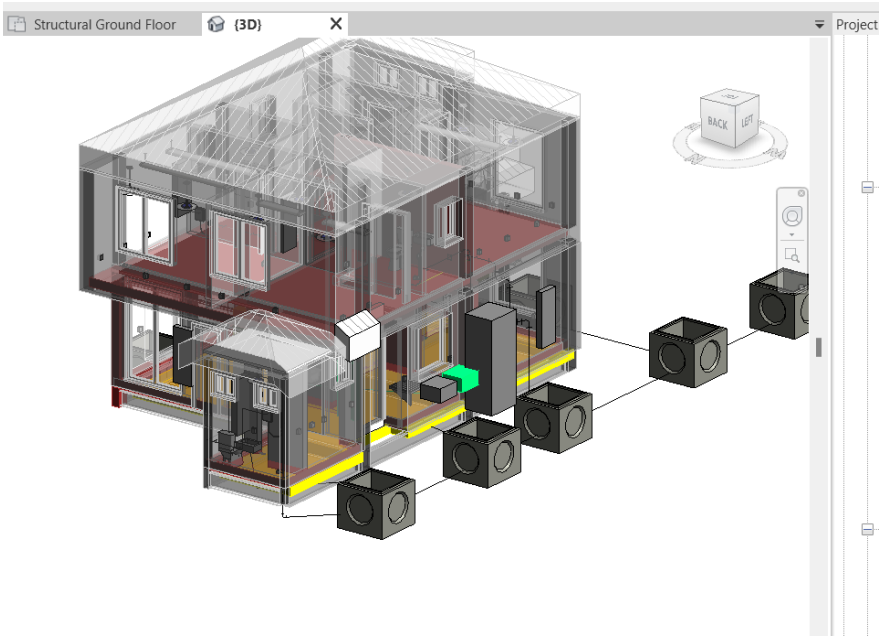

Figure 66 – 3D other point of view of the visualized case study

After clicking on the green transformer, one can notice the reason why the element is green. It was classified as low for the due date of calls. This can be found in the communication information of the item. (Figure 67)

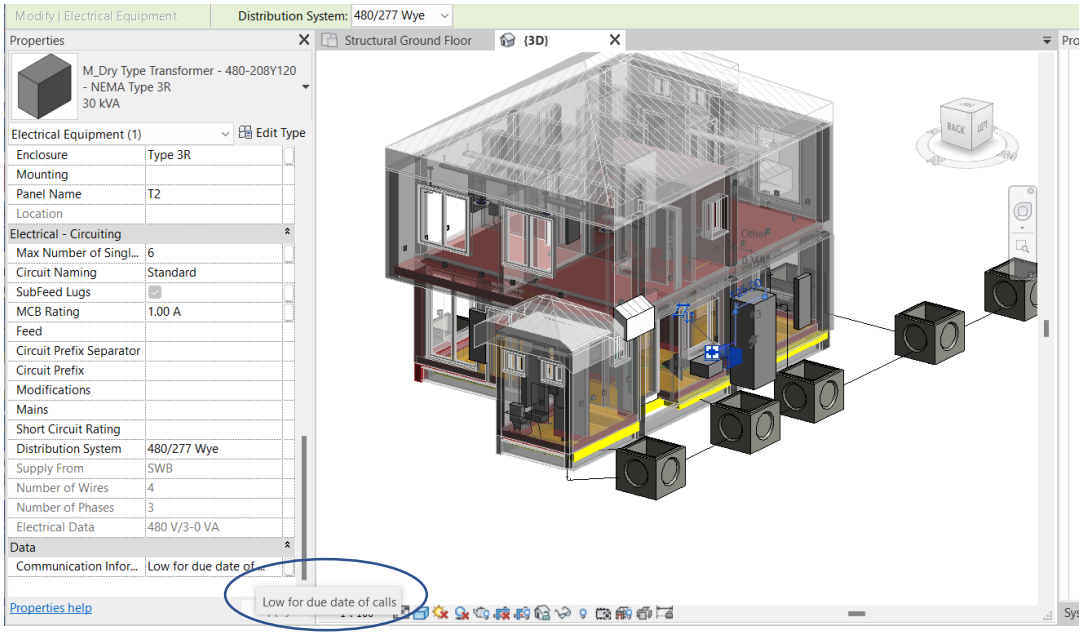

Figure 67 – Communication information of the green transformer

After clicking on the yellow floor, one can notice the reason why the element is yellow. It was classified as medium for the due date of emails. This can be found in the communication information of the item. (Figure 68)

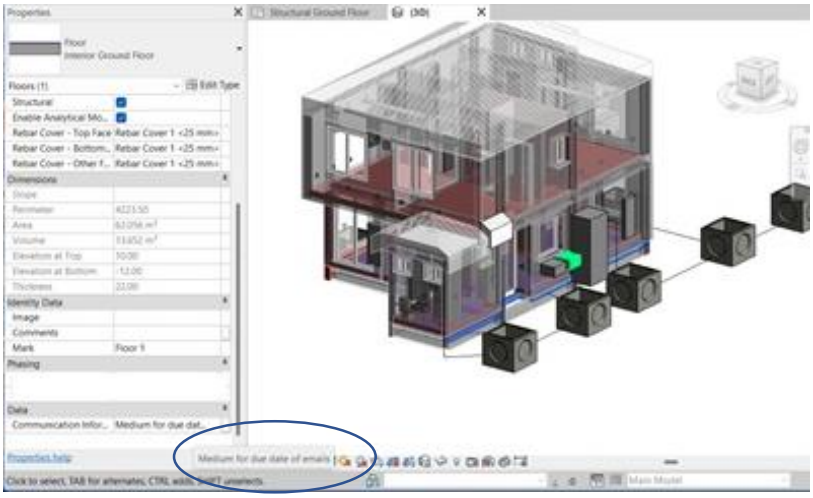

Figure 68 – Communication information of the floor 1

After clicking on the red floor 3, one can notice the reason why the element is red. It was classified as high for the due date of calls. This can be found in the communication information of the item. (Figure 69)

