TÉCNICO LISBOA

Electrical Installation Design using BIM Software

Afonso Manuel Reis Silva

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Supervisors: Prof. Duarte de Mesquita e Sousa
Engr. Fernando Miguel de Araújo

Examination Committee

Chairperson: Prof. Teresa Maria Canavarro Menéres Mendes de Almeida
Supervisor: Prof. Duarte de Mesquita e Sousa
Member of the Committee: Prof. António Eusébio Velho Roque

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Dedicated to my parents.

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Resumo

Numa indústria que, historicamente, tem sido uma das mais lentas a digitalizar os seus processos [1], os arquitetos e engenheiros civis estão a adotar uma metodologia para combater esta tendência: o fluxo de trabalho *Building Information Modelling* (BIM) visa reunir todas as informações sobre cada elemento do edifício, de todas as disciplinas, num modelo tridimensional.

Mas parece haver alguma resistência por parte dos engenheiros eletrotécnicos em adaptar os seus fluxos de trabalho habituais a esta nova forma de desenvolver projetos de edifícios. Este trabalho apresenta uma visão geral da forma típica como as instalações elétricas são atualmente concebidas e explora a forma como a metodologia BIM pode impactar cada tarefa.

Após o desenvolvimento de um projeto da instalação eléctrica de um hospital, as principais razões identificadas para o atraso na adoção do BIM foram o investimento necessário na formação dos profissionais para a utilização do software, a falta de vontade dos clientes em corresponder às propostas mais elevadas que estes projetos devem ter para serem rentáveis, e uma relutância natural dos engenheiros eletrotécnicos mais experientes em alterar o fluxo de trabalho a que estão habituados e que sabem que produz resultados satisfatórios. No entanto, é importante que estes desafios sejam ultrapassados o mais rapidamente possível para poder cumprir as leis Portuguesas previstas para 2030, que tornarão obrigatória a entrega de um modelo BIM para cada projeto de um edifício.

Palavras-chave: eletricidade, projeto, modelização, edifício.

Abstract

In an industry that has historically been one of the slowest to digitalize its processes [1], architects and civil engineers are adopting a methodology to fight this trend: the Building Information Modelling (BIM) workflow aims to gather every piece of information about the components of the building, across all disciplines, in a three-dimensional model.

But there seems to be some resistance from the side of electrical engineers to adapt their usual workflows to this new way of developing projects of buildings. This work presents an overview of the typical way in which electrical installations are currently designed, and explores how the BIM methodology can impact each task.

After developing a project for the electrical installation of a hospital, the main reasons identified for the delay in the BIM adoption were the investment needed in training the professionals to use the software, a lack of willingness by the clients to match the higher bids that such projects must have to be profitable, and a natural reluctance of more experienced electrical engineers to change the workflow they are used to and know produces satisfactory results. It is important, however, that these challenges are overcome as soon as possible to be able to meet the Portuguese laws that are scheduled for 2030 that will make it mandatory to deliver a BIM model for every project of a building.

Keywords: electricity, project, modelling, building.

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Nomenclature

Acronyms

AC	Alternating Current
AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
AR	Augmented Reality
BCF	BIM Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Modelling
BMS	Building Management System
bSI	buildingSMART International
CAD	Computer-Aided Design
DC	Direct Current
EPS	Emergency Power Supply
HV	High Voltage
IDS	Information Delivery Specification
IFC	Industry Foundation Classes
IMD	Insulation Monitoring Device
IoT	Internet of Things
LOD	Level of Development
LV	Low Voltage
MEP	Mechanical, Electrical and Plumbing
MV	Medium Voltage

NPS Normal Power Supply

QP Switchboard

QS Panelboard

RCDs Residual Current Devices

RTIEBT Regras Técnicas das Instalações Elétricas de Baixa Tensão

UGR Unified Glare Rating

UPS Uninterruptible Power Supply

VR Virtual Reality

Electrical Quantities and Factors

$\cos\varphi$ Power Factor

ΔU Voltage Drop in %

Δu Voltage Drop in V

ΔU_{max} Maximum Voltage Drop

λ Reactance of the Conductors per Unit Length

ρ Resistivity of the Conductors in Normal Service, 1,25 times the resistivity at 20 °C

b Phase-related Coefficient

FS Diversity Factor

I_2 Conventional Functioning Current

I_a Fusion Current

i_b Operating Current

I_{cu} Breaking Capacity

I_d Fault Current

I_{fict} Fictional Current

I_i Short-circuit Instantaneous Relay Trip Current

I_k Rated Short-time Withstand Current

I_m Short-circuit Relay Trip Current (Magnetic)

I_n Nominal Full-load Current

I_r Overload Relay Trip Current (Thermal)

I_Z Permissible Current

k Factor Dependent on the Characteristics of the Protection Conductor

k_P Multi-conductor Correction Factor

k_T Temperature Correction Factor

S_{ap} Transformer Rating

S_n Nominal Power Rating

U Phase-to-phase Voltage at No-load

Lighting Quantities and Factors

ϕ Luminous Flux

ρ_s Reflectance

E Illuminance

E_{avg} Average Illuminance

E_{min} Minimum Illuminance

Fb Ballast Factor

Fd Depreciation Factor

Fu Utilisation Factor

hw Energy Efficiency

I Luminous Intensity

L Luminance

L_b Background Luminance

Ra Colour Rendering Index

U_0 Uniformity

Other Symbols

Δt Time Interval

ω Solid Angle

A Area

a Angle

d Distance

k Constant with a Value that Depends on the Insulation of the Cable

l Circuit Length

p Guth Position Index

S Conductor Cross-section

S_{min} Minimum Conductor Cross-section

T Room Temperature

t Tripping Time of the Protection Device

Chapter 1

Introduction

1.1 Motivation

Productivity is arguably the word of order in the contemporary labour world, everything needs to be done fast and flawlessly, minimising costs and maximising profits, and there are some concepts that play an important role in achieving this goal.

Efficiency is the most obvious one, defined as ”the quality of being able to do a task successfully, without wasting time or energy” [2].

Then, there is automation, which has been introduced as of the Ford period [3], and consists of letting machines perform repetitive tasks. It results in an exponential growth in productivity as the personnel costs can be reduced, employees can be assigned to other more creative tasks and the products of the automated work are more accurately predictable, which positively contributes to planning. The planning activity is also a main contributor to the increase in productivity as it enables the definition of realistic deadlines, the definition of the correct sequence of tasks to achieve a desired goal and the correlations between those tasks — which ones can be performed in parallel and which ones must be performed in sequence. It also contributes to avoiding misestimation of the resources needed and misinterpretation of tasks by the people involved.

Another key concept to point out is collaboration. Assigning different tasks to people with the needed skills, by itself, does not guarantee an increase in productivity. To achieve such goal, it is fundamental that the teams can collaborate smoothly with one another, which is achieved by regular communication and quick conflict management.

Lastly, a recently introduced concept is that of digitalisation. Today, the simplest processor can be a powerful helper for any business, and the tendency is for the computational power, that is to say, the speed at which the processor can perform calculations, to keep growing. The key to making the most of digitalisation is to master the translation of anything from the real world into the digital one, and once that is done, it is just a matter of time before one can apply all the functionalities mentioned above to represent one’s vision of how to reshape the world we live in.

Now, one rarely finds oneself in places where the intervention of human beings comes down to the footprints he or she has left behind by walking to that place, most of us spend the vast majority of our time inside buildings, whether it is our home, the place we work at, the stores we need to go to, the monuments we visit, the hospitals where we go for a needed treatment, so it is vital that these buildings contribute to our well-being in every possible way. Note that, in the workplace, a person's productivity is correlated with their well-being [4]. When correctly designed, buildings can please at least four of the five human senses: the touch is mainly triggered by the thermal sensation experienced, which can be controlled by room temperature regulation devices; sound comfort is a crucial factor in one's well-being but, unfortunately, often overlooked, as verified in places with noisy air conditioners or other digital devices; unwanted smells, for example from pipes, is also something to look out for, whereas a scented entrance hall has an immediate positive impact in one's perception of a place; and, finally, the sight can be a source of discomfort in places where artificial lighting is not well planned according to the activities that are carried out in that place, as well as a source of well-being when, for example, natural light is given its deserved attention, or when someone finds beauty in the architecture of a place.

From the paragraph above, it is possible to extract a list of requirements to take into consideration when designing a building, but these constitute just a small portion of everything that has to be planned before a project of a building is ready for construction, so it is naturally understandable how complex these entities are, and therefore, how complex it is to develop a project for the design of a new one. It is necessary that multiple stakeholders, with different skill sets and different interests, come together and plan these buildings, and then operate sharing the same physical space, so the cooperation between them is fundamental.

Before digitalisation was broadly adopted, every deliverable[1] was done by hand, which meant that repetitive tasks took a long time and calculations were more prone to human error. Also, 2D drawings of 3D entities were hard to interpret, leading to a waste of time in the architectural perception of the represented entity.

To digitalize the drawings, most designers and engineers started using Computer-Aided Design (CAD) software, which is still used in many situations, and as for materials and expense tables, Excel is currently the spreadsheet application with the biggest presence in the professional environment [5].

The tools mentioned above are quite powerful at doing what they were designed to do, although, when used in architecture and civil engineering projects, they work in a rather detached manner from what the lines and numbers represent in the real world. Furthermore, they were not originally designed to be used cooperatively, and attempts to do so often result in overlapping files and an excessive number of meetings. Also, for different specialties[2] it is common to use different specialised software, which typically results in project mistakes and spatial overlaps only being verified on the construction site, leading to unforeseen costs and deadlines not being met.

[1] Final version of a document that describes the specifications of the project to be submitted to the Municipality for approval. Some deliverables are mandatory (e.g., floor plans) and others are complementary.

[2] Disciplines in charge of defining specifications that require expertise knowledge, not necessarily related to civil engineering (e.g., heating, ventilation and air conditioning (HVAC) systems, electrical installation, and plumbing)

For these reasons, the Building Information Modelling (BIM) methodology has been gaining a lot of popularity in the Architecture, Engineering and Construction (AEC) industry over recent years.

The BIM methodology is defined by the Centre for Digital Built Britain [6] as ”a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, delivering and maintaining physical built assets. BIM embeds key product and asset data in a 3D computer model that can be used for effective management of information throughout an asset’s lifecycle”. It is a revolutionary way of developing AEC projects, where each element is characterised not only by its dimensions but also by a vast spectrum of characteristics with considerable relevance to this type of project: the thermal characteristics of a material, the price per m^2 of a glass type, the conductivity of an electrical cable, among many others. These specifications can then be used to automatically generate quantity tables, economic analyses, structural calculations, and much more [7]. It also facilitates immensely the communication between different computer programs and the engagement of all stakeholders, as will be further explained in Subsection 2.2.1.

As of now, architects and civil engineers around the world are adopting this methodology at a fast pace. Unfortunately, however, this transition has been much slower in arguably one of the most important specialties: the design of electrical installations. The majority of the well-being factors mentioned above rely on electric power supply, the progress made in terms of digitalisation relied on electric power supply, and, in fact, a great deal of humanity’s recent innovations relies on electric power supply, and yet, surprisingly enough, the majority of electrical installation designers seems reluctant to adapt their workflow to match the one of their colleagues in the architecture and civil engineering fields, not making the most out of the available tools in the industry, holding on to Excel spreadsheets and CAD drawings.

So, the question is: what is the reason for such stagnation?

1.2 Objectives and Problem Statement

The objective of this Thesis is to answer the question asked at the end of the previous Section by designing the electrical installation of a hospital, first specifying how it would be traditionally done, then developing it following the BIM methodology and making use of the appropriate software, such that a comparison can be established.

The fieldwork presented in this document was developed in direct collaboration with TPF — Consultores de Engenharia e Arquitetura S.A. [8], a company specialising in Engineering and Architectural Studies, Design and Project Management, and Construction Supervision. TPF provided all project constraints according to their client’s needs.

1.3 Thesis Outline

This document is structured as follows: Chapter 1 introduced the Thesis’ main theme by stating a problem and clarifying the motivation behind the choice to dig deeper into it; Chapter 2 describes the current state of the art of electrical installation design and the BIM methodology; then, Chapter 3 presents both the theoretical background needed before starting the fieldwork and a brief description of each BIM program used; in Chapter 4, an analysis of the usual way of designing electrical installations is presented, followed by the description of the fieldwork developed in collaboration with TPF for the design of the electrical installation of a hospital using the BIM methodology, which resulted in the gathering of data on the drawbacks and improvements of using that methodology; and, finally, Chapter 5 sums up the key takeaways of that work and suggests possible directions for future research in the field of electrical installation design using BIM software.

Chapter 2

State of the Art

2.1 Electrical Installation Design

In the AEC industry, the specialty of electrical installation design is included in the broader acronym MEP, which stands for Mechanical, Electrical and Plumbing. The mechanical elements of the building are mainly related to the heating and cooling systems, the electrical elements are everything that is used for electricity distribution and electricity consumption (e.g., lighting), and the plumbing system is the one that manages water distribution and drainage. The most likely explanation for being put together in the same term is their grouping when it comes to spatial organisation inside a building — usually sharing the same plumbs[1] —, and the fact that these specialties support the activities carried out by the people in the building, rather than supporting the building itself.

Now, the usual AEC project flow, presented in [9] but applicable to the generality of the projects, consists of the phases shown in the diagram of Figure 2.1: initial project meeting with the client, feasibility study, preliminary and detail designs, construction, and closeout and warranty. Focusing on the design phase, it is subdivided into the programming stage, schematic design stage — which is when the MEP is designed —, design development stage, and construction documentation stage.

As mentioned, the MEP design comes at a stage of the building design phase when most of the architectural and construction elements have been defined, and that is because it needs a spatial reference and room usage definition for its own parameters' definition: it is necessary to know the volume of a given room and the thermal characteristics of the walls to be able to decide which HVAC equipment is needed; one cannot estimate the number of luminaires without knowing the specific use of a given room, as the regulation for the level of illuminance (further explained in Section 3.1.5) varies according to the purpose of the room; and it is necessary to know how many floors the building will have in order to decide if a pump is needed, among other examples.

It is a double-edged sword as, on the one hand, most of the input information for decision-making is directly given to the engineers responsible for the MEP design, but, on the other hand, when there

[1] Vertical space designed for passing HVAC ducts, electricity cables and water pipes across the levels of the building.

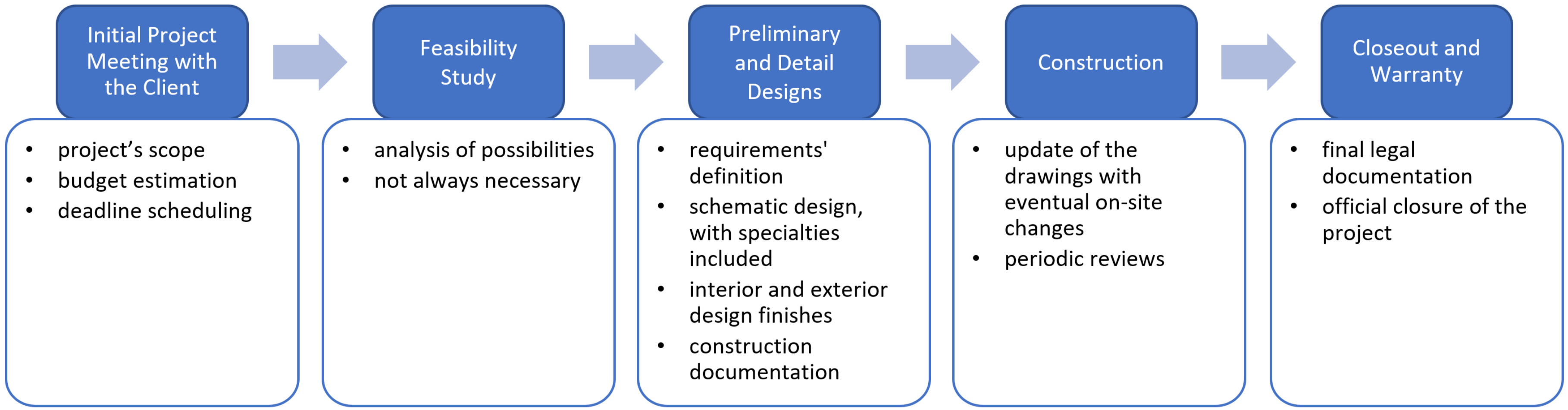


Figure 2.1: AEC project phases, with a brief description of each stage of each phase.

are physical impossibilities caused by the previously imposed constraints — for instance, lack of space between the false and the real ceilings to fit the cable trays and the HVAC ducts — colleagues from other disciplines might not be too receptive to accommodate changes at such a late stage, which emphasises the importance of collaboration in this kind of projects.

Then, at the construction phase, there are a few challenges for the installation of MEP systems: usually, they are arranged in a way that all controls and measurement display instruments are confined in the same cabinet, reducing the flexibility of their layout; then, the installation of these systems is usually the responsibility of different subcontractors who simultaneously install their systems; and there is a challenge more related to the preparation of the on-site work which is the fact that, frequently, a lot of information is given to the subcontractors, who then have to filter it and focus on the useful parts (which, in many cases, is done on-site, decreasing efficiency) [10].

Specifying for the electrical installation design in Portugal, the mandatory documentation to be delivered, when applicable, is the following [11]:

- Project Identification — brief description of the project and identification of the entities involved in the licensing;
- Drawings of Insertion in the Building — layout of the electrical installation within the building, with georeferenced coordinates and the connection point to the public grid;
- Descriptive Memory (DM) — brief description of the electrical installation;
- Justifying Calculations (CL) — results obtained from the calculation of electrical quantities that justify the decisions made in the design of the installation;
- Bill of Quantities (BQ) — list of needed materials and equipment;
- Secondary Substations — characterisation and drawings of the installations meant to change the voltage level;
- Medium Voltage (MV) / High Voltage (HV) Grid — characterisation and drawings of the private distribution grids that operate either in MV — 1 kV to 35 kV — or HV — more than 36 kV;
- Low Voltage (LV) Grid — characterisation and drawings of the private distribution grids that operate in LV — 230 V;
- MV/HV Installations — characterisation and drawings of the installations that consume electrical energy at MV or HV;
- LV Installations — characterisation and drawings of the installations that consume electrical energy at LV;
- Generator Groups — characterisation and drawings of the temporary and/or safety installations that generate LV energy.

Not all the deliverables described above are presented in Chapter 4 as the ones that were not included are either referred to elements that are not present in the project, or beyond the scope of this Thesis.

The decisions made in terms of electrical installation design must follow many technical regulations, some are international, others European, and there are also national regulations. An international reference for electrical engineers worldwide is the Electrical Installation Guide from Schneider [12], as it was developed using the international standards as a guideline. In the case of Portugal, the main regulatory document for LV installations is the Regras Técnicas das Instalações Elétricas de Baixa Tensão (RTIEBT) [13].

Also, all designers, including the ones of the other specialties, strive to maximise the energy efficiency of the building, which is economically and socially rewarding: economically because the operating costs of the building are directly proportional to its energy consumption; and socially because it is a valuable contribution to the fight against the environmental crisis the world is currently facing.

2.2 BIM Methodology

2.2.1 BIM in General

First of all, BIM is a methodology, not a computer program in itself, which is a frequent misconception in the AEC industry. Then, there are several programs that help implement the methodology, 4 of which are used in this work and will be further described in Section 3.2.

Before using such software, certain aspects of the implementation of BIM must be defined, which is done by creating the BIM Execution Plan (BEP). The BEP is a contractual agreement between the project team and the client, considering his requirements, that defines the workflow of the project, estimated deadlines, what information the elements of the model must contain, the technologies to be used, and the object and document naming standards [14]. Two important concepts represent some of the definitions mentioned: the required dimension and Level of Development (LOD).

On the one hand, the required dimension refers to the geometric dimensions of the drawings of the model, 2D — length and width — and, by adding the height, 3D. But, in BIM, there are defined dimensions that go beyond 3D, which, alongside the previously mentioned information associated with every object that bridges the gap between the real and the virtual worlds, are what distinguishes the BIM workflow from the common one. The literature recognises 4D and 5D [14], and some companies and online publications define up to ten dimensions, mainly for marketing purposes. These extra dimensions are also included in this document as they give a name to important features of BIM software which would have been mentioned anyway. Every higher dimension has the characteristics of the previous, plus an extra one, defined as follows:

- 4D — ”time-dependent view of a BIM model in which objects are associated with activities in a construction plan” [14];
- 5D — ”cost-dependent view of a BIM model in which budget line items are associated with specific measurable features of model objects” [14];
- 6D — use of thermal characteristics of the materials for energy analysis during the design phase, to maximise the environmental sustainability of the project [15];

- 7D — specific equipment represented in the model as a digital twin[2] for real-time asset management [15];
- 8D — model of the construction site and analysis of potential security and safety risks [15];
- 9D — implementation of the lean construction principles — better model for interaction between stakeholders, performance-based management system, and staff's capabilities development — for a minimisation of the gap between the forecasted and the final costs and project duration [15];
- 10D — implementation of all the previous dimensions at an integrated holistic AEC industry level [15].

On the other hand, the LOD refers to how detailed the digital representation of a certain physical entity needs to be and is defined by the American Institute of Architects (AIA) as the concept that "describes the minimum dimensional, spatial, quantitative, qualitative, and other data included in a [m]odel [e]lement" [16]. Figure 2.2 is an example of the impact of the chosen LOD in the degree of detail of the 3D representation of a construction element, but some requirements are related to non-visual data, as listed in detail in Table 2.1. Also, some examples specifically related to electrical installation design are presented for each LOD. Note that LOD 350 is not included in the table but is sometimes used, especially in the industry, and it is a combination of some of the requirements of LOD 300 and some of LOD 400 [16].

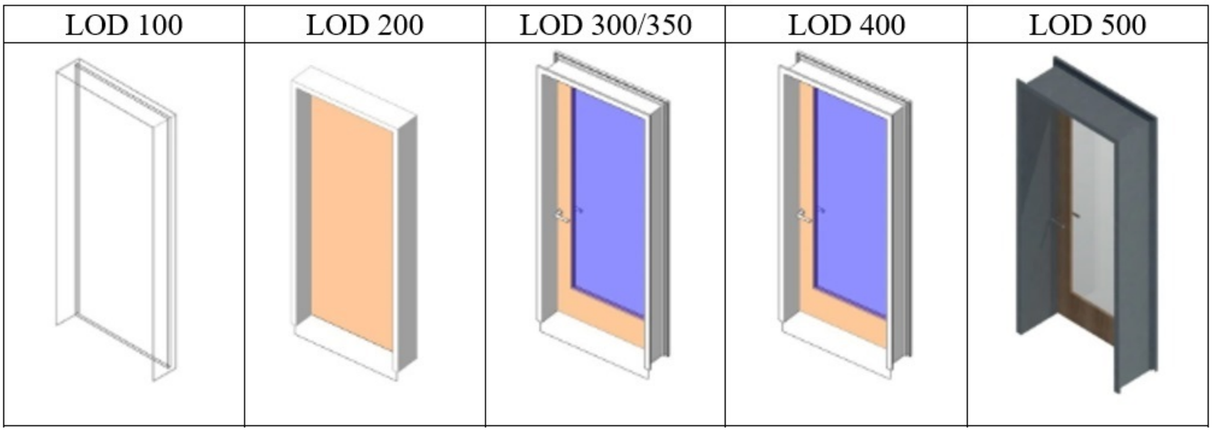


Figure 2.2: Graphical representation of a door, according to different LODs (from [17]).

These are definitions to account for during the entire project. In fact, BIM tools are usually used to manage the whole life cycle of the project [7]. It is important to note the difference between this and the concept of Life Cycle Assessment (LCA) of the building, which is also present in the literature. The latter is an analysis of the environmental impacts of the whole life cycle of the building, from harvesting the materials to the construction phase and waste management [18].

Let us bring back the concepts that enable a rise in productivity — efficiency, automation, collaboration and digitalisation —, reorder them by the chronological sequence of their impact in an AEC project, and see how straightforwardly BIM implements them.

[2] As-built digital representation of a physical entity, with an associated link for two-way updating.

Table 2.1: Characteristics of each LOD and how they apply to electrical installation design.

LOD	General description	Examples for electrical installation design
100	”The [m]odel [e]lement may be graphically represented in the Model with a symbol or other generic representation” [16].	”A unit quantity of watts per square foot power consumption linked to floor elements” [16].
200	”The [m]odel [e]lement is graphically represented within the [m]odel as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the [m]odel [e]lement” [16].	”Lighting fixtures can be modeled as generic 3D objects to begin determination of layout and identification of coordination issues. Switch gear and major panels can also be modeled as generic 3D objects to aid in sizing and layout of equipment rooms and identification of access requirements” [16].
300	”The [m]odel [e]lement is graphically represented within the [m]odel as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the [m]odel [e]lement” [16].	”Equipment, switch gear and panels are represented at their actual sizes and locations, and required access space and clearances are shown. Fixtures and devices are accurately located at their actual configuration” [16].
400	”The [m]odel [e]lement is graphically represented within the [m]odel as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the [m]odel [e]lement” [16].	Same as LOD 300.
500	”The [m]odel [e]lement is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the [m]odel [e]lements” [16].	Same as LOD 300.

Starting with digitalisation, BIM software developers continuously look for ways to digitalize every aspect of the AEC industry, for all the stakeholders. Once the preliminary decisions are made and the project workflow is defined, the modelling can start. BIM modelling software is mainly visually oriented, which makes it very intuitive and appealing to everyone involved in the project. The computer programs allow users to model in 2D, while, in fact, automatically creating 3D elements, or to model directly in 3D. Furthermore, most programs provide tools that go a step further in terms of visualisation, for instance, the 3D section tool (with up to 6 cutting planes) demonstrated in Figure 2.3.

And it does not stop there. Top-tier architecture firms are already using Virtual Reality (VR) — simulation of a virtual 3D environment that the user can access and interact with using a helmet or goggles as if he was physically inside of the environment — for client meetings, as it enables a surprisingly realistic view of how the designed building would look like after construction, and it enables aesthetic alternatives to be compared in real-time, for example, changing the wall colour or changing the pavement material. This technology is more suitable for off-site demonstrations [19], but a similar one is being used for on-site work: Augmented Reality (AR). The distinguishing factor of this technology is that it puts together the information of the real environment with the information of the virtual one. There is an increasing number

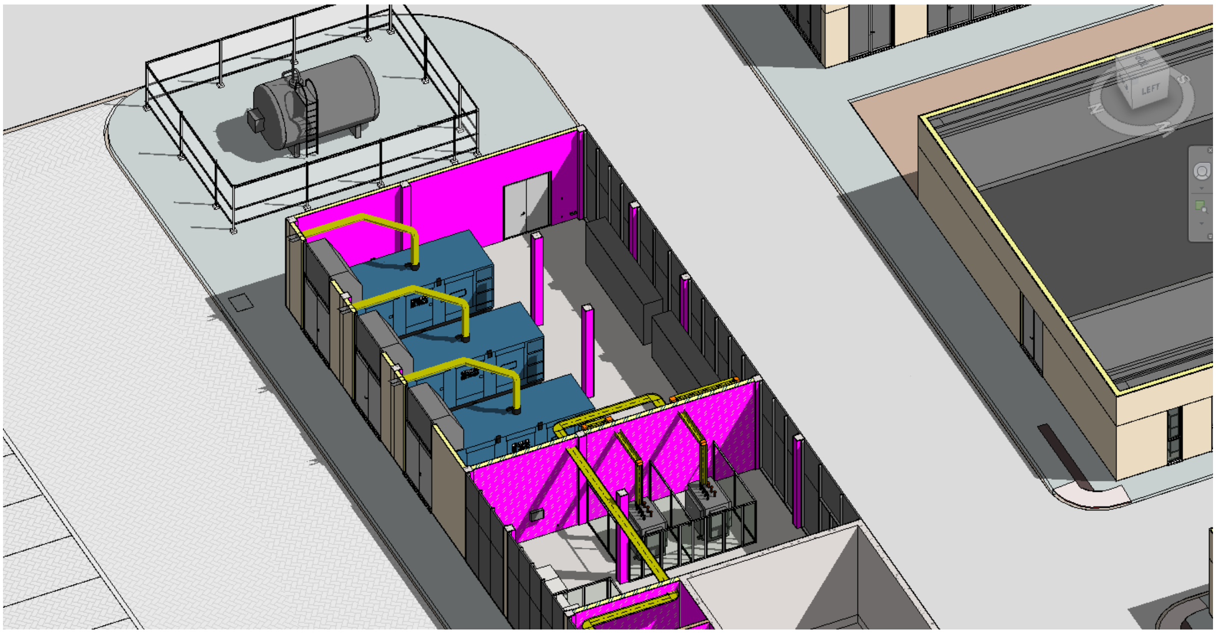


Figure 2.3: 3D section of the technical building of the hospital project.

of tasks that are being optimised with AR [19]: live support to the technicians performing maintenance from a colleague watching the live stream of what is happening through a camera installed in the AR device and/or from an application running in that device that can display useful additional information about what the technician sees, such as labelling of construction elements or the location of pipes that are covered by a wall or that are designed to pass in a certain location but are not yet installed, as seen in Figure 2.4; in some cases, it also works the other way around, meaning that the application running in the AR device can extract information from the real environment and update the virtual models.

Helmets and goggles were mentioned as the supporting devices for VR, and they are as well for AR — with the adjustment of letting the user see the real and the virtual environments contemporaneously —, but there is a rising trend of using mobile devices such as smartphones to run these applications [21] since they are already considered an essential commodity by the majority of people, and because of their powerful processing capabilities, as the computational workload needed by image processing applications is high. However, there are some challenges to the on-site implementation of AR [19]: users need training beforehand; sometimes the positioning of virtual elements is inaccurate; usually, it is hard to establish good internet and GPS connections on-site, which are fundamental requirements for most AR applications to work properly; and some mobile devices lack the processing power needed for running those applications.

Still related to digitalisation, a concept that is currently being developed and globally implemented, and can facilitate the previously mentioned translation from the real world into the digital one, is the concept of the Internet of Things (IoT). It consists of connecting physical objects via the internet, collecting data from sensors, and remotely acting upon the physical environment. Typical examples of this concept are: checking the available parking spots in a neighbourhood through a smartphone application; self-driving vehicles; controlling street lighting based on the presence or absence of people; and centralised

Figure 2.4: AR application in MEP, where 2 technicians wearing AR goggles are able to see, in fluorescent colours, a virtual representation of MEP elements in their precise future location (from [20]).

industrial management.

Focusing on the AEC industry, IoT enables construction site sensing and monitoring, which helps update digital models with as-is information, as well as after-construction building management, which hugely impacts energy consumption monitoring and control by allowing the implementation of smart lighting — based on occupancy and presence of natural light —, smart HVAC — based on occupancy and weather —, and integration and monitoring of micro-generation of renewable energy [22, 23]. The main challenges for the wide implementation of this concept are the capability of real-time processing and actuation, and the coexistence of the wide variety of wireless devices that communicate with different protocols[3] and share the same propagation medium: the air.

Secondly, another crucial contribution BIM provides is the automation of tasks. Two of them that used to be a source of information decentralisation were physical quantities calculations and cost estimations. With BIM software, it is possible to have certified, and therefore reliable, tools that implement the formulas used for those tasks with a few mouse clicks, as the computer program gets the necessary information from the model and automatically generates the desired tables. Therefore, it is a good modelling practice to add the mentioned information to each construction element at the time of their insertion in the model.

Along the same line of digitalisation, an emphasis is being put on making the most out of the latest available technology in the area of automation, which is currently led by Artificial Intelligence (AI). AI's

[3] Set of rules that devices must follow to establish successful digital communication. Much like human languages, different protocols are used in different contexts.

influence is already being felt at the earliest stage of the building design, with architects using generative design tools to explore different architectural options that respect a set of defined constraints [24]. It is also being used for optimising clash detection[4] and autonomously trying out and suggesting design corrections to deal with those clashes [25].

Also, as noted throughout the Thesis, the advantages of the BIM methodology are dependent on data availability, the more data the better, which leads to the rapid creation of enormous databases associated with each AEC project. To manage these databases, computer programs use the so-called Big Data Analytics algorithms, which are designed to optimise data accessing, filtering and analysis [25]. These databases result from the models created by the designer and the data collected by the technicians and the IoT devices on-site. By having a two-way data stream between the physical object and its virtual representation, where it is possible to both control the behaviour of the object through the virtual model and send information about the state of the object to the virtual model, one has what the literature calls a digital twin [4], as mentioned earlier in this Section. Having digital twins in the model reduces the need for human intervention in the translation from the real world to the digital one, and vice versa [26], which frees the designers from certain repetitive and not intellectually challenging tasks.