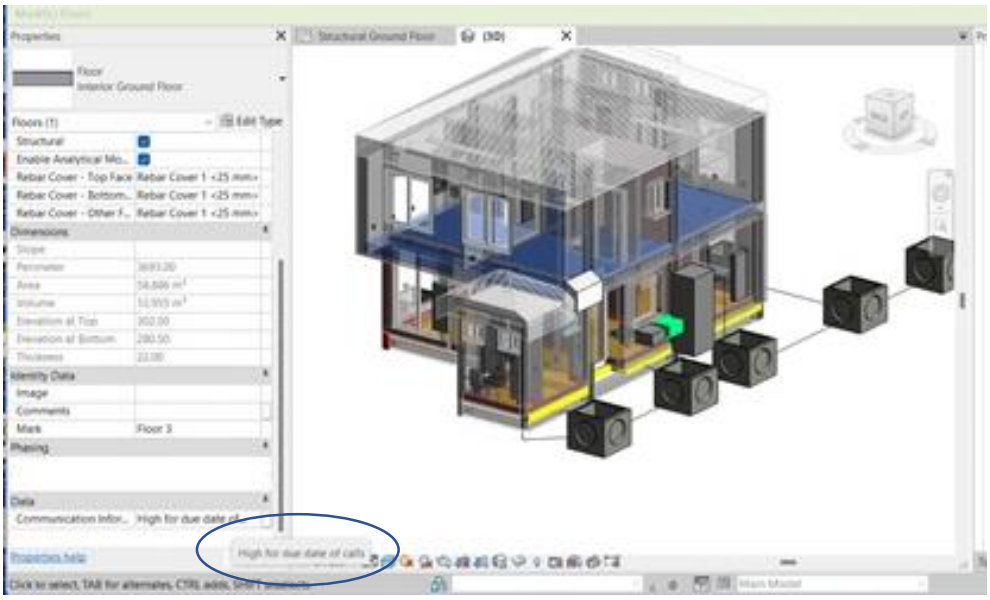

Figure 69 – Communication information of the floor 3

After clicking on the yellow pipe, one can notice the reason why the element is yellow. It was classified as medium for the due date of calls. This can be found in the communication information of the item. (Figure 70)