Finally, collaboration is a major focus of the BIM methodology. It is essential that all stakeholders are able to share their ideas, communicate their concerns, and present their requirements for the project. There are many software providers in the market, so the probability that not every party in a project is using the same software is close to one, which makes the collaboration between them seemingly hard from a technological point of view. The buildingSMART International (bSI) is the standardisation organisation that paves the way for interoperability between different BIM computer programs by defining open standards for data exchange. bSI continuously proposes new standards to improve cooperation in the AEC industry. Below is a list of three of the most relevant standards currently in use, and the diagram of Figure 2.5 shows how they are used throughout a project:

- Industry Foundation Classes (IFC) — officially "standardized, digital description of the built environment": identity, semantics, characteristics, and relationships between objects, abstract concepts, processes, and stakeholders [27]. It is an open international standard (ISO 16739-1:2018) and referred to as the PDF of BIM, meaning that it is technically possible to edit, but its intended purpose is to be used as a reference copy of the original design to be shared with other parties;
- BIM Collaboration Format (BCF) — official standard for the communication of issues in the IFC model through comments associated with specific elements, which can be made available to the relevant parties [28];
- Information Delivery Specification (IDS) — soon to be official standard document that defines the requirements that the project elements must comply with. BIM software can be used to validate if the model complies with the defined requirements [29, 30].

[4] Verifying the existence of overlapping elements from different specialties in a project.

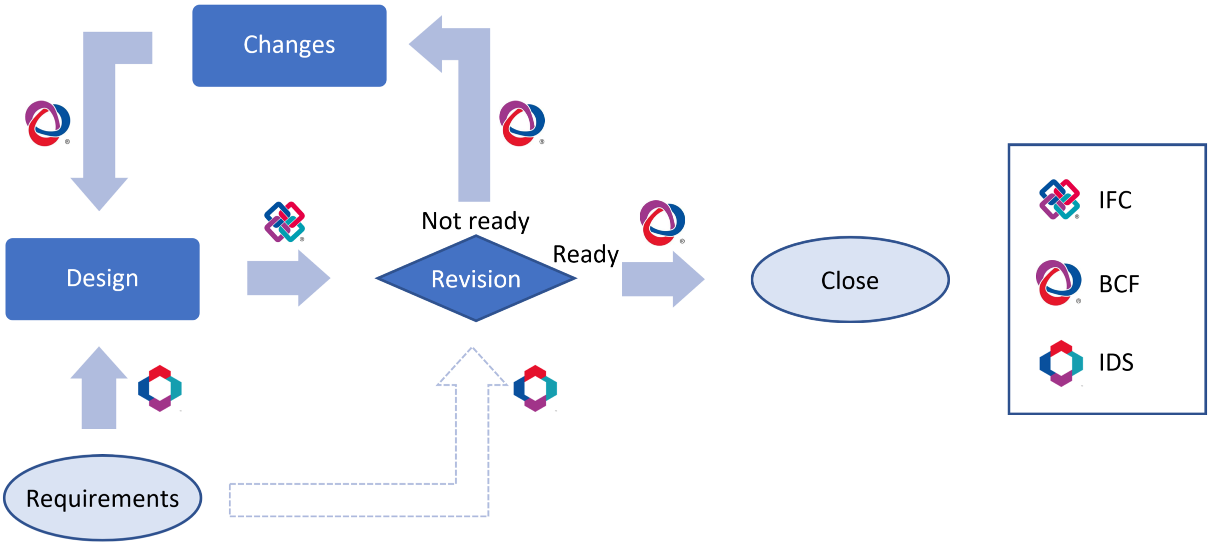


Figure 2.5: Flowchart of typical project development, indicating which transitions are simplified by which BIM standard.

Another way in which the BIM methodology contributes to collaboration is through procedure standardisation across an organisation, leading to everyone knowing where to look for information in a document produced by another colleague.

Then, a rather popular time-saving kind of BIM software is the one that enables the previously mentioned clash detection. This used to be done by overlapping drawings or CAD files, but often led to doubts that needed to be addressed on-site as the third dimension is not present in these documents. The available computer programs dedicated to this task are powerful, and even when a clash is not detected or the designers from the different specialties cannot reach an agreement off-site, it is possible to address it on-site thanks to the previously mentioned AR applications.

When implementing BIM, it is possible to have files stored in the cloud, avoiding different versions of the same file to circulate between team members, and facilitating the involvement of the owner of the project at the earliest possible stage of the design phase, given that, as Eldeep et al. [31] refer, a large number of change orders comes from owners' requests at a late stage of the design phase, which results in redesigning work that could have been reduced or completely avoided if it was addressed at an earlier stage. It is important to note that there are more security risks inherent to cloud-based storage when compared to local storage, but these risks can be reduced by using Blockchain technology, as it can reliably keep track of changes in the documents of the project thanks to an immutable ledger[5], distributed among the stakeholders [33]. Unfortunately, as of now, BIM software does not reliably keep track of the integrity of the data related to the models, nor does it implement Blockchain technology. There have been some attempts to make use of it in the AEC industry but Celik et al. [34] concluded that its use is still sparse, limited and at an embryonic stage, and pointed out the main challenges to be

[5]"A book in which a company or organisation writes down the amounts of money it spends and receives" [32]. In the context of Blockchain technology, the ledger can contain any type of information, not necessarily financial.

a lack of standards, limited scalability, operational requirements, and the complexity of the technology.

Despite all the presented benefits of implementing the BIM methodology, some factors are decelerating its adoption, especially among smaller-sized companies: it needs a non-negligible extra initial investment as it is necessary to acquire BIM software licenses; if not well implemented, it can be a source of confusion and lower the productivity, so it is important to invest time in training the designers who work directly with BIM software; and it is sometimes hard to find objects in the programs' libraries that correctly represent the construction elements to be used on-site [7].

2.2.2 BIM for Electrical Installation Design

As mentioned before, the electrical installation is one of the systems that is last designed. Thankfully, architecture and civil engineering are already very much developed when it comes to BIM implementation, but, sadly, that is not verified in the electrical installation design, both in the labour world and in academia.

In many companies that have already implemented the BIM methodology, the electrical installation design still relies on Excel spreadsheets and/or specialised software with no automatic transportability into the models. Furthermore, Sampaio et al. [7] pointed out in their case study that the existent software is complex and not intuitive when it comes to electrical elements, but research is already underway for facilitating the inclusion of this specialty in the BIM methodology.

Isaac and Shimanovich [10] proposed a method for the planning of MEP installation using BIM, which is meant to address the previously pointed out challenges in the designing of electrical installations in general. Also, Maglad et al. [35] performed a case study where a building model was rotated 360 degrees, with 45-degree steps, to analyse the impact of the orientation of the building on energy consumption, resorting exclusively to BIM software. Furthermore, there is some research on using deep learning[6] for information extraction (IE) from MEP digital documentation that can be used for maintenance and device control [37].

[6]A type of AI algorithm that mimics the human brain in order to ”learn” from large amounts of data [36].

Chapter 3

Methodologies

To accomplish the objective proposed in Section 1.2, an electrical installation of a hospital was designed in collaboration with TPF. The design of electrical installations around Europe is undergoing a process of standardisation, with norms and guides being published both at the national and the European levels. This project is to be implemented in Angola, but the client required that it followed the Portuguese regulation for electrical design, as it is stricter than the Angolan norms. In Section 3.1, the main rules and equations needed for determining electrical quantities are presented, most of them extracted from the RTIEBT [13], and some of them from the Electrical installation guide from Schneider [12], referenced when needed.

Then, Section 3.2 describes the four BIM computer programs used for the fieldwork.

3.1 Theoretical Background

To know what theoretical background is needed, the diagram of Figure 3.1 identifies the written and drawn deliverables of the electrical installations specialty typically developed in a building project.

The symbols used in the diagrams presented in this Section are specified in Appendix A.

3.1.1 Normal and Safety Power Supplies

In Portugal, the public low voltage distribution grid operates at a voltage of 230/400 V AC, with tolerances of +6% and -10%. When the installation is powered by a secondary substation[1], the private electrical installation must operate in one of the following normalised voltage levels: 230/400 V AC, 227/480 V AC, 400/690 V AC or 1000 V DC. In terms of frequency, the public low voltage distribution grid operates at 50 Hz, with tolerances of $\pm$1%. To determine the nominal full-load current (I_n) on the low voltage side of a 3-phase transformer, Equation (3.1) is used:

[1] Point of an MV distribution grid where an MV/LV transformer is installed to either distribute LV electrical power to many consumers or to feed a single LV electrical installation.

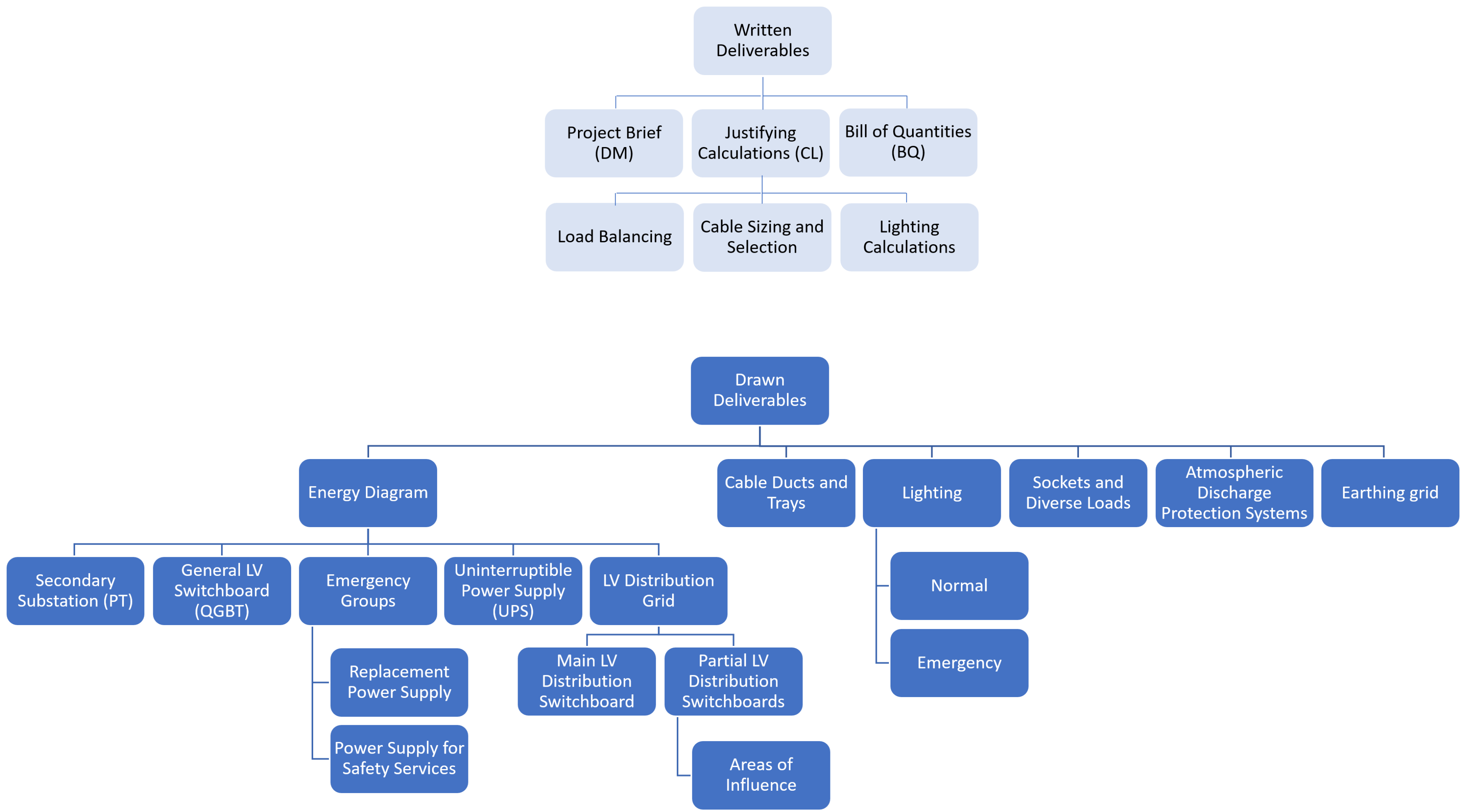


Figure 3.1: Identification of the electrical installation written and drawn deliverables.

$$I_n = \frac{S_{ap}}{U\sqrt{3}}\,, \tag{3.1}$$

where: I_n $=$ nominal full-load current, in A,

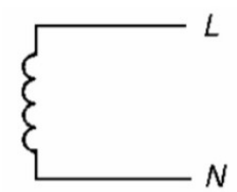
S_{ap} $=$ transformer rating, in VA,

U $=$ phase-to-phase voltage at no-load, in V.

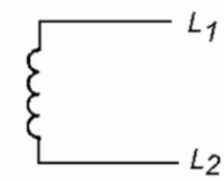
Depending on the value obtained, one of three types of power feed must be chosen, which correspond to the following classifications of the electrical installation [38]:

- Type A — The installation will have its own electricity production;
- Type B — The installation will be fed by the medium, high or very high voltage public distribution grid;
- Type C — The installation will be fed by the LV public distribution grid.

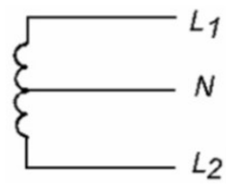
Then, it is necessary to choose one of the live conductor schemes shown in Figure 3.2.



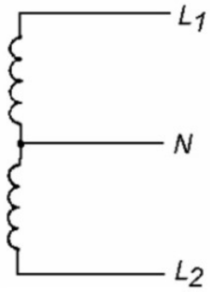
(a) 1-phase 2 conductors (1).



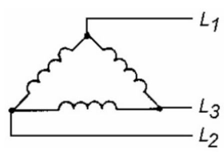
(b) 1-phase 2 conductors (2).



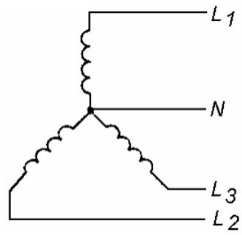
(c) 1-phase 3 conductors.



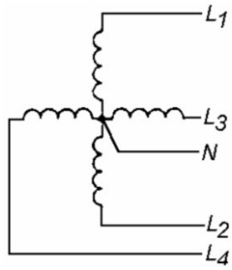
(d) 2-phase 3 conductors.



(e) 3-phase 3 conductors.



(f) 3-phase 4 conductors.



(g) 4-phase 5 conductors.

Figure 3.2: Live conductor schemes for alternating current (AC) as defined in the Portuguese norm (from [13]).

To complement the power supply from the public grid or the power generation on-site — the Normal Power Supply (NPS) —, there are cases where it is necessary to foresee an Emergency Power Supply (EPS) to feed the electrical installation in case of a disruption in the NPS network. This requirement might be imposed by the fire safety authorities, might be required given the use of the building, or might even be a project requirement from the client. Examples of power sources commonly used to feed the EPS network are accumulator batteries, independent power generators, and public distribution grid connections that are guaranteed to be electrically independent from the one used as NPS. The locations of these emergency power sources must be accessible only to qualified (BA5) or instructed (BA4)[2] individuals and be ventilated. Also: if the EPS is guaranteed by a single group, it cannot be used for other purposes; circuits should not cross spaces with fire or explosion risk; and each protection device must protect one circuit only.

3.1.2 External Influences

Chapter 32 of the RTIEBT [13] presents several tables of classification according to themes that range from room temperature, water presence and fire risk to the competence of the users and building structure, among others. These classifications of spaces, users and buildings are key factors that impose constraints on the electrical installation design. Examples of these constraints are the tables presented in chapter 512.2 of the RTIEBT [13] which define how to select and install electrical equipment given the external influences previously mentioned. In those tables, IP and IK codes of equipment are often mentioned, which relate to the resistance against water and particle penetration, and impact, respectively, as shown in Figure 3.3.

3.1.3 Earthing Systems

For protection reasons, every electrical installation must have earth connections through which any leak current can be safely routed. There are three main earthing schemes in AC systems: TN, TT and IT (RTIEBT [13] also defines earthing schemes for DC systems, but they are not deemed relevant in this project). The letters used in the scheme nomenclature have the following meanings:

- First letter — power supply earthing:

  T — Direct earth connection;

  I — Isolation of live parts, or earth connection through an impedance.

- Second letter — electrical masses[3] earthing:

  T — Direct earth connection;

  N — Connected to the point of the power supply that has a direct earth connection (usually the neutral conductor).

- Other letters (TN scheme, optional):

  S — Neutral and protection conductors are separate;

  C — Neutral and protection conductors are one conductor.

Therefore, in the TN scheme, the power supply is directly connected to the earth and the electrical masses are connected to the point where that connection is made. The masses' connection may be

[2]These classifications are related to the contents of Subsection 3.1.2.

[3]Conductive part of electrical equipment that might be touched, usually isolated from the live parts of the equipment, but which can be at a different electric potential in case of a fault [13].

Element	Numerals or letters	Meaning for the protection of equipment	Meaning for the protection of persons
Code letters	IP		
First characteristic numeral		**Against ingress of solid foreign objects**	**Against access to hazardous parts with**
	0	(non-protected)	(non-protected)
	1	⩾ 50 mm diameter	Back of hand
	2	⩾ 12.5 mm diameter	Finger
	3	⩾ 2.5 mm diameter	Tool
	4	⩾ 1.0 mm diameter	Wire
	5	Dust-protected	Wire
	6	Dust-tight	Wire
Second characteristic numeral		**Against ingress of water with harmful effects**	
	0	(non-protected)	
	1	Vertically dripping	
	2	Dripping (15°tilted)	
	3	Spraying	
	4	Splashing	
	5	Jetting	
	6	Powerful jetting	
	7	Temporary immersion	
	8	Continuous immersion	
	9	High pressure and temperature water jet	
Additional letter (optional)			**Against access to hazardous parts with**
	A		back of hand
	B		Finger
	C		Tool
	D		Wire
Supplementary letter (optional)		**Supplementary information specific to:**	
	H	High-voltage apparatus	
	M	Motion during water test	
	S	Stationary during water test	
	W	Weather conditions	

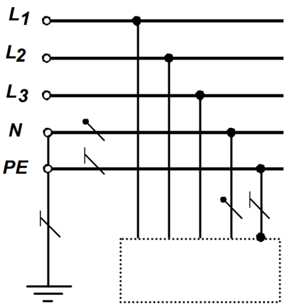
(a)

IK code	Impact energy (in Joules)	AG code
00	0	
01	⩽ 0.14	
02	⩽ 0.20	AG1
03	⩽ 0.35	
04	⩽ 0.50	
05	⩽ 0.70	
06	⩽ 1	
07	⩽ 2	AG2
08	⩽ 5	AG3
09	⩽ 10	
10	⩽ 20	AG4

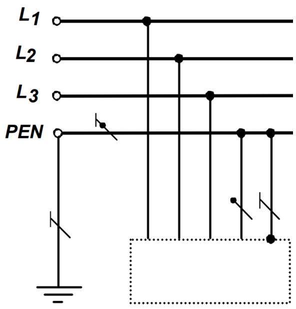
(b)

Figure 3.3: IP (a) and IK (b) codes of equipment. For the IP code, in case one of the numerals is not required to be specified, it may be replaced by an ”X” (from [12]).

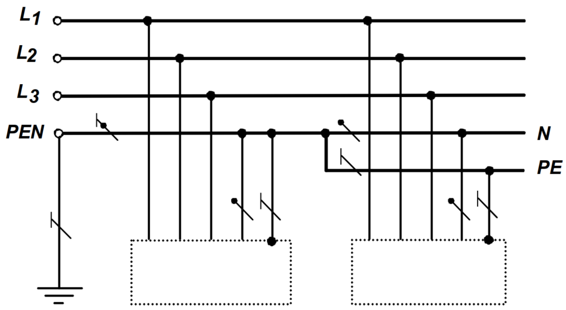
done via a separate protection conductor which is then connected to the neutral at the power supply — TN-S scheme — or directly via the neutral conductor — TN-C scheme. There is a third variation that allows a part of the installation downstream to a TN-C scheme to be TN-S, originating a TN-C-S scheme, but never the other way around. All three schemes are represented in Figure 3.4.



(a) TN-S earthing scheme.



(b) TN-C earthing scheme.



(c) TN-C-S earthing scheme.

Figure 3.4: TN earthing scheme variations (from [13]).

Then, in the TT scheme, both the power supply and the electrical masses are directly connected to the earth, which can be represented as shown in Figure 3.5.

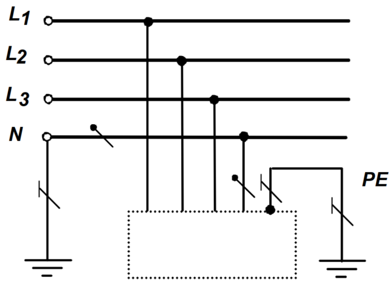


Figure 3.5: TT earthing scheme (from [13]).

Finally, the IT scheme is used when the continuity of service is a priority. It is designed so that the first fault current is not harmful, therefore a cut-off is not necessary on the first fault, but it is important to search for and eliminate its cause given that a potential second fault would be equivalent to a fault in a TN or TT scheme. To monitor these faults, an Insulation Monitoring Device (IMD) must be installed. Figure 3.6 represents the IT scheme.

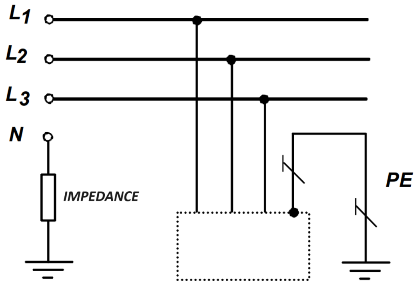


Figure 3.6: IT earthing scheme. Note that the impedance in the figure might not be included, making the power supply isolated from the earth (from [13]).

Regarding how the actual connection to the ground is made, the Portuguese norm allows tubes, rods, tapes, rings of tapes or bare conductors, the reinforcement of concrete elements, or metallic water pipes (as long as there is a previous agreement with the water distributor and any changes in the piping system are communicated to the owner of the electrical installation) to be used as earthing electrodes. They are usually laid out in a grid around the building and must be buried with a minimum depth of 0.8 m. The minimum cross-section of the protection conductors that will connect electrical equipment and fixtures to these electrodes is defined in chapter 542.3 of the RTIEBT [13], with a main earthing terminal connecting them to the earthing grid.

3.1.4 Conductors and Conduits

The cables that connect the loads to the power supply(ies) are sized according to the current needed to feed these loads and to the maximum voltage drop that can be verified along the cable, due to its impedance.

In terms of current, the diagram in Figure 3.7 gives a visual aid on the dimensioning of cables (and protections, which will be further explained later in this Section).

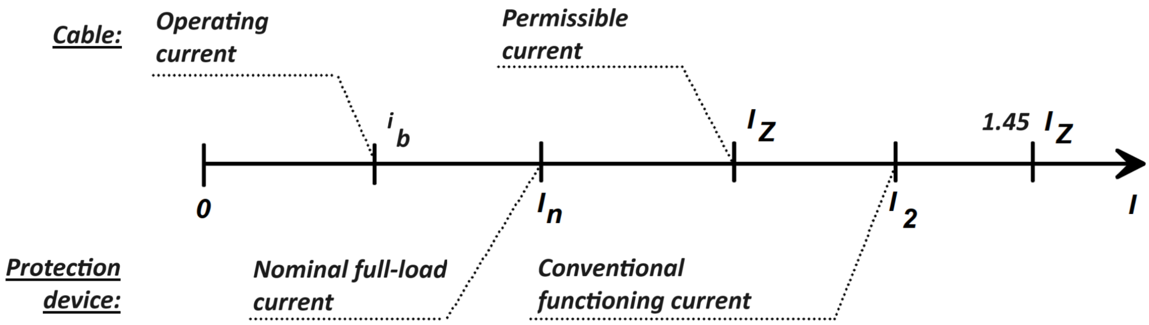


Figure 3.7: Important values of current in cable and protection sizing (adapted from [13]).

In order to not damage the cables, the operating current (i_b), which is not greater than the nominal full-load current (I_n), should also not be greater than the permissible current (I_Z) of the cable, a relationship that the norm expresses in Equation 3.2. Then, as a safety measurement, it is also important that the conventional functioning current of the protection device (I_2) is not over 1.45 times higher than the permissible current (I_Z) of the cable, which is expressed by Equation 3.3.

$$i_b \leq I_n \leq I_Z \tag{3.2}$$

where: i_b = operating current, in A,
I_n = nominal full-load current, in A,
I_Z = permissible current, in A.

$$I_2 \leq 1.45\, I_Z \tag{3.3}$$

where: I_2 = conventional functioning current, in A,
I_Z = permissible current, in A.

To then size the cable, one can follow the flowchart represented in Figure 3.8 and explained in detail in the next paragraph.

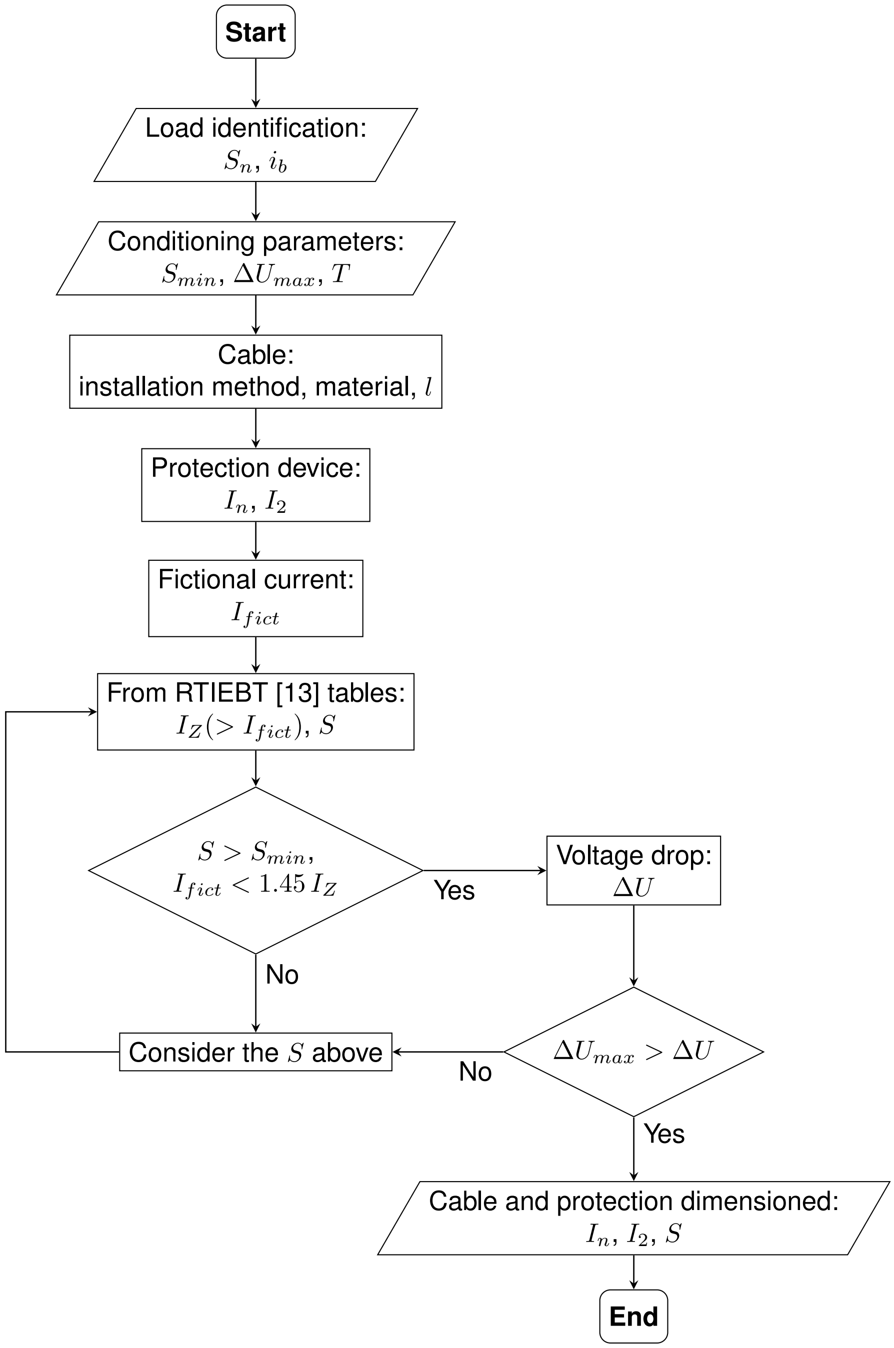
The first thing to do is define the nominal power rating (S_n), and obtain the operating current (i_b). Then it is important to check the normative requirements and conditioning parameters: minimum conductor cross-section (S_{min}), which is defined in table 52J of the RTIEBT [13]; maximum voltage drop at the end of the circuit (ΔU_{max}), which is defined in table 52O of the RTIEBT [13]; and room temperature (T). Moreover, cables are usually installed in such ways that they are not visible to the regular users of the buildings, so it is necessary to route them, for example, between the real and the false ceilings, or through walls, or under the floor, and the RTIEBT [13] defines standard installation methods in its chapter 521.3. These methods shall vary across the installation and be chosen according to architectural needs and the previously mentioned external influences classifications. They also impact wire sizing in the form of correction factors applied to the calculations (k_P), which can be found in table 52-C3 of the RTIEBT [13]. Something that should also be defined is the conductor material — copper or aluminium —, and the cable length, which will be useful for later calculations.

After that, based on the value of i_b, the electrical engineer should choose a protection device with the lowest possible values of I_n that is greater than i_b, which will have a certain I_2. Then, a fictional current (I_{fict}) is calculated using Equation 3.4, which represents the current after the application of the temperature (k_T) and multi-conductor (k_P) factors. As the cable must keep normal operation when run by this value of current, and, after applying the correction factor related to the installation method, the conductor cross-section which corresponds to the lowest value of permissible current (I_Z) that is greater than the previously obtained value is preliminarily chosen.

$$I_{fict} = \frac{I_n}{k_T.k_P} \, , \tag{3.4}$$

where: I_{fict} = fictional current, in A,
I_n = nominal full-load current, in A,
k_T = temperature correction factor — table 52E1 of the RTIEBT [13],
k_P = multi-conductor correction factor — table 52D1 of the RTIEBT [13].

Finally, to confirm the value of the conductor cross-section, the first verification to do is related to the currents, both 3.2 and 3.3 must be verified: if not, the cross-section above should be considered and the conditions re-verified; if so, the voltage drop in V (Δu) should be calculated using Equation 3.5 [39], to then obtain the voltage drop in % (ΔU). If the value of ΔU obtained is greater than the value of ΔU_{max}, the cross-section above should be considered and both the current and the voltage drop conditions re-verified, if not, both the cable and the protection devices are correctly sized. Note that ΔU_{max} varies according to the type of load to be fed.



where: S_n = nominal power rating, in VA,
i_b = operating current, in A,
S_{min} = minimum conductor cross-section, in mm^2,
ΔU_{max} = maximum voltage drop, in %,
T = room temperature, in $^\circ$,
l = circuit length, in m,
I_n = nominal full-load current, in A,
I_2 = conventional functioning current, in A,
I_{fict} = fictional current, in A,
I_Z = permissible current, in A,
S = conductor cross-section, in mm^2,
ΔU = voltage drop, in %.

Figure 3.8: Cable and protection sizing flowchart.

$$\Delta u = b\left(\rho.\frac{l}{S}.\cos\varphi + \lambda.l.\sin\varphi\right) i_b\,, \tag{3.5}$$

where: Δu = voltage drop, in V,

b = phase-related coefficient, equal to 1 for three-phase circuits, and equal to 2 for single-phase circuits,

ρ = resistivity of the conductors in normal service, 1.25 times the resistivity at 20 °C, equal to 0.0225 Ωmm^2/m for copper, and 0.0360 Ω mm^2/m for aluminium,

l = circuit length, in m,

S = conductor cross-section, in mm^2,

$\cos\varphi$ = power factor, between 0 and 1,

λ = reactance of the conductors per unit length, in mΩ/m,

$\sin\varphi = \sqrt{1-\cos^2\varphi}$,

i_b = operating current, in A.

Note that, when the copper phase conductors have a cross-section greater than 16 mm^2 (25 mm^2 for aluminium), the neutral conductor cross-section may be inferior to that of the phase conductors, but never less than 16 mm^2 (25 mm^2 for aluminium).

Also, the minimum cross-section (S_{min}) for the protection conductors must not be less than the value obtained with Equation 3.6.

$$S_{min} = \frac{I_d\sqrt{t}}{k}\,, \tag{3.6}$$

where: S_{min} = minimum conductor cross-section, in mm^2,

I_d = fault current, in A,

t = tripping time of the protection device, in s,

k = a factor dependent on the characteristics of the protection conductor, further specified in tables 54B, 54C, 54D and 54E of the RTIEBT [13].

At the end of this process, the electrical engineer has all the information he needs to choose the cables necessary from Appendix B.

3.1.5 Lighting

For the lighting design, there are a few important concepts to understand and determine so that the lighting of every room in the building is compliant with the European regulations, both for interior [40] and exterior [41] areas. Table 3.1 sums up some of the concepts that are at the basis of the physical quantities required by the norm, which are then summed up in Table 3.2.

Table 3.1: Physical quantities related to lighting that form the basis for the physical quantities that must be in line with the European regulations — symbols, descriptions and measurement units.