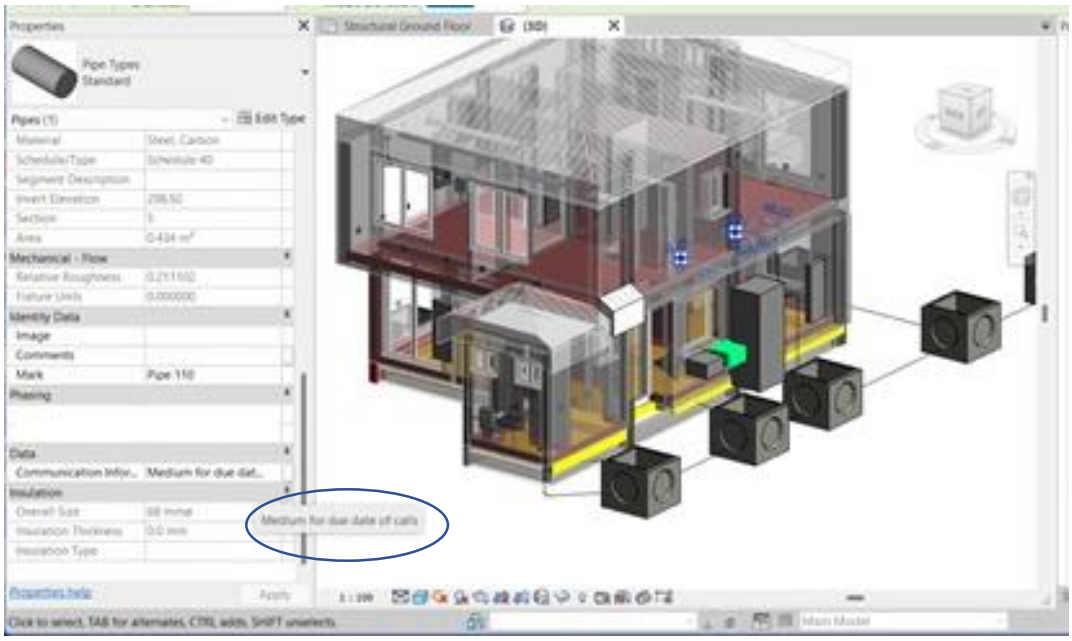

Figure 70 – Communication information of the pipe 110

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7. CONCLUSIONS

Nowadays the construction sector has methods for increasing efficiency through digital transformation. The adoption of these state of the art mechanisms will definitely depend on the investment of leaders of cities, countries and company owners. The construction industry is known to be one of the largest contributors to the world economy, for this reason is highly important to embrace everything that technology can provide to achieve enhancement in productivity and significant reduction of costs, environmental impacts and construction problems. The construction phase is important because it involves risks and issues. Unfortunately, there is a lag of complete BIM adoption during this phase that needs to be tackled rapidly to have a proper construction mechanism. Many of the issues that arise during the construction phase affect the construction situation and influence productivity directly. This dissertation addresses the organization and classification of these issues and presents an easy way to represent them in a graphical programming model. The main focus of the dissertation was to transmit knowledge to the project manager about how to deal with all the communication information that emerges during the construction phase, determine how critical it would be and how to prioritize the information to distinguish what issues to examine and solve first.

This dissertation proposes a color coding visualization of the issues of items during the construction phase on the graphical programming model of any construction project, which is possible through the organization of issues depending on the criteria of the project manager. Compared to other visualization methods, this technique will be adjustable according to the needs of the user; the user can be a project manager, a company, a field engineer or other worker that has the knowledge on how to use these tools. In the dissertation, a survey was conducted to gather the insights of professionals from academia and industry regarding their criteria to define critical communication of items during the construction phase. The records of communication originating from site problems are stored in an xlsx file that can be updated constantly. This proposed solution includes a naming convention, to have the extracted communication information from a database with the detailed information of the specific items and be uploaded to the graphical programming tool. The information considered for the analysis was communication obtained from calls, text messages and emails among project manager, site engineer, material suppliers, ironworker, architectural and structural design office, machinery owner, crew supervisor, plumbing and electrical supervisor. The exchange of information is assumed to be already in digital format stored and clustered in the described database mentioned in the framework that in this case is a xlsx file. The content of the information will be the name of the professionals involved in the communication, subject of the issue, date, due date, item, location of the item, among other important data. The information was classified by volume (number of calls, emails or text messages regarding one subject), time (due date when that issue must be solved), matrix of volume and time (number of calls, text message and emails in a specific time range), content (if it is part of the critical path or mentioned as urgent) and classified by sender of communication. All of this classification is possible thanks to the visual programming tool that organizes, categorizes and links the data to the model.

The objectives of the study were achieved and there is a detailed description and explanation of the steps in the content of this dissertation that made the organization, classification, and visualization of the information conceivable. It will generate a genuine and real-life result that will considerably erase time-consuming decision making methods and human error prone procedures. If used properly and adjusted

to the data of the construction project, this practice can be very successful for quick decision making. There is a case study presented in the dissertation where one can see the results and functionality of the developed script.

The digital world is constantly changing, offering new state of the art ways of optimization, parametrization and automation. There are several possible solutions to the problem that this dissertation tackles that can be developed in the visual programming tool. The proposed solution includes a corresponding naming situation. It is recommended that further research can exclude the naming convention and can start identifying the elements that are in a specific room or matching the coordinates of the location of the items for example first floor, left side. Another research is proposed for the process of extracting communication and transforming it into the excel sheet that is presented in this study. Suggested future research can look for a way to visualize issues that arise and have no connection to a specific element of the model like bureaucratic, legal and environmental issues.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEC	Architecture, Engineering and Construction
BIM	Building Information Modelling
CAD	Computer Aided Design
HVAC	Heating, Ventilation and Air Conditioning
MEP	Mechanical, Electrical and Plumbing

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APPENDICES

In this chapter the appendices are shown. The database of emails, text messages and calls used for the case study can be found in appendix 1 (Figure 71-Figure 73). The survey done for this dissertation is available in appendix 2.