Symbol	Physical quantity	Units	Expression
ϕ	Luminous flux — light emitted by the source.	lm	-
I	Luminous intensity — luminous flux in a specific direction.	cd	-
L	Luminance — (visible) luminous flux, that is reflected by a surface of area A and reflectance ρ_s inclined at an angle a from a plane perpendicular to the observer's vision level.	cd/m^2	Equation 3.7.
ρ_s	Reflectance — coefficient that represents the relationship between the reflected and the absorbed light by a surface. Depends on the material and colour of the surface.	%	-
hw	Energy efficiency — number of lumens emitted per Watt absorbed by a lamp.	lm/W	-
Fb	Ballast factor — performance of the reactor in the ballast of discharge lamps.	%	Equation 3.8.
Fu	Utilisation factor — related to the proportions of the enclosure where the luminaire is installed.	%	-
Fd	Depreciation factor — related to the age and presence of dust in the luminaire.	%	-

$$L = \frac{I}{A.\cos a}\,, \tag{3.7}$$

where: L = fictional current, in A,

I = luminous intensity, in cd,

A = area, in m^2,

a = angle, in rad.

$$Fb = \frac{Obtained\ \phi}{Nominal\ \phi}\,, \tag{3.8}$$

where: Fb = ballast factor, between 0 and 1,

ϕ = luminous flux, in lm.

$$E = \frac{\phi}{A}\,, \tag{3.9}$$

where: E = illuminance, in lx,

ϕ = luminous flux, in lm,

A = area, in m^2.

Table 3.2: Physical quantities related to lighting that must be in line with the European regulations — symbols, descriptions and measurement units.

Symbol	Physical quantity	Units	Expression(s)
E	Illuminance — luminous flux that reaches a surface of area A at a distance d.	lx	Equations 3.9 and 3.10.
U_0	Uniformity — on a scale from 0 (not uniform) to 1 (completely uniform), the relationship between the minimum illuminance (E_{min}) and the average illuminance (E_{avg}) in a specific area.	-	Equation 3.11.
UGR	Unified Glare Rating — on a scale from 5 (low glare) to 40 (high glare), the level of discomfort produced by a luminance that is much greater than the one the observer's eyes are adapted to in that instance, which depends on the background luminance (L_b), "the luminance of the luminous parts of each luminaire in the direction of the observer's eye" [40] (L_i), "the solid angle (steradian) of the luminous parts of each luminaire at the observer's eye" [40] (ω_i), and "the Guth position index for each individual luminaire which relates to its displacement from the line of sight" [40] (p_i).	-	Equation 3.12.
Ra	Colour rendering index — on a scale from 1 (minimum) to 100 (maximum), the ability of a light source to make the colour seen by the observer as close to the true colour of the object as possible.	R	-

$$E = \frac{I}{d^2}\,, \tag{3.10}$$

where: E = illuminance, in lx,
I = luminous intensity, in cd,
d = distance, in m.

$$U_0 = \frac{E_{min}}{E_{avg}}\,, \tag{3.11}$$

where: U_0 = uniformity, between 0 and 1,
E_{min} = minimum illuminance, in lx,
E_{avg} = average illuminance, in lx.

$$UGR = 8\,\log_{10}\left(\frac{0.25}{L_b}\sum_{i=1}^{k}\frac{L_i^2.\omega_i}{p_i^2}\right)\,, \tag{3.12}$$

where: UGR = Unified Glare Rating, between 5 and 40,

L_b = background luminance, in cd/m^2,

k = number of luminaires,

L = luminance, in cd/m^2,

ω = solid angle, in steradian,

p = Guth position index, related to the displacement from the line of sight of each luminaire.

The main focus of the norm is to guarantee the minimum value of maintained average Illuminance ($\overline{E}_m$) on the task area and the immediate surrounding area, which varies according to the task performed at the observed reference plane, the minimum value of Uniformity (U_0) on the task area and the immediate surrounding area, the maximum value of Unified Glare Rating (UGR), and the minimum value of the Colour Rendering Index (R_a).

To calculate the number of luminaires needed in a space, one of two methods can be used: the efficiency method or the point-by-point method (not further explained in this document). Also, luminaire suppliers make the photometric polar diagram of each luminaire available to the public, which represents the value of I in each direction, as in the example of Figure 3.9.

3.1.6 Safety of the Installation

This subsection builds upon the concepts presented in the previous subsections in this chapter, but the safety of the electrical installation is the main objective of the RTIEBT [13]. Its first chapter is centred around this theme, and it is present throughout the whole document.

The main hazards the installation must protect people from are electric shock, thermal effects, overcurrent[4] and fault current. Overvoltage due to improper isolation or atmospheric discharges and undervoltage are also mentioned but not further explained in this document.

Starting with electrical shock, it is defined as the pathophysiological effect that results from the passing of an electrical current through the human or animal body [13][5], and the protection against it is achieved by avoiding direct[6] and indirect[7] contacts.

To avoid direct contacts, it is recommended to isolate the live parts of the installation and/or use barriers/cases of at least IP2X (for easily accessible horizontal surfaces at least IP4X). In some cases, it is possible to simply put obstacles like guardrails between the live parts and accessible areas, keeping

[4]Current greater than I_Z for cables or I_n for protection devices [13].

[5]Original text: "Efeito fisiopatológico resultante da passagem de uma corrente eléctrica através do corpo humano ou do corpo de um animal" [13].

[6]Touching live parts of the electrical installation [13].

[7]Touching masses that are at a different electric potential due to a fault [13].

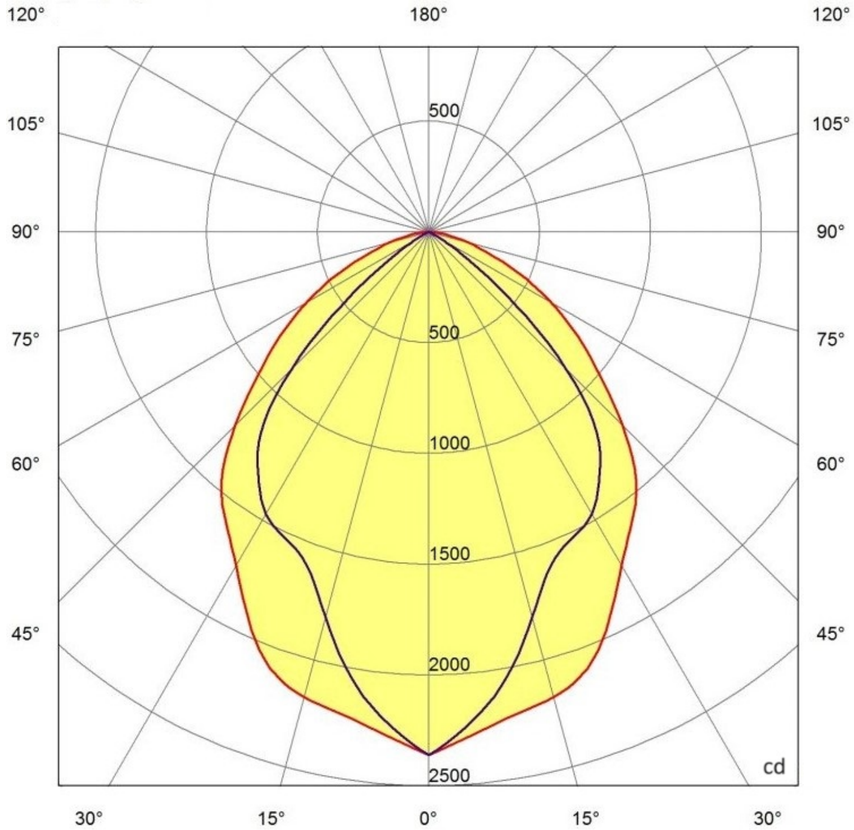
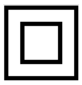
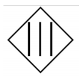


Figure 3.9: Example of a photometric polar diagram, where the light source is at the origin of the referential, the radial lines represent the angles in degrees relative to the direction that is perpendicular to the task reference plane, and the circular lines represent the levels of I, in cd (from [42]).

them out of reach (at least 2.5 m). Finally, Residual Current Devices (RCDs) with nominal full-load current (I_n) not above 30 mA are also a means of protection against direct contacts, but using them does not mean that the measures previously mentioned are negligible.

On the other hand, avoiding indirect contacts is achieved through the automatic cut-off of electricity, which implies both the existence of a fault grid that interconnects the masses of all electrical equipment, that depends on the earthing scheme, through which the fault current (I_d) can be safely routed to the earth, and an appropriate protection device, sensitive to the fault current (I_d), according to the earthing scheme: protection devices against overcurrent — circuit breakers and fuses —, and RCDs for the TN scheme; preferably RCDs for the TT scheme, but overcurrent protection devices are also possible; and for the IT scheme both the overcurrent protection devices and RCDs are possible, plus the previously mentioned IMDs. To determine the maximum tripping time of circuit breakers and fuses, the most accurate way would be to consider the touch voltage (U_c), but, in practice, that voltage is difficult to estimate so the nominal voltage (U_0) is commonly used instead as it guarantees protection against the worst-case scenario. The protection against indirect contacts is also done by electrical separation, which means using separate conductors to feed a certain part of the installation, and, in practice, is used for the protection of single devices that must be supplied by a separation transformer or an equivalent power source. Note that the voltage of the the separate circuit must not exceed 500 V and the masses must not be connected to protection conductors or masses of other circuits. Also related to electrical equipment, the use of equipment with appliance class II of insulation, as defined in Table 3.3, is a way to protect people against indirect contacts, as well as the use of non-conductive spaces, which means that the masses are spatially laid out such that no two masses or a mass and a conductor are simultaneously reachable (this can be guaranteed using isolating floor and walls).

Table 3.3: Appliance classes of insulation, with respective symbol and description.

Symbol	Class	Description
-	0	Appliances with no earth connection and one level of insulation.
	I	Casing and other conductive parts are connected to an earth conductor.
	II	Double insulated, such that the earth conductor is not necessary for indirect contact protection.
	III	Supplied from an extra-low voltage power source, so no other measures are necessary for indirect contact protection

Moving on to the protection against thermal effects, in terms of fire protection, electrical equipment must be contained in insulated cases or installed at a distance such that the temperature of the equipment and possible electric arcs do not pose a risk of starting a fire, with special attention to the construction materials classified as M3 or M4 on the external influences' tables. Also, protection against burning is obtained by limiting the maximum temperatures of the electrical equipment, as defined in chapter 423 of the RTIEBT [13].

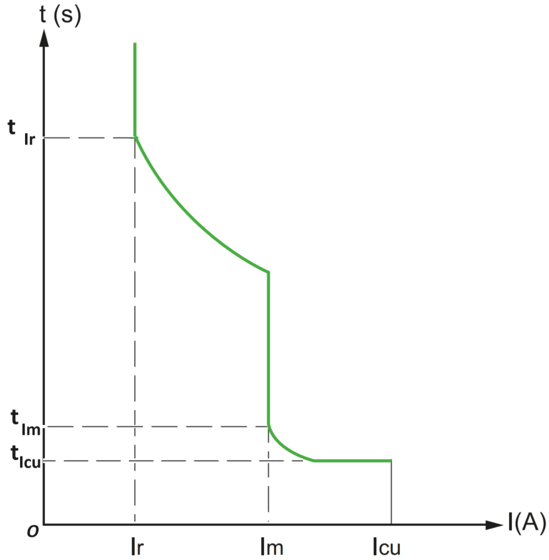
Finally, diving deeper into the protection devices, an important characteristic about them is their breaking capacity (I_{cu}), meaning the limit value of current that the device is able to cut-off [13], and this is what an electrical designer must analyse when choosing protection devices for a circuit. To prevent an overcurrent caused by an overload, meaning there was no short-circuit to the ground, the previously mentioned diagram in Figure 3.7 gives a visual aid on the dimensioning of protections.

Note that, when conductors in parallel are used, I_Z is the sum of the permissible currents in the conductors if the current in each of them is approximately the same.

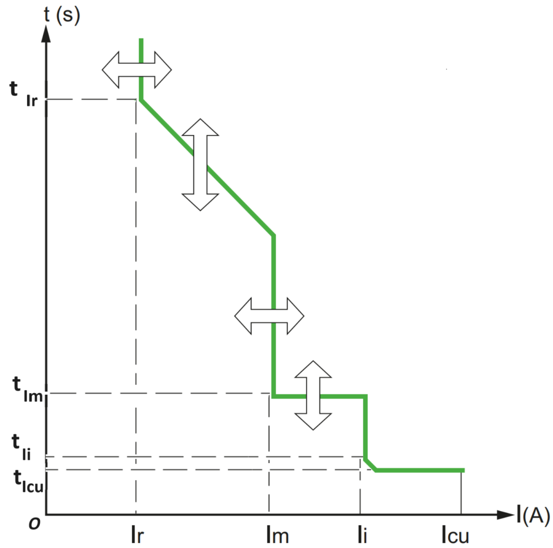
The coordination between the various upstream and downstream protection devices can be understood by overlapping their characteristic curves. Figure 3.10 shows an example of the typical characteristic curve of a circuit breaker, how a circuit breaker with an advanced electronic trip unit can adjust its curve, all in a single device, and the typical characteristic curve of a fuse. Then, Figure 3.11 shows three examples of the overlap of these curves, and, by tuning the tripping values, it is possible to obtain selectivity in the installation, which means that a fault at a certain point of the installation only causes the tripping of the devices downstream, therefore improving the continuity of service.

3.1.7 Special Installations

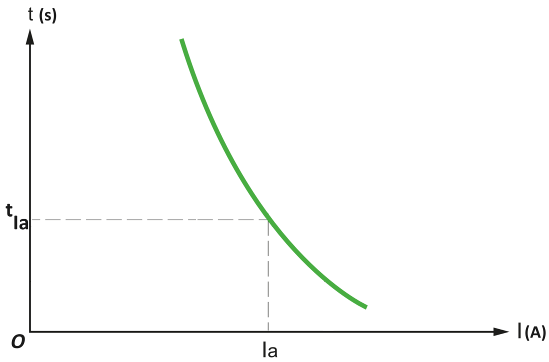
Some installations, or parts of installations, because of the permanent external influences of the space where they must operate, or the type of use given to that space, must follow a set of rules that



(a) Circuit breakers and RCDs.



(b) Circuit breakers with an advanced electronic trip unit, where the arrows represent the possibility to regulate the tripping values of the circuit breaker.



(c) Fuses.

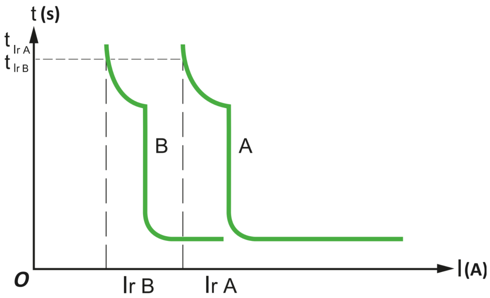
where: I_r $=$ overload relay trip current (thermal), in A,
t_{I_r} $=$ time it takes for the device to trip when a current equal to I_r is flowing in the circuit, in s,
I_m $=$ short-circuit relay trip current (magnetic), in A,
t_{I_m} $=$ time it takes for the device to trip when a current equal to I_m is flowing in the circuit, in s,
I_{cu} $=$ breaking capacity, in A,
$t_{I_{cu}}$ $=$ time it takes for the device to trip when a current equal to I_{cu} is flowing in the circuit, in s,
I_i $=$ short-circuit instantaneous relay trip current, in A,
t_{I_i} $=$ time it takes for the device to trip when a current equal to I_i is flowing in the circuit, in s,
I_a $=$ fusion current, in A,
t_{I_a} $=$ time it takes for the device to trip when a current equal to I_a is flowing in the circuit, in s.

Figure 3.10: Examples of characteristic curves of protection devices (from [12]).

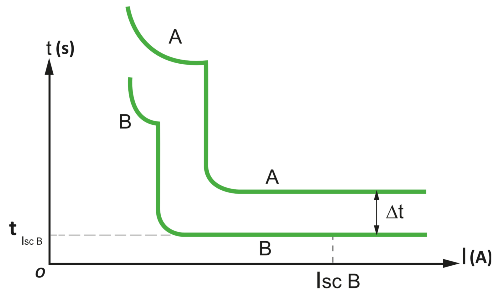
overlap the ones previously mentioned in this Section.

An example of the first case is the bathroom space (not including pre-fabricated shower cabinets or toilets just containing sinks and/or toilets). In this type of space, the RTIEBT [13] defines 4 volumes, as represented in Appendix C, each of which representing a different level of constraints in terms of equipment and wiring, as summarised in Table 3.4.

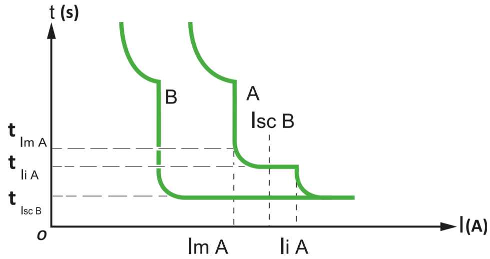
There should also be a supplementary earth connection, protection using obstacles or non-conductive spaces is not allowed, and there are restrictions to the type of conduits used.



(a) Selectivity based on current.



(b) Selectivity based on time.



(c) Selectivity based on current and time.

where: $I_r\ A$ = overload relay trip current (thermal) for circuit breaker A, in A,
$t_{I_r\ A}$ = time it takes for the device to trip when a current equal to $I_r\ A$ is flowing in the circuit, in s,
$I_r\ B$ = overload relay trip current (thermal) for circuit breaker B, in A,
$t_{I_r\ B}$ = time it takes for the device to trip when a current equal to $I_r\ B$ is flowing in the circuit, in s,
$I_{sc}\ B$ = 3-phase short-circuit current that trips circuit breaker B, in A,
$t_{I_{sc}\ B}$ = time it takes for the device to trip when a current equal to $I_{sc}\ B$ is flowing in the circuit, in s,
Δt = time interval, in s,
$I_m\ A$ = delayed short-circuit relay trip current (magnetic) for circuit breaker A, in A,
$t_{I_m\ A}$ = time it takes for the device to trip when a current equal to $I_m\ A$ is flowing in the circuit, in s,
$I_i\ A$ = short-circuit instantaneous relay trip current for circuit breaker A, in A,
$t_{I_i\ A}$ = time it takes for the device to trip when a current equal to $I_i\ A$ is flowing in the circuit, in s.

Figure 3.11: Demonstration of the different ways of achieving selectivity by overlapping the characteristic curves of the protection devices (from [12]).

On the other hand, an example of the second case would be a public facility, which is the case of a hospital. For this type of building, the Portuguese norm defines categories based on their occupancy capacity, and, for each specific use, it defines how to calculate that capacity.

Here, the electrical circuits that feed spaces not accessible to the public must be controlled and protected independently from the circuits feeding spaces accessible to the public, and the emergency escape paths must not be crossed by conduits unless they are fire-resistant. In terms of normal lighting, the electrical designer must guarantee that a malfunction or a power cut by a protection device does not result in a cut-off of all normal lighting devices, and, in rooms with a capacity of more than 50 people, plus all corridors and emergency escape paths, the command devices available to the public, for example, light switches, must not enable turning off all normal lighting in that room. Then, in terms of emergency lighting, evacuation lighting is mandatory in rooms with a capacity of more than 50 people,

Table 3.4: Toilet volumes' constraints per type of object (adapted from [13])

Object	Volume 0	Volume 1	Volume 2	Volume 3
Conduits	X	II[a]	II[a]	II[a]
Electrical Fixtures	X	X[b]	X[b][d]	Separation Transformer, U $\leq$ 25 V, RCD 30 mA
Electrical Equipment	X[b] IPX7	X[b][c] IPX5	II[a] or X[b][c][e] IPX4 (public dressing rooms — IPX5)	X[e] or II or III IPX1 (public dressing rooms — IPX5)

where:

– X = Generally not allowed.
– II = Generally allowed if of class II of isolation.
– III = Generally allowed if of class III of isolation and fed by a separation transformer, U $\leq$ 25 V AC or U $\leq$ 60 V CC.
– (a) = Limited to conduits that are necessary to feed electrical fixtures in that volume or the ones above.
– (b) = Only allowed if the circuit has a voltage of 12 V AC or 30 V CC.
– (c) = Only allowed if water heating equipment and it must be protected by an RCD 30 mA.
– (d) = Sockets fed by a separation transformer are allowed.
– (e) = Only allowed if of class I of isolation and protected by an RCD 30 mA.

plus all corridors and emergency escape paths, and ambient lighting with a luminous flux not below 5 lm is mandatory in rooms with a capacity of more than 100 people above ground level / 50 people below ground level.

To conclude, specifying for the medical use spaces, the norm defines where each type of lighting is mandatory, including orientation lighting in patient's rooms, infirmaries and corridors that serve these spaces, and where the IT scheme, coupled with a separation transformer, must be used: operation rooms and intensive care rooms.

3.2 Software Description

Four BIM computer programs were used in this work, each serving a different purpose: Autodesk® Revit® was used for modelling the elements of the building, etap® Caneco mainly for detailed electrical quantities calculation and cable sizing, DIAL GmbH DIALux evo for the lighting design, and BIMcollab® as the centralised collaboration tool.

The interoperability between them is represented in Figure 3.12.

3.2.1 Modelling Program — Autodesk® Revit®

Starting with Revit®, according to Schop [43], it was the most used BIM program in Europe in the second quarter of 2021. This, together with its completeness, versatility, and ease of customisation, was the main reason for choosing to use Revit® in this work. Construction elements are called "instances" and they are organised hierarchically: categories are the top level, and these can be columns, doors, etc. Inside each category, there are several families, which are instances that have the same function

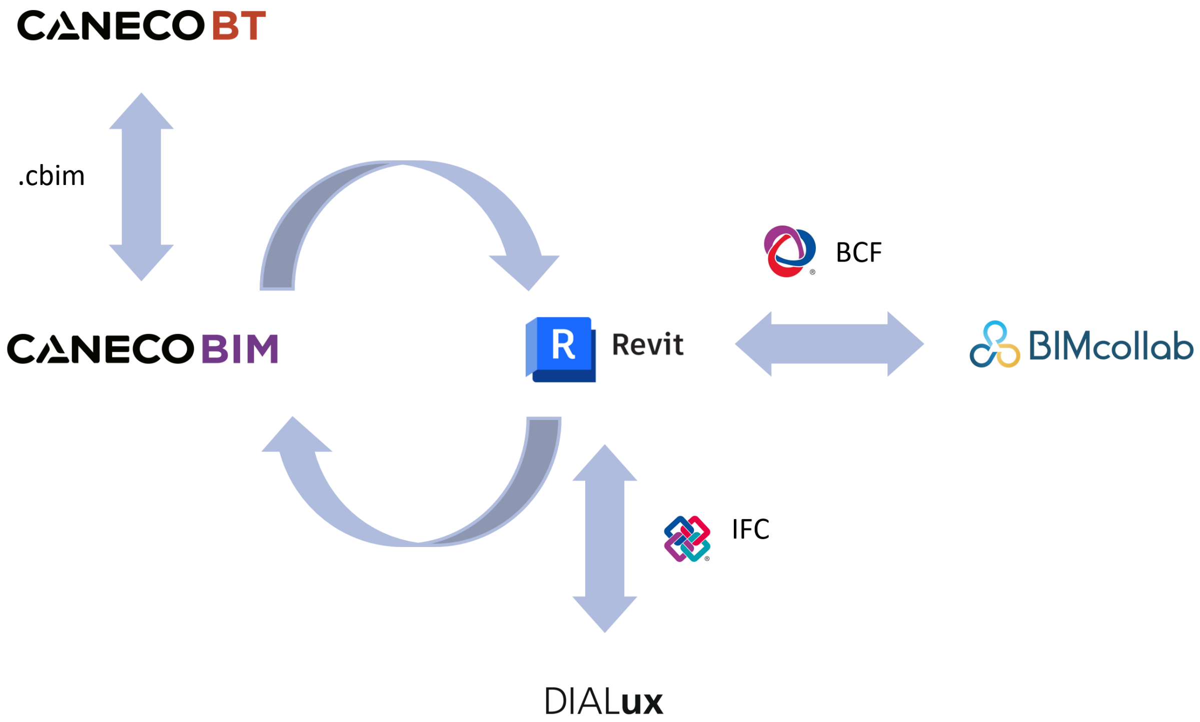


Figure 3.12: Diagram that explains how it was possible to exchange data between the BIM programs used in this work. Note that Caneco BIM runs as a plugin inside Revit® so no file extension is specified.

but might differ in terms of shape, and each family usually allows for more than one type, meaning more than one set of dimensions. A fundamental part of families, types and instances is the existence of parameters, which let you include information about the real object they are virtually representing, and act as the sprockets for the most useful functions of Revit®. Note that it is possible to use and/or edit families from the libraries of the program or create new families and types, but categories are intrinsic to Revit®, therefore not editable. It is also possible to specify general project information such as the company in charge of the project and the geographic coordinates of the building site, among others, that can then be referenced in the deliverables' title blocks. The completeness of the software is shown, in part, by the possibility of modelling architectural and structural construction elements, as well as components from the three MEP specialties, and, as previously mentioned, modelling may be done in a 2D or a 3D view, depending on the designer's preference, with the software automatically creating 3D instances in both cases.

Once the elements are modelled and the desired information added to them, it is possible to make annotations of relevant dimensions, add comments on parts of the model, tag instances, and even identify rooms and/or spaces, which are automatically recognised in the space between walls, or manually defined when needed, such as defining outdoor spaces, a feature that is very useful in the electrical installation design for the definition of the areas of influence. Another fundamental feature of Revit® is the ability to generate fully customizable tables, the so-called schedules[8], for quantity billing and cost

[8]Schedules are not output tables, but rather another way of viewing and interacting with the model.

calculations, as well as perform energy analysis and optimisation. Furthermore, the use of external files can be done either by importing them into the model or by attaching the files, which assures that, if a change is made in the source file, the updates are automatically reflected in the model as it is reloaded every time the model is opened. 4D BIM can be easily implemented by associating each instance to a project phase, allowing for construction elements' filtering in views based on temporal relationships. These views may have different detail levels, which will affect the performance of the program and can represent floor plans, sections, 3D views from certain definable angles, and 3D sections, as previously mentioned, with up to 6 cutting planes, with the possibility of being quasi-instantly inserted in the drawn deliverables. Yet another functionality that makes Revit® such a complete program is the ability to generate high-quality rendered views of the model, which are realistic representations of the 3D views considering natural and artificial lighting, and the construction elements' materials.

The last attribute to point out about this software is its collaboration tools that enable cloud document storage and assignment of permissions to edit certain instances by the manager to each team member. Also, some extra features are made available by adding plugins and/or add-ons from other software developers, which accelerates the development of new tools and creates more space for innovation. In the end, it is possible to export the model to the IFC standard and other formats such as PDF.

3.2.2 Electrical Quantities Calculation Program — etap® Caneco

Secondly, Caneco was used for detailed electrical quantities calculation and cable sizing. The software is subdivided into four programs, namely Caneco BT — electrical quantities calculation and cable sizing for LV electrical installations —, Caneco BIM — Revit® plugin which allows for a more efficient circuit management and establishes the communication between Revit® and Caneco BT —, Caneco Implan — similar to Caneco BIM but for AutoCAD® (not used in this project) —, and Caneco HT — similar to Caneco BT but for HV electrical installations (not used in this project).

Regarding Caneco BT, it is possible to define the loads connected to each panelboard, and automatically obtain the loads for each panelboard and each switchboard, taking into account the diversity[9] and the utilisation[10] factors, and simulating the electrical installation for different scenarios of power supply, such as normal, emergency or uninterruptible[11]. It also performs load balancing across the three phases, busbar trunking[12] sizing, and sizing of capacitor banks for power factor correction. This program is also geared with the European and national norms of a wide range of countries, including the cable types tables. Then, according to the specified loads and the obtained cables, it is able to size the protection devices needed, providing tools to analyse their characteristic curves and selectivity.

On the other hand, Caneco BIM adds the following features to Revit® regarding circuits: faster bulk

[9] Factor between 0 and 1 that accounts for the degree of simultaneity at which the electrical equipment of the installation are expected to be turned on, applied in load estimation calculations.
[10] Factor between 0 and 1 that accounts for the relationship between the rated power of an equipment and the actual power at which it normally functions, applied in load estimation calculations.
[11] Its usefulness is explained in Section 4.1.
[12] Similar to the busbar inside the panelboard, but it is used for distribution, similarly to the cable trays.

point-to-point circuit creation; circuit grouping by electrical busbar inside the panelboard; automatic cable routing through cable trays and conduits; resizing of cable trays based on the desired occupation percentage; and definition of cable length safety margins.

3.2.3 Lighting Calculations Program — DIAL GmbH DIALux evo

Thirdly, DIALux evo is a program exclusively dedicated to lighting design. It is widely used in this area, not exclusively but also due to being free of charge, which is made possible by the extensive number of luminaire manufacturers with a membership that allows them to publish their products' catalogues, company news and digital models of the luminaires directly inside the program. This business model improves both the manufacturers' visibility and the accuracy of the lighting calculations since the models provided have the same parameters as the corresponding real-life luminaires they represent, which was the main reason for choosing this software.

Interoperability is not a problem, as one can directly import IFC models generated from any modelling software, avoiding the time-wasting task of remodelling the building or the specific room to be analysed, although it is possible to model directly inside DIALux evo. Once again, general project information can be defined and automatically included in the exported documentation, and it is possible to perform the analysis of both inside and outside lighting, differentiating normal and emergency lighting, and consider various lighting scenarios, varying which luminaires are turned on or off.

In terms of calculations, one can define the planes to perform illuminance estimation on, which are represented by isolines and/or colours, according to the numerical values (in lux), as seen in Figure 3.13, and calculate UGR as referred in Section 3.1.5. These calculations take into account factors of luminaires mentioned in Section 3.1.5 and the surfaces' materials, which have an impact on parameters such as the reflection coefficients. After performing the calculations, the program validates if the illuminance levels respect the regulations, according to the previously defined activity carried out in that specific plane. The energy demand of the lighting system can also be calculated inside DIALux evo.

Furthermore, annotations and rendered views of the 3D model are also available, as previously mentioned for Revit, and the documentation regarding lighting calculations and luminaires' datasheets can be automatically generated and exported as PDFs. At the end of the lighting design, it is possible to export the luminaires' model back to Revit via IFC to have the complete model of the building in the same file.

3.2.4 Collaboration Program — BIMcollab®

Lastly, BIMcollab® was used for centralised collaboration, meaning that stakeholders who were not part of the team had access to the project documents through this software. The main reason for using BIMcollab® instead of the collaboration functionalities of Revit® is that this software allows collaboration regardless of the modelling computer programs that the different parties have as it works exclusively with the three open standards mentioned in Section 2.2.1, and the choice of using this specific software compared to its competitors was due to being the one used at TPF.

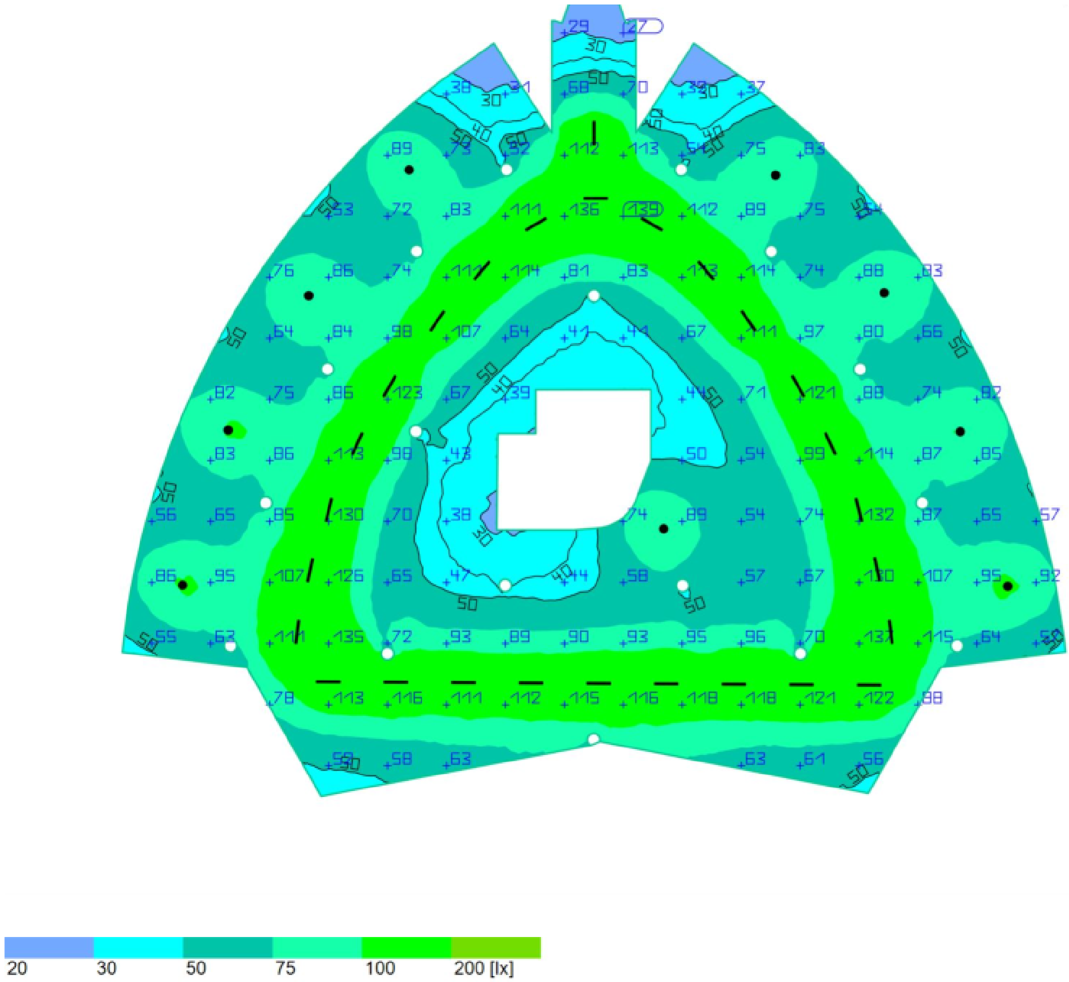


Figure 3.13: Example of the isolines obtained when calculating the illuminance of a given surface in DIALux, in this case, at floor height, in a parking lot.