APPENDIX 1: EMAILS, TEXT MESSAGES AND CALLS EXTRACTED

Remitter	Mailbox (addresse)	Receiver	Subject	Date	Due Date in Days	Item	Location of the item	X if part of Critical Path	Type of message	Room
material supplier	project.manager@mail.com	project manager	Delay of delivery of steel elements	3/30/2022	8	Column 4	ground floor, right side	X	normal	living room
material supplier	fieldeng@mail.com	field engineer	Delay of delivery of steel elements	3/30/2022	8	Column 4	ground floor, right side	X	normal	living room
field engineer	project.manager@mail.com	project manager	Excavation dimension not according to the drawings	4/18/2022	8	Floor 1	ground floor, right side		normal	office
field engineer	arch.design@mail.com	architectural design office	Excavation dimension not according to the drawings	4/18/2022	8	Floor 1	ground floor, right side		normal	office
architectural design office	project.manager@mail.com	project manager	Excavation dimension not according to the drawings	4/18/2022	8	Floor 1	ground floor, right side		normal	office
field engineer	project.manager@mail.com	project manager	A section with a different shape	5/10/2022	5	Wall 45	first floor, left side	X	urgent	main bedroom
designer office	project.manager@mail.com	project manager	A section with a different shape	5/10/2022	5	Wall 45	first floor, left side	X	important	main bedroom
material supplier	project.manager@mail.com	project manager	Delay of delivery of bricks	5/10/2022	14	Wall 9	ground floor, back side		normal	living room
material supplier	fieldeng@mail.com	field engineer	Delay of delivery of bricks	5/10/2022	14	Wall 9	ground floor, back side		normal	living room
project manager	fieldeng@mail.com	field engineer	Delay of delivery of bricks	5/10/2022	14	Wall 9	ground floor, back side		normal	living room
field engineer	project.manager@mail.com	project manager	Different material selection	5/11/2022	14	Wall 15	ground floor, center		normal	living room
project manager	matsupp@mail.com	material supplier	Different material selection	5/11/2022	14	Wall 15	ground floor, center		normal	living room
material supplier	fieldeng@mail.com	field engineer	Different material selection	5/11/2022	14	Wall 15	ground floor, center		normal	living room
field engineer	project.manager@mail.com	project manager	Incorrect alignment internal brickwork	5/12/2022	5	Wall 28	ground floor, right side		normal	living room
project manager	arch.design@mail.com	architectural design office	Incorrect alignment internal brickwork	5/12/2022	5	Wall 28	ground floor, right side		normal	living room
architectural design office	fieldeng@mail.com	field engineer	Incorrect alignment internal brickwork	5/12/2022	5	Wall 28	ground floor, right side		normal	living room
plumbing supervisor	fieldeng@mail.com	field engineer	Wrong pipe diameter	6/3/2022	14	Pipe 95	ground floor, left side	X	normal	laundry room
field engineer	project.manager@mail.com	project manager	Wrong pipe diameter	6/3/2022	14	Pipe 95	ground floor, left side	X	normal	laundry room
supplier office	electrical.supervisor@mail.com	Electrical Supervisor	electrical material shortage	6/13/2022	16	Wire 114	ground floor, left side		normal	kitchen
electrical supervisor	project.manager@mail.com	project manager	electrical material shortage	6/13/2022	16	Wire 114	ground floor, left side		normal	kitchen
supplier office	electrical.supervisor@mail.com	Electrical Supervisor	Different wire material	6/20/2022	16	Wire 113	ground floor, right side		normal	pump room
electrical supervisor	project.manager@mail.com	project manager	Different wire material	6/20/2022	16	Wire 113	ground floor, right side		normal	pump room
material supplier	project.manager@mail.com	project manager	Material unavailable	7/10/2022	7	Wall 37	first floor, right side	X	normal	main bedroom and bedroom 1
material supplier	fieldeng@mail.com	field engineer	Material unavailable	7/10/2022	7	Wall 37	first floor, right side	X	normal	main bedroom and bedroom 1
project manager	fieldeng@mail.com	field engineer	Material unavailable	7/10/2022	7	Wall 37	first floor, right side	X	normal	main bedroom and bedroom 1
field engineer	project.manager@mail.com	project manager	Different finishing of façade	7/12/2022	7	Wall 35	first floor, center		normal	bedroom 1 and bedroom2
project manager	finish.matsupp@mail.com	finishing material supplier	Different finishing of façade	7/12/2022	7	Wall 35	first floor, center		normal	bedroom 1 and bedroom2
finishing material supplier	fieldeng@mail.com	field engineer	Different finishing of façade	7/12/2022	7	Wall 35	first floor, center		normal	bedroom 1 and bedroom3

Figure 71 – Database of emails

Number (sender)	Sender	Receiver	Subject	Date	Due Date in Days	Item	Location of the item	X if part of Critical Path	Type of message	Room
xxxxxxx	field engineer	project manager	Excavation dimension not according to the drawings	4/23/2022	3	Floor 1	ground floor, center		vital	living room, dinning room, office, kitchen, laundry room
xxxxxxx	project manager	architectural design office	Excavation dimension not according to the drawings	4/23/2022	3	Floor 1	ground floor, center		urgent	living room, dinning room, office, kitchen, laundry room
xxxxxxx	field engineer	project manager	unexpected malfunction of the excavator	4/11/2022	2	Floor 1	ground floor, center		normal	living room, dinning room, office, kitchen, laundry room
xxxxxxx	field engineer	machine owner	unexpected malfunction of the excavator	4/11/2022	2	Floor 1	ground floor, center		normal	living room, dinning room, office, kitchen, laundry room
xxxxxxx	project manager	machine owner	unexpected malfunction of the excavator	4/11/2022	2	Floor 1	ground floor, center		normal	living room, dinning room, office, kitchen, laundry room
xxxxxxx	material supplier	project manager	Delay in formwork delivery	4/12/2022	8	Wall 12	ground floor, left side		normal	dinning room and kitchen
xxxxxxx	project manager	field engineer	Delay in formwork delivery	4/12/2022	8	Wall 12	ground floor, left side		normal	dinning room and kitchen
xxxxxxx	field engineer	project manager	unexpected weather conditions for piling	4/13/2022	14	Floor 1	ground floor, center		normal	living room, dinning room, office, kitchen, laundry room
xxxxxxx	project manager	material supplier	Delay in delivery of steel elements	4/13/2022	7	Column 4	ground floor, right side	X	normal	living room
xxxxxxx	project manager	field engineer	Delay in delivery of steel elements	4/13/2022	7	Column 4	ground floor, right side	X	normal	living room
xxxxxxx	ironworker	project manager	Column missplaced	5/2/2022	5	Column 3	ground floor, right side	X	normal	living room
xxxxxxx	field engineer	project manager	Column missplaced	5/2/2022	5	Column 3	ground floor, right side	X	normal	living room
xxxxxxx	field engineer	structural design office	Column missplaced	5/2/2022	5	Column 3	ground floor, right side	X	normal	living room
xxxxxxx	field engineer	structural design office	A section with a different shape	5/10/2022	5	Wall 45	first floor, left side	X	critical	main bedroom
xxxxxxx	field engineer	project manager	A section with a different shape	5/10/2022	5	Wall 45	first floor, left side	X	normal	main bedroom
xxxxxxx	structural design office	project manager	A section with a different shape	5/10/2022	5	Wall 45	first floor, left side	X	normal	main bedroom
xxxxxxx	structural design office	field engineer	A section with a different shape	5/10/2022	5	Wall 45	first floor, left side	X	normal	main bedroom
xxxxxxx	field engineer	structural design office	Different shape than drawings	5/15/2022	5	Roof 1	roof of first floor, center		normal	main bedroom, bedroom 1 and 2 and restrooms
xxxxxxx	field engineer	project manager	Different shape than drawings	5/15/2022	5	Roof 1	roof of first floor, center		normal	main bedroom, bedroom 1 and 2 and restrooms
xxxxxxx	structural design office	project manager	Different shape than drawings	5/15/2022	5	Roof 1	roof of first floor, center		normal	main bedroom, bedroom 1 and 2 and restrooms
xxxxxxx	structural design office	field engineer	Different shape than drawings	5/15/2022	5	Roof 1	roof of first floor, center		normal	main bedroom, bedroom 1 and 2 and restrooms
xxxxxxx	field engineer	project manager	Incorrect alignment internal brickwork	5/15/2022	2	Wall 28	ground floor, right side		normal	living room
xxxxxxx	field engineer	bricklayer	Incorrect alignment internal brickwork	5/15/2022	2	Wall 28	ground floor, right side		normal	living room
xxxxxxx	field engineer	project manager	Delay of delivery of bricks	5/17/2022	7	Wall 9	ground floor, back side		normal	living room
xxxxxxx	project manager	material supplier	Delay of delivery of bricks	5/17/2022	7	Wall 9	ground floor, back side		normal	living room
xxxxxxx	field engineer	project manager	Different material selection	5/18/2022	8	Wall 15	ground floor, center		normal	living room
xxxxxxx	material supplier	project manager	Different material selection	5/18/2022	8	Wall 15	ground floor, center		normal	living room
xxxxxxx	plumbing supervisor	field engineer	Wrong pipe quality	6/1/2022	7	Pipe 110	first floor, left side		normal	restroom 1
xxxxxxx	field engineer	project manager	Wrong pipe quality	6/1/2022	7	Pipe 110	first floor, left side		normal	restroom 1
xxxxxxx	project manager	plumbing supervisor	Wrong pipe quality	6/1/2022	7	Pipe 110	first floor, left side		normal	restroom 1
xxxxxxx	plumbing supervisor	field engineer	Plumbing components damaged after test	6/7/2022	4	Pipe 118	first floor, right side		normal	restroom 2
xxxxxxx	plumbing supervisor	field engineer	Wrong pipe diameter	6/10/2022	7	Pipe 95	ground floor, left side	X	normal	laundry room
xxxxxxx	field engineer	project manager	Wrong pipe diameter	6/10/2022	7	Pipe 95	ground floor, left side	X	normal	laundry room
xxxxxxx	plumbing supervisor	field engineer	Missconnection of drain from main restroom	6/10/2022	3	Plumbing Fixture 14	first floor, right side		important	main restroom
xxxxxxx	field engineer	project manager	Missconnection of drain from main restroom	6/10/2022	3	Plumbing Fixture 14	first floor, right side		important	main restroom
xxxxxxx	electrical supervisor	field engineer	Electrical material shortage	6/14/2022	14	Electrical Equipment 17	ground floor, left side		normal	kitchen
xxxxxxx	field engineer	project manager	Electrical material shortage	6/14/2022	14	Electrical Equipment 17	ground floor, left side		normal	kitchen
xxxxxxx	electrical supervisor	field engineer	Simple switch instead of a 3way switch	6/19/2022	3	Switch 9	ground floor, left side		normal	laundry room
xxxxxxx	field engineer	project manager	Simple switch instead of a 3way switch	6/19/2022	3	Switch 9	ground floor, left side		normal	laundry room
xxxxxxx	electrical supervisor	field engineer	Light point placed in another site	6/19/2022	7	Lighting Point 11	first floor, left side		normal	main bedroom
xxxxxxx	field engineer	project manager	Light point placed in another site	6/19/2022	7	Lighting Point 11	first floor, left side		normal	main bedroom
xxxxxxx	electrical supervisor	field engineer	Other type of transformer	6/20/2022	7	Electrical Equipment 16	ground floor, left side		normal	outside hall
xxxxxxx	field engineer	project manager	Other type of transformer	6/20/2022	7	Electrical Equipment 16	ground floor, left side		normal	outside hall
xxxxxxx	plumbing supervisor	field engineer	Change of sanitary point	7/4/2022	7	Plumbing Fixture 6	ground floor, right side		normal	guest restroom
xxxxxxx	field engineer	project manager	Change of sanitary point	7/4/2022	7	Plumbing Fixture 6	ground floor, right side		normal	guest restroom
xxxxxxx	finishing material supplier	project manager	Different finishing of façade	7/15/2022	3	Wall 35	first floor, center		normal	bedroom 1 and bedroom 2
xxxxxxx	field engineer	project manager	Different finishing of façade	7/15/2022	3	Wall 35	first floor, center		normal	bedroom 1 and bedroom 3