It provides three powerful tools, as follows:

- BIMcollab® ZOOM — a local application that performs clash detection on imported IFC models and lets the user extract model information regarding quantities and materials needed;
- BIMcollab® Cloud — a web application used to create and manage issues, and involve all stakeholders. Issues contain information such as resolution deadline, priority, and responsible team member, and, when adding users to the project, it is possible to assign them to a group (e.g., construction management, electrical engineers) and define what kind of permissions they have (e.g., view permission, edit permission). Additionally, the users receive notifications of new issues, comments on an issue, and state changes, and it is possible to generate reports with Microsoft Power BI, a widely used business intelligence platform;
- BCF Manager — a plugin available for a variety of modelling programs that lets the user integrate his with the BIMcollab® Cloud web application, allowing for issue creation and management directly inside the modelling program, and automatically synchronize with the BIMcollab® Cloud project.

Chapter 4

Results

As mentioned in Section 1.3, this chapter presents an analysis of the usual workflow of an electrical installation design, followed by the fieldwork developed for the design of the electrical installation of a hospital, this time following the BIM methodology, resulting in the gathering of data that allows for a comparison between the two workflows.

4.1 Usual Project Development

The first thing to do is confirm that all the preliminary information needed for designing the electrical installation is at hand, namely:

- Type of building;
- Definition of the intended use for each room;
- Specific equipment that will be directly fed by the LV distribution for each room (e.g., air conditioning, electric blinds), or by sockets (e.g., coffee machines, medical equipment);
- Architectural floor plans.

Only then is the electrical designer ready to start the preliminary estimation of load demand. To do that, it is recommended to classify each room according to the tables mentioned in Section 3.1.2. Then, it is possible to define the load demand per m^2 taking into account common industry values, such as the ones presented for lighting and power circuits in the Schneider guide [12] and the values presented in the old Portuguese norm [44] that stopped being mentioned in the later norms but are still usable for accurate design of electrical installations — in this project, a value of 30 W/m^2 was used for both lighting and power circuits, in all areas.

Based on the load demand estimated and its spatial distribution across the building, the next step is to define the number of secondary panelboards, their location and their areas of influence, as seen in Appendix D, which is sketched on the architect's AutoCAD floor plans. The objective here is to minimise the distance between rooms to feed and the panelboards and to optimise cable types and lengths in the project to minimise costs. Also, the number and location of the switchboards used to feed the panelboards are decided in this stage. When ready, to summarise panelboard designations and connections, the energy diagram is drawn, which is an important drawn deliverable for the construction phase.

Next, it is time to put all this information on an Excel spreadsheet and sum the load demands per m^2 multiplied by the associated areas of influence of each panelboard with the load demand of specific electrical equipment to get the estimation of the total load demand, as seen in Figure 4.1.

While finishing the load estimation at this step would result in a compliant electrical installation project, there is an underlying and unreasonable assumption that all loads are consuming at 100% of their capacity, all at the same time. So, to have a realistic estimation and drastically reduce the cost of the installation, the obtained values are then multiplied by diversity and utilisation factors, again, according to common industry values — in this project, values for diversity factor of 0.3 for sockets, 0.5 for lighting, 1.05 for each panelboard (a conservative value in case new equipment was added after the installation was ready or the supplier changed and the equipment had a slight increase in consumption), and 0.75 for each switchboard were used, leaving the utilisation factor equal to 1.

It is now possible to size the secondary substation and contact the energy grid provider that will be in charge of feeding the installation, a process that can take a reasonable time but can be executed in parallel with most of the other designing tasks. Depending on the load demand, one of the three types described in Section 3.1.1 is selected. In Portugal, the public distributor of electrical energy can say that they will not feed an installation of over 200 kVA in LV, so a secondary substation needs to be included in the project to feed the installation at MV. The electrical installation in this project is of type B, fed by the MV public distribution grid at 15 kV, and has a secondary substation inside its premises, with two 1250 kVA transformers. The MV switchboard consists of two entry cubicles, a circuit breaker protection cubicle, a metering cubicle, a gain cubicle, and two circuit breaker protection cubicles for the two transformers, with SF6[1] insulation. Note that the use of F gases is on its way to being banned by the European Commission by 2030 [45] as they have been proven to damage the environment.

Another thing that must be defined early in the project is the distribution networks needed, as defined in Section 3.1.1, which, in this project, were the NPS/EPS network — using the same distribution cables and feeding every equipment, as it is a hospital, but the power only being supplied by a group of 3 generators when a fault occurs in the Normal Power Supply —, and a UPS network. A disadvantage of switching to the EPS is that the generators take a few minutes to be ready to take the loads, which, in some cases, is not a problem, but, in others, such as data centres or hospitals, the continuity of power supply is crucial, so the third distribution network — UPS — assures this continuity. Uninterruptible Power Supply (UPS) groups have a shorter battery life than generators but have average startup times in the range of milliseconds, whereas it might take a few seconds for the generators to be ready to feed the loads of the electrical installation. For this hospital, a UPS group of 300 kVA was used, consisting of batteries with a 10-minute battery life, and it was designed to feed priority equipment such as server racks, emergency lighting and door retainers, among others.

[1] A gas used as insulation for avoiding the occurrence of electrical arcs.

MDB GENERAL	
	MDB01
	MDB02
	MDB03

	Sockets	Sockets (UPS)	Lighting Fixtures	Lighting Fixtures (UPS)
W/m2	30	9.9	30	5
FS	0.3	0.3	0.5	0.5

	BMS Switchboards
kVA	0.5

FS QS	FS QP
1.05	0.75

		NPS / EPS	AREA (m2)	SOCKETS (kW)	SOCKETS (kVA)	LIGHTING FIXTURES (kW)	LIGHTING FIXTURES (kVA)	EQUIPMENT (kW)	EQUIPMENT (kVA)	OTHER (kW)	OTHER (kVA)	WATER (kW)	WATER (kVA)	HVAC (kW)	HVAC (kVA)	GASES (kW)	GASES (kVA)	TOTAL QS (kVA)	TOTAL QS x FS QS (kVA)	TOTAL QP (kVA)	TOTAL QP x FS QP (kVA)
MDB GENERAL	MDB01	- MDB.01(N/E)	172	1.545	1.931	2.574	3.218		0.000	0.400	0.500	0.000		8.499	10.624	0.000		16.272	17.086		
		- TD.L00.C.OXIGENIO(N/E)		0.000	0.000	0.000	0.000		0.000	0.000		0.000		0.000		236.000	295.000	295.000	309.750		
		- TD.L00.MOR(N/E)	581	5.229	6.536	8.714	10.893	27.690	34.613	0.400	0.500	1.200	1.500	0.436	0.545	0.000		54.586	57.316		
		- TD.L00.HVAC.MOR(N/E)		0.000	0.000	0.000	0.000		0.000	0.000		0.000		17.317	21.646	0.000		21.646	22.729		
		- TD.L00.WASTE(N/E)	77	0.692	0.866	1.154	1.443	63.000	78.750	0.000		0.000		0.000		0.000		81.058	85.111		
		- TD.L00.WATER.PUMP(N/E)		0.000	0.000	0.000	0.000		0.000	0.000		11.000	13.750	0.000		0.000		13.750	14.438		
		- TD.L00.FIRE.PUMP(N/E)		0.000	0.000	0.000	0.000		0.000	0.000		45.000	56.250	0.000		0.000		56.250	59.063		
		- TD.L00.FIRE.JOCKEY.PUMP(N/E)		0.000	0.000	0.000	0.000		0.000	0.000		1.100	1.375	0.000		0.000		1.375	1.444		
		- TD.L00.WATER.RESERV(N/E)		0.000	0.000	0.000	0.000		0.000	0.000		11.000	13.750	0.000		0.000		13.750	14.438	728.945	546.709
		- TD.L00.SEPTIC(N/E)	20	0.181	0.227	0.302	0.378		0.000	0.400	0.500	67.255	84.069	0.000		0.000		85.173	89.432		
		- TD.L00.SPARE1(N/E)	84	0.757	0.946	1.262	1.577		2.500	0.000		1.200	1.500	4.036	5.046	0.000		11.569	12.147		
		- TD.L00.SPARE2(N/E)	84	0.757	0.946	1.262	1.577		2.500	0.000		1.200	1.500	4.036	5.046	0.000		11.569	12.147		
		- TD.L00.SPARE3(N/E)	84	0.757	0.946	1.262	1.577		2.500	0.000		1.200	1.500	4.036	5.046	0.000		11.569	12.147		
		- TD.L00.SPARE4(N/E)	84	0.757	0.946	1.262	1.577		2.500	0.000		1.200	1.500	4.036	5.046	0.000		11.569	12.147		
		- TD.L00.ENT.W(N/E)	9	0.085	0.106	0.141	0.176	0.000	0.000	0.000		0.000		1.166	1.458	0.000		1.740	1.827		
		- TD.L00.PUB.EXT(N/E)	146	1.317	1.646	2.195	2.744	0.100	0.125	0.000		0.000		0.368	0.460	0.000		4.975	5.224		
		- TD.L00.ENT.E(N/E)	9	0.085	0.106	0.141	0.176	0.000	1.500	0.000		0.000		0.480	0.600	0.000		2.382	2.501		

where: FS = diversity factor,
BMS = Building Management System,
QS = panelboard,
QP = switchboard,
$kVA = \frac{kW}{0.8}$.

Figure 4.1: Example of the load estimation for a panelboard, where inputs of equipment required by other specialties are included.

In terms of the earthing grid, a galvanised steel tape grid and a copper cable ring were buried below the main and the secondary buildings, which connected the earth electrodes consisting of three earthing rods plus a graphite electrode. The grid is represented in the drawing of Appendix E, with the electrical installation of this project following the TT earthing scheme, except for the operating rooms where the continuity of service was a priority, so the IT scheme was used in those spaces.

Then, regarding the atmospheric discharge protection system, it is mandatory to install as many lightning rods as necessary and at an effective height to capture all potential atmospheric discharges. In this project, three of those were foreseen, with a diameter of 10 mm, and another grid was designed on the roof of the building to conduct the potential atmospheric discharges captured by the lightning rod to the buried earthing grid previously mentioned.

After all this, one can start with the lighting calculations using one of the methods described in Section 3.1.5.

The emergency lighting positioning is defined by the Fire Protection specialty, and, in this project, the luminaires were then placed according to the indications given in their project.

Note that the normal lighting design is often made in collaboration with the architects as it has a significant impact on the interior design of the building. Also, it is necessary to design both the normal lighting and the emergency lighting scenarios, the latter being more demanding as it concerns people's safety in case of an emergency.

This task can be done in parallel with the definition of the energy distribution in the building. Here, the two main elements of focus are the spatial location of each equipment in its room, so that sockets and/or energy supply points can be distributed in the room accordingly, and the respective load demand. In this project, if the operating current (I_b) of a given equipment was below 16 A, the power supply was done by a socket, if equal or above 16 A it would have a direct connection to the LV distribution. Note that both spreadsheets and drawing software are needed in this phase, but they do not communicate with each other, so it is the designer's responsibility to make sure everything is coherent, which increases the chances of involuntary human mistakes, especially in projects of considerable size.

After defining the placement of the lighting, sockets, and other equipment, it is necessary to balance loads between the three phases, which is a trial-and-error process, usually done using the same Excel spreadsheet used for the preliminary estimation of load demand. Balancing loads is a way of reducing energy waste, by minimising Joule effect losses and voltage drop on the cables, therefore increasing the energy efficiency of the electrical installation.

Now that the peripheral components of the LV distribution have been sized, it is possible to estimate accurate dimensions for the partial LV distribution switchboards, for the emergency groups and for the UPS. In this project, it was necessary to dimension more than one UPS as it is recommended [46] to have an individual UPS for every surgery room. Also, in the case of buildings needing large servers, it is good practice to feed each server rack with two different UPS sources. The dimensions of the partial LV distribution panelboards depend on the protection devices needed, as seen in Appendix F. Usually, it is good practice to have a maximum of 8 sockets per circuit, and, in Portugal, it is common to separate lighting circuits from sockets and load feeding circuits, whereas, for example, in France, it is common to use web distribution, where they have a junction box over the room and from there feed all the lighting, sockets and specific loads with the same circuit. Another good practice is to group a few circuits with an RCD to increase selectivity, as, if there is a fault in one of them, just a part of the circuits of the panelboard is cut off.

All these calculations are taken into account when sizing cables and circuit protections, which is done by following the steps described by the diagram in Figure 3.8 of Section 3.1.4. To obtain an estimation of the cable lengths, all connections are drawn as lines in the floor plans, of which it is possible to sum the lengths, but they do not include the vertical sections, so it is reasonable to use a margin of error, in the form of a percentage of the initial value, in the final values delivered to the client.

One of the most used installation methods in large buildings, which requires itself another type of dimensioning, is using cable trays. These are usually the main source of clashes with other specialties and are commonly placed between the real and the false ceilings, when present. Different types of cable trays result in the use of different correction factors for the cable dimensioning, and there usually is a specific drawn deliverable dedicated to cable trays. It is important to take into account their occupation percentage and their weight to define the spacing between the supports. This is a very specific task which is usually done by the installer rather than the electrical designer himself. On the other hand, cable ducts are also a very common installation method, but they are usually given an estimated length and their placement is defined on-site.

Finally, in terms of the written deliverables, the Descriptive Memory (DM) is the text document that describes the technical design decisions and is accompanied by the Justifying Calculations (CL), which gathers the in-depth calculations that led to the power demand values, cable and protection sizing, and lighting analysis. The third written deliverable, the Bill of Quantities (BQ), presents a breakdown of all components needed to bring the electrical installation to life, usually including, for each item, the reference number, the description of the item, the quantity, the unitary price and the total price.

In the meantime, some project requirements might have changed, or project decisions might have had an impact on the overall electrical distribution network, so, before submitting the deliverables, it is important to revise the energy diagram drawn in the early stages of the project. Regarding all drawn deliverables, one must have a coherent title block with the project and drawing information across all of them, which is generally done with an AutoCAD block inserted in every drawing, but, in case there is a change in any of the information, it is necessary to change the drawings one by one.

To wrap up this chapter, it is important to keep in mind during the whole project design that every decision has an environmental cost associated, and the electrical engineer has the responsibility to opt for the option that minimises that impact whenever possible. Ways in which this is possible to implement are by foreseeing capacitor banks for power factor correction, larger cross-section cables mean less Joule effect losses, choosing electrical equipment with high efficiency, thorough load balancing across phases, and implementing a Building Management System (BMS) to monitor and control appliances more efficiently, enabling, for example, dynamic dimmable lighting controlled by luminous flux and/or presence sensors, and HVAC control according to room occupancy and outside weather.

4.2 BIM Methodology Project Development

This section presents how the electrical installation design might be enhanced using the BIM methodology, enhancements which are only achieved with previous training of the modellers and by defining the BEP document mentioned in Section 2.2.1 before the modelling begins.

Please recall Section 3.2.1 where a description of Revit® is presented, as many of the concepts presented and explained there are used in this section, namely categories, families, types, instances, spaces, schedules and file attachments.