Figure 72 – Database of text messages

Number (caller)	Caller	Call receiver	Subject	Date	Due Date in Days	Item	Location of the item	X if part of Critical Path	Type of message	Call Duration in minutes	Room
xxxxxx	field engineer	project manager	Delayed arrival of hired excavator	4/4/2022	1	Floor 1	ground floor, center		normal	3:46	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	machinery owner	Delayed arrival of hired excavator	4/4/2022	1	Floor 1	ground floor, center		normal	2:25	living room, dinning room, office, kitchen, laundry room
xxxxxx	project manager	machinery owner	Delayed arrival of hired excavator	4/4/2022	1	Floor 1	ground floor, center		exigent	1:09	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	project manager	Unqualified truck driver	4/4/2022	1	Floor 1	ground floor, center		normal	4:15	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	machinery owner	Unqualified truck driver	4/4/2022	1	Floor 1	ground floor, center		normal	7:23	living room, dinning room, office, kitchen, laundry room
xxxxxx	project manager	machinery owner	Unqualified truck driver	4/4/2022	1	Floor 1	ground floor, center		normal	5:17	living room, dinning room, office, kitchen, laundry room
xxxxxx	project manager	machinery owner	Unexpected malfunction of the excavator	4/12/2022	1	Floor 1	ground floor, center		normal	8:35	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	project manager	Unexpected malfunction of the excavator	4/12/2022	1	Floor 1	ground floor, center		normal	4:28	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	project manager	Unexpected weather conditions for piling	4/17/2022	3	Floor 1	ground floor, center		normal	1:10	living room, dinning room, office, kitchen, laundry room
xxxxxx	project manager	field engineer	Delay in delivery of steel elements	4/19/2022	2	Column 4	ground floor, right side	X	normal	6:34	living room
xxxxxx	project manager	material supplier	Delay in delivery of steel elements	4/19/2022	2	Column 4	ground floor, right side	X	normal	3:47	living room
xxxxxx	field engineer	project manager	Excavation dimension not according to the drawings	4/25/2022	1	Floor 1	ground floor, right side		normal	1:50	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	project manager	Delay in formwork delivery	4/17/2022	2	Wall 12	ground floor, left side		normal	3:10	dinning room and kitchen
xxxxxx	project manager	material supplier	Delay in formwork delivery	4/17/2022	2	Wall 12	ground floor, left side		normal	5:52	dinning room and kitchen
xxxxxx	field engineer	project manager	Failure of formwork while pouring the concrete	4/28/2022	2	Column 5	ground floor, center and front side		normal	5:09	dinning room and hall
xxxxxx	field engineer	carpenter	Failure of formwork while pouring the concrete	4/28/2022	2	Column 5	ground floor, center and front side		normal	5:00	dinning room and hall
xxxxxx	project manager	carpenter	Failure of formwork while pouring the concrete	4/28/2022	2	Column 5	ground floor, center and front side		normal	4:40	dinning room and hall
xxxxxx	field engineer	project manager	Missing qualified welder	4/28/2022	0.04167	Column 13	ground floor, right side		imperative	28:16:00	living room
xxxxxx	field engineer	crew supervisor	Missing qualified welder	4/28/2022	1	Column 13	ground floor, right side		immediate attention	10:05	living room
xxxxxx	project manager	crew supervisor	Missing qualified welder	4/28/2022	1	Column 13	ground floor, right side		serious	7:20	living room
xxxxxx	project manager	field engineer	Column missplaced	5/5/2022	2	Column 3	ground floor, right side		normal	3:00	living room
xxxxxx	structural design offic	field engineer	Column missplaced	5/5/2022	2	Column 3	ground floor, right side		normal	2:14	living room
xxxxxx	structural design offic	project manager	Column missplaced	5/5/2022	2	Column 3	ground floor, right side		normal	1:49	living room
xxxxxx	field engineer	structural design office	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X	normal	5:18	living room
xxxxxx	field engineer	project manager	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X	normal	3:27	living room
xxxxxx	structural design offic	project manager	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X	normal	2:51	living room
xxxxxx	structural design offic	field engineer	Different size of column	5/5/2022	2	Column 12	ground floor, right side	X	normal	1:36	living room
xxxxxx	field engineer	project manager	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side		immediate attention	13:10	bedroom
xxxxxx	field engineer	ironworker	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side		immediate attention	7:09	bedroom
xxxxxx	project manager	ironworker	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side		immediate attention	8:20	bedroom
xxxxxx	project manager	field engineer	Inaccurate rebar spacing	5/7/2022	0.04167	Floor 3	first floor, left side		immediate attention	7:29	bedroom
xxxxxx	field engineer	project manager	Different rebar spacing	5/8/2022	0.04167	Floor 2	finished ground floor, center		normal	5:30	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	ironworker	Different rebar spacing	5/8/2022	0.04167	Floor 2	finished ground floor, center		normal	3:26	living room, dinning room, office, kitchen, laundry room
xxxxxx	project manager	ironworker	Different rebar spacing	5/8/2022	0.04167	Floor 2	finished ground floor, center		normal	2:37	living room, dinning room, office, kitchen, laundry room
xxxxxx	project manager	field engineer	Different rebar spacing	5/8/2022	0.04167	Floor 2	finished ground floor, center		normal	2:29	living room, dinning room, office, kitchen, laundry room
xxxxxx	field engineer	ironworker	Different rebar diameter	5/9/2022	1	Floor 3	first floor, right side		normal	1:25	bedroom
xxxxxx	project manager	ironworker	Different rebar diameter	5/9/2022	1	Floor 3	first floor, right side		normal	0:35	bedroom
xxxxxx	project manager	field engineer	Different rebar diameter	5/9/2022	1	Floor 3	first floor, right side		normal	1:25	bedroom
xxxxxx	field engineer	structural design office	A section with a different shape	5/12/2022	3	Wall 45	first floor, right side	X	normal	5:32	main bedroom
xxxxxx	project manager	structural design office	A section with a different shape	5/12/2022	3	Wall 45	first floor, right side	X	normal	7:42	main bedroom
xxxxxx	field engineer	project manager	A section with a different shape	5/12/2022	3	Wall 45	first floor, right side	X	normal	6:29	main bedroom
xxxxxx	field engineer	bricklayer	Incorrect alignment internal brickwork	5/16/2022	1	Wall 28	ground floor, right side		normal	3:31	living room
xxxxxx	field engineer	project manager	Incorrect alignment internal brickwork	5/16/2022	1	Wall 28	ground floor, right side		normal	2:17	living room
xxxxxx	field engineer	structural design office	Different shape than drawings	5/17/2022	3	Roof 1	roof of first floor, center		normal	5:03	main bedroom, bedroom 1 and 2 and restrooms
xxxxxx	project manager	structural design office	Different shape than drawings	5/17/2022	3	Roof 1	roof of first floor, center		normal	1:09	main bedroom, bedroom 1 and 2 and restrooms
xxxxxx	field engineer	project manager	Different shape than drawings	5/17/2022	3	Roof 1	roof of first floor, center		normal	2:01	main bedroom, bedroom 1 and 2 and restrooms
xxxxxx	field engineer	project manager	Delay of delivery of bricks	5/22/2022	2	Wall 9	ground floor, back side		normal	5:17	living room
xxxxxx	project manager	material supplier	Delay of delivery of bricks	5/22/2022	2	Wall 9	ground floor, back side		normal	5:26	living room
xxxxxx	project manager	field engineer	Delay of delivery of bricks	5/22/2022	2	Wall 9	ground floor, back side		normal	4:03	living room
xxxxxx	field engineer	project manager	Different material selection	5/23/2022	2	Wall 15	ground floor, center		normal	0:45	living room
xxxxxx	plumbing supervisor	field engineer	Wrong pipe quality	6/6/2022	2	Pipe 110	first floor, left side		normal	0:57	restroom 1
xxxxxx	field engineer	project manager	Wrong pipe quality	6/6/2022	2	Pipe 110	first floor, left side		normal	0:42	restroom 1
xxxxxx	plumbing supervisor	field engineer	uest for approval to change damaged plumbing elem	6/7/2022	1	Pipe 5	ground floor, right side		major	14:28	guest restroom
xxxxxx	field engineer	project manager	uest for approval to change damaged plumbing elem	6/7/2022	1	Pipe 5	ground floor, right side		instant	9:45	guest restroom
xxxxxx	plumbing supervisor	field engineer	Missconnection of drain from main restroom	6/12/2022	2	Plumbing Fixture 14	first floor, right side		normal	3:40	main restroom
xxxxxx	field engineer	project manager	Missconnection of drain from main restroom	6/12/2022	2	Plumbing Fixture 14	first floor, right side		normal	2:25	main restroom
xxxxxx	plumbing supervisor	field engineer	Wrong pipe diameter	6/15/2022	2	Pipe 95	ground floor, left side	X	critical	2:31	laundry room
xxxxxx	field engineer	project manager	Wrong pipe diameter	6/15/2022	2	Pipe 95	ground floor, left side	X	critical	2:25	laundry room
xxxxxx	electrical supervisor	field engineer	Placement of 110v instead of 220v	6/15/2022	0.083333	Outlet 46	ground floor, left side		normal	1:17	laundry room
xxxxxx	field engineer	project manager	Placement of 110v instead of 220v	6/15/2022	0.083333	Outlet 46	ground floor, left side		normal	0:35	laundry room
xxxxxx	electrical supervisor	field engineer	Simple switch instead of a 3way switch	6/20/2022	2	Switch 9	ground floor, left side		normal	0:57	laundry room
xxxxxx	electrical supervisor	project manager	Simple switch instead of a 3way switch	6/20/2022	2	Switch 9	ground floor, left side		normal	0:49	laundry room
xxxxxx	electrical supervisor	field engineer	Other type of transformer	6/23/2022	3	Electrical Equipment 16	ground floor, left side		normal	1:28	outside hall
xxxxxx	field engineer	project manager	Other type of transformer	6/23/2022	3	Electrical Equipment 16	ground floor, left side		normal	1:35	outside hall
xxxxxx	electrical supervisor	field engineer	Light point placed in another site	6/23/2022	3	Lighting Point 11	first floor, left side		normal	0:41	main bedroom
xxxxxx	field engineer	project manager	Light point placed in another site	6/23/2022	3	Lighting Point 12	first floor, left side		normal	0:38	main bedroom
xxxxxx	electrical supervisor	field engineer	Electrical material shortage	6/25/2022	3	Electrical Equipment 17	ground floor, left side		normal	3:28	kitchen
xxxxxx	field engineer	project manager	Electrical material shortage	6/25/2022	3	Electrical Equipment 17	ground floor, left side		normal	3:35	kitchen
xxxxxx	plumbing supervisor	field engineer	Change of sanitary point	7/8/2022	2	Plumbing Fixture 6	ground floor, right side		normal	2:29	guest restroom
xxxxxx	field engineer	project manager	Change of sanitary point	7/8/2022	2	Plumbing Fixture 6	ground floor, right side		normal	3:17	guest restroom
xxxxxx	field engineer	project manager	Different finishing of façade	7/16/2022	3	Wall 35	first floor, center		normal	1:23	bedroom 1 and bedroom 2

Figure 73 – Database of Calls

APPENDIX 2: SURVEY BIMA+ DISSERTATION

BIMA+ Dissertation Gabriela Pineda Questionnaire

1.- Brief explanation

The aim of this dissertation study is to analyze procedures in order to show project critical items on a BIM model as an easy and quick visual reference for a project manager. The aim of this questionnaire is to determine priorities of critical items (items that have a significant effect on the construction and can cause major delay if not attended on time) during the construction phase. Imagine that you are the project manager of a construction project and all the records of telephone calls, emails and text messages are added to a database for analysis. Please answer the following questions based on this simulation.

1. Please select the one that reflects your working area *

☐ Academia

☐ Industry

2.- Calls

2. Please classify when to consider an item to have Low(1), Medium(2) or High (3) criticality when having the mentioned amount of calls regarding one specific construction issue within the shown amount of time? Please place the numbers 1-3 according the criticality in the blank space. Low criticality would be something that does not impact at the moment, medium would mean that requires consideration and high criticality would mean that it requires immediate attention. *

	1 -3 days	3 -7 days	7-14 days	14-28 days	28 days or more
Less than 3 calls					
3-7 Calls					
More than 7 Calls					

3. How many telephone calls regarding one issue that is not part of the critical path would you consider to be critical? *

- [ ] 1-3 calls
- [ ] 3-6 calls
- [ ] 6-7 calls
- [ ] 7-10 calls
- [ ] Other (please specify):

4. What is the maximum number of telephone calls regarding one issue that you would not consider to be critical at all? *

- [ ] 1-2 calls
- [ ] 2-4 calls
- [ ] 4-7 calls
- [ ] Other (please specify):

3.- Text Messages

5. Please classify when to consider an item to have Low(1), Medium(2) or High (3) criticality when having the mentioned amount of text messages regarding one specific construction issue within the shown amount of time? *

	1-3 days	3-7 days	7-14 days	14-28 days	28 days or more
Less than 5 text messages					
5-10 text messages					
more than 10 text messages					

6. How many text messages regarding one issue that is not part of the critical path would you consider to be critical? *

- [ ] 1-3 text messages
- [ ] 3-6 text messages
- [ ] 6-10 text messages
- [ ] 10-20 text messages
- [ ] Other (please specify):

7. What is the maximum number of text messages regarding one issue that you would not consider to be critical at all? *

- [ ] 1-3 text messages
- [ ] 3-5 text messages
- [ ] 5-7 text messages
- [ ] Other (please specify):

4.- Emails

8. Please classify when to consider an item to have Low(1), Medium(2) or High (3) criticality when having the mentioned amount of emails regarding one specific construction issue within the shown amount of time? *

	1-3 days	3-7 days	7-14 days	14-28 days	28 days or more
less than 7 emails					
7-15 emails					
more than 15 emails					

9. How many emails regarding one issue that is not part of the critical path would you consider critical? *

- ☐ 1-5 emails
- ☐ 5-9 emails
- ☐ 9-10 emails
- ☐ 10-15 emails
- ☐ more than 15 emails
- ☐ Other (please specify):

10. How many emails regarding one issue would you consider not to be critical at all? *

- ☐ less than 7 emails
- ☐ 7-15 emails
- ☐ more than 15 emails
- ☐ Other (please specify):

5.- Other classifications

11. Please indicate how critical would you consider receiving a communication from these workers? Considering 1 Low Criticality and 3 High Criticality *

	1 Low Criticality	2 Medium Criticality	3 High Criticality
Structural Design Office	☐	☐	☐
Architecture Design Office	☐	☐	☐
Field Engineer	☐	☐	☐
Electrical Supervisor	☐	☐	☐
Plumbing Supervisor	☐	☐	☐
Skilled Laborer	☐	☐	☐

	1 Low Criticality	2 Medium Criticality	3 High Criticality
Ironworker			
Material Supplier			

12. Rank the following three communication methods in order of criticality when information is requested (1 = low criticality, 2= medium criticality, 3= high criticality) *

	1 Low	2 Medium	3 High
Emails			
Text messages			
Calls			

13. Please comment here if you would like to add a suggestion that would be very useful to the research study. Thank you very much.