Following the same chronological order as the usual project development, the first step of the project that is enhanced by using BIM software is the way in which project requirements are exchanged. Referring back to Section 2.2.1, it is now possible to produce IDS documents to communicate project requirements to all parts involved, and even validate if these requirements are respected by the BIM model. With this standard still being a novelty, it is not yet widespread across the industry, so, unfortunately, it was not explored in a practical way in this project.

The second one is the preliminary estimation of load demand. Revit® lets the user define electrical analytical loads, which means that they are not modelled in the project, they are just accounted for in the preliminary calculations, and this can be done both by defining a load demand per m^2 and/or by defining specific equipment loads that are already known to be necessary. The load demand per m^2 can be associated with a type of area and reused for as many areas as necessary, and, for each area, the apparent (in VA) or true (in W) power density, power factor, demand factor (which, in Revit®, is the diversity factor) and voltage are defined by the designer, which results in the automatic calculation of the current and the and the total apparent and true loads. Finally, it is possible to define the conceptual distribution system through which the analytical power sources feed the analytical loads. One can also add busbars, transformers, and transfer switches for incorporating emergency power sources into the analytical distribution system, as shown in Figure 4.2.

Afterwards, regarding the areas of influence of the secondary panelboards, in this project, a parameter was associated with every space, which referred to the panelboard that fed the loads in that space, and Revit® automatically calculated the total area of influence and generated a colour code for representing them in the deliverable floor plans. The advantage with respect to the usual project development is that, if the architectural model changes, the spaces are easily adjusted, and all calculations and colour coding are automatically kept up to date.

Now, regarding lighting calculations, lighting fixture families in Revit® have a user-defined photometric web, which can be chosen from the standard library or imported as a .ies file provided by most manufacturers. With the photometric web and the parameters defined in [47], some non-detailed preliminary calculations [48] were obtained, which were not a full lighting study, but were very useful for an initial estimation of the number and layout of the luminaires to be used in the project. Note that using some Autodesk® plugins it is possible to have photometric plans regarding natural and artificial lighting, but these were not further explored in this project.

For the extensive lighting study, and to make sure the lighting project followed the European [40, 41]

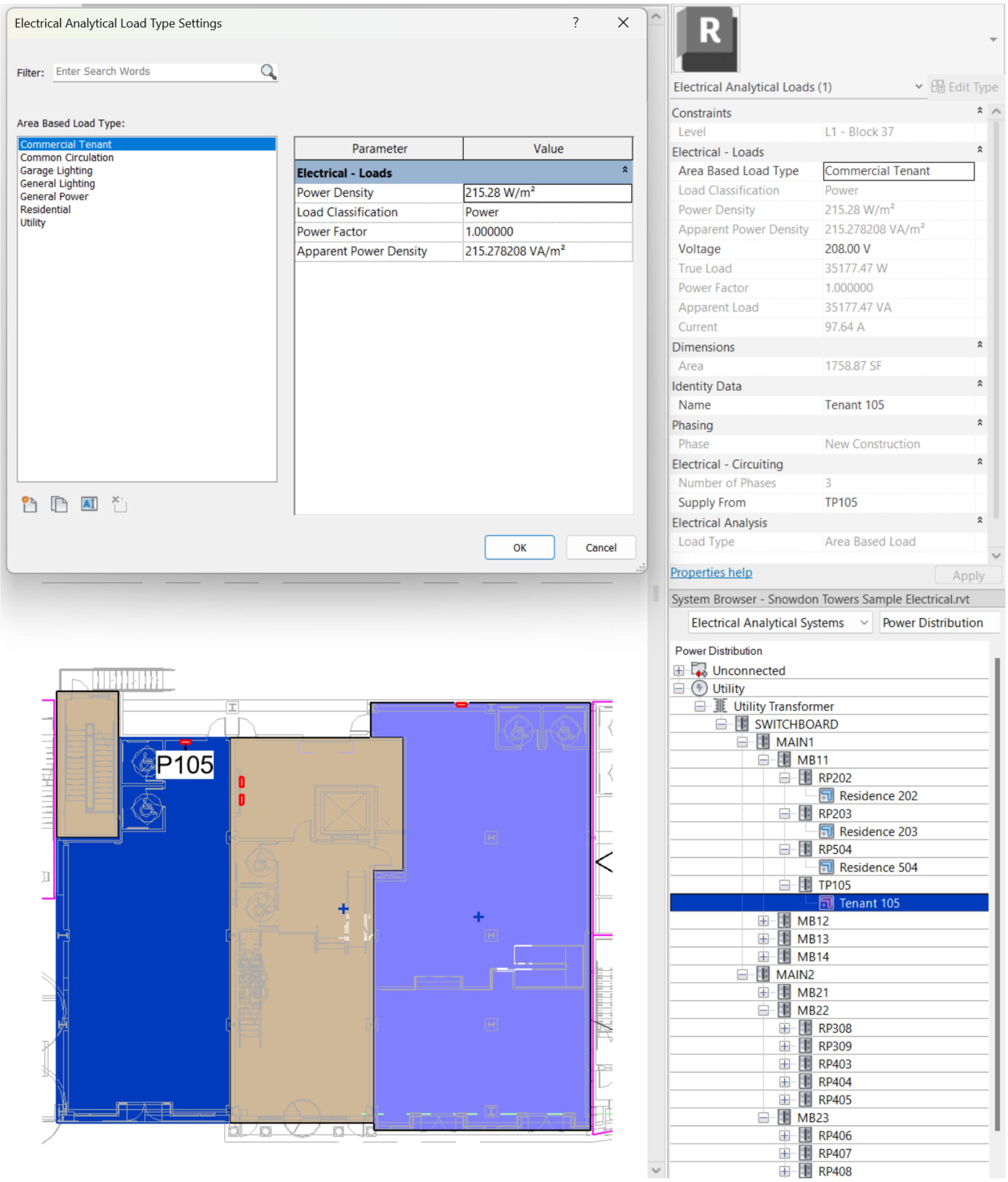


Figure 4.2: Example of an analytical distribution in Revit, where the floor has been divided into 4 areas, each with an associated type (upper left window), where their load characteristics are defined, and the system browser (lower right window) representing the analytical distribution system in a tree structure (not from the Hospital project as it was developed in an earlier version of Revit® which did not support this feature).

and national regulations, the previously mentioned DIALux software was used. It is possible to use the 3D model of the building exported as an IFC from Revit® or other modelling software as the input, or the electrical designer can use AutoCAD floor plans as in the usual project development, and then manually create the 3D model of the building inside DIALux. After choosing the number of luminaires in each room, their positioning, and their specific type from the available catalogues, respecting any constraints identified in the room classification regarding the external influences, such as minimum IP and/or IK, the software calculated many variables regarding the desired work planes, which allowed for making sure that the lighting design was compliant with all regulatory requirements mentioned in Section 3.1.5.

After the lighting study is done and all requirements are met, it is possible to export both the report on the study and an IFC of the luminaires, which can be imported back into the Revit® model, as mentioned in Section 3.2.3.

Regarding the electrical equipment and the power sockets, modelling in a BIM program took longer than a classical CAD drawing as the elements must be placed exactly where they will be installed, three dimensionally speaking, it is no longer just an indicative symbol in a floor plan. However, the extra time invested in this task was counterbalanced by the ease of circuit creation and quantity extraction. In fact, for every element that was powered by the electrical distribution network, the respective family in the model had an electrical connector, as seen in Figure 4.3, which enabled the creation of the electrical circuit and all the electrical calculations (these were independent of the analytical model previously mentioned).

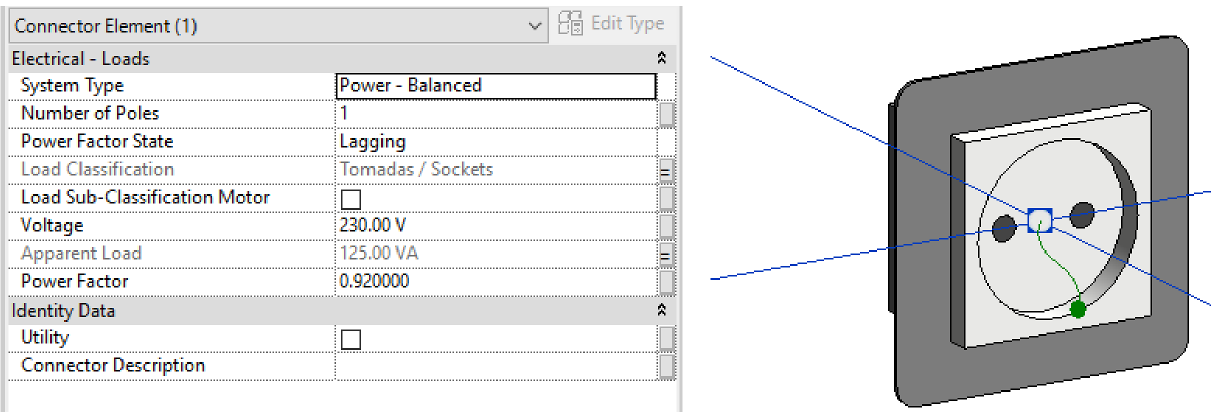


Figure 4.3: Example of an electrical connector (in blue) and respective parameters (table on the left) of a socket family in Revit®.

Before the creation of circuits, cable tray positioning and sizing was another task that was very positively influenced by the adoption of the BIM methodology and tools. Again, these were modelled in 3D, which meant one had to mind the height at which the cable tray was passing in that particular segment, but Revit® helps the modeller by automatically connecting different height segments with a vertical cable tray segment as they are drawn, and it also places cable tray fittings for curves and junctions with other segments (Figure 4.4). If needed, cable ducts are also modellable, but, in this project, it was not a requirement given the size of the hospital.

With most peripheral components of the LV distribution and the cable trays modelled, it was then possible to take advantage of the electrical connectors previously mentioned and create the electrical circuits in the model. Figure 4.5 shows an example of an automatically generated panel schedule, with circuits it fed. All the information in all the columns, apart from the wire type, was automatically generated just by assigning components to the circuit, which consisted of clicking on each component intended to

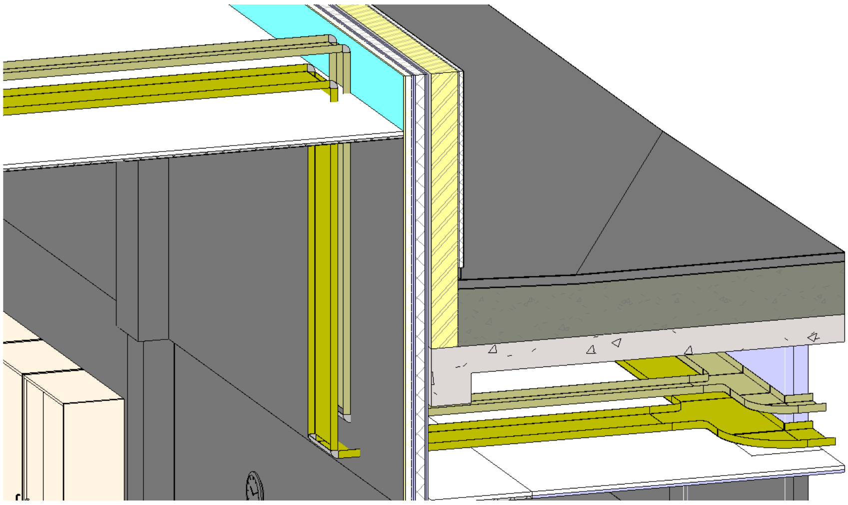


Figure 4.4: Example of cable tray segments at different heights, in yellow.

be in the same circuit, clicking a "Power" button, and choosing which panelboard should the circuit be connected to.

Switchboard | Quadro Elétrico : TD.L00.GEW1-NPS/EPS

Location / Localização:	Ground Floor	Distribution Syst. / Sist. de Distribuição:	3-phase
Supplied From / Alimentado por:	LV.MDB02-NPS/EPS	Phases / Fases:	3
Mounting / Montagem:		Wires / Condutores:	4
Enclosure / Proteção do Armário:		Max. Number of Circuits / Número Máx. de Circuitos:	45

Notes | Notas:

Circuit / Circuito	Description / Descrição	True Load / Pot. (W)	Power Factor / Fator Pot.	Apparent Load / Pot. Aparente (VA)	Ib (A)	Circuit Breaker / Disj. (A)	Voltage / Tensão(V)	A	B	C	Wire Type / Condutor|Cabo	Est. Length / Comp. Est. (m)
I1	Iluminação Normal / Normal Lighting - Room CDA 020, GEW1 003, CHA 077, GEW1 001	400	1	400	1,7	10	230	400 VA			XZ1 (frt,zh) 3G1,5	63,675
I2	Iluminação Normal / Normal Lighting - Room GEW1 046, GEW1 011, GEW1 043, GEW1 051	214	1	214	0,9	10	230	214 VA			XZ1 (frt,zh) 3G1,5	22,727
I3	Iluminação Normal / Normal Lighting - Room GEW1 052, GEW1 040, GEW1 041, GEW1 050	214	1	214	0,9	10	230	214 VA			XZ1 (frt,zh) 3G1,5	42,327
I4	Iluminação Normal / Normal Lighting - Room CDA 020, CHA 077, GEW1 001	340	1	340	1,5	10	230	340 VA			XZ1 (frt,zh) 3G1,5	19,483
I5	Iluminação Normal / Normal Lighting - Room GEW1 049, GEW1 042	107	1	107	0,5	10	230	107 VA			XZ1 (frt,zh) 3G1,5	57,226
I6	Iluminação Normal / Normal Lighting - Room GEW1 048, GEW1 013, GEW1 009, GEW1 054	214	1	214	0,9	10	230	214 VA			XZ1 (frt,zh) 3G1,5	24,935
I7	Iluminação Normal / Normal Lighting - Room GEW1 056, GEW1 005, GEW1 057, GEW1 008, GEW1 053, GEW1 006	156	1	156	0,7	10	230	156 VA			XZ1 (frt,zh) 3G1,5	53,272
I8	Iluminação Normal / Normal Lighting - Room GEW1 026, GEW1 035, GEW1 029, GEW1 031, GEW1 037, GEW1 036	436	1	436	1,9	10	230	436 VA			XZ1 (frt,zh) 3G1,5	51,819
I9	Iluminação Normal / Normal Lighting - Room GEW1 044, GEW1 034, GEW1 039, GEW1 038, GEW1 030, GEW1 ...	251	1	251	1,1	10	230	251 VA			XZ1 (frt,zh) 3G1,5	67,936
T1	Tomadas / Sockets - Room GEW1 046, GEW1 011, GEW1 043, GEW1 051	460	0,92	500	2,2	16	230	500 VA			XZ1 (frt,zh) 3G2,5	24,134
T2	Tomadas / Sockets - Room GEW1 052, GEW1 040, GEW1 041, GEW1 050	460	0,92	500	2,2	16	230	500 VA			XZ1 (frt,zh) 3G2,5	43,734
T3	Tomadas / Sockets - Room GEW1 049	230	0,92	250	1,1	16	230	250 VA			XZ1 (frt,zh) 3G2,5	57,474
T4	Tomadas / Sockets - Room GEW1 048, GEW1 013, GEW1 009, GEW1 054	460	0,92	500	2,2	16	230	500 VA			XZ1 (frt,zh) 3G2,5	26,339
T5	Tomadas / Sockets - Room GEW1 056, GEW1 006, GEW1 053, GEW1 057	690	0,92	750	3,3	16	230	750 VA			XZ1 (frt,zh) 3G2,5	57,070

Figure 4.5: Example of a panel schedule, where every value in every column is automatically generated, except for the Circuit Breaker and the Wire Type. Note that all loads were connected to phase A by default, this figure was generated before load balancing.

Then, for the circuits to be a reliable representation of the future electrical installation, it was essential to edit the circuit path, a task that was automatically done using Caneco BIM as it recognised cable trays and conduits and routed the circuit path through them. This way, cable lengths were as close as possible to their on-site value, just by doing a few clicks, with no manual measuring as it used to be done in the usual project workflow.

Having the circuits defined, it was time to size the cables and protections, after which the partial and main switchboards in terms of physical dimensions. Despite Revit® including its calculation methods for loads [49], currents [50] and wire sizing [51], using Caneco BIM enabled the creation of busbars (which are only available in Revit® when creating conceptual distribution systems) and busbar trunking. Then, by exporting the model to a Caneco BT readable file, one had access to much more complete calculations for the electrical installation, namely: load balancing; cable sizing; protection devices sizing; selectivity analysis, as seen in Figure 4.6; and generation of energy diagrams. These used scenario simulations for the cases where only the emergency or the UPS networks were used and sized everything according to the most unfavourable case. In terms of energy efficiency, Caneco BT provided a visual tool to analyse the return on investment of choosing larger cross-section cables, reducing Joule effect losses, as seen in Figure 4.7.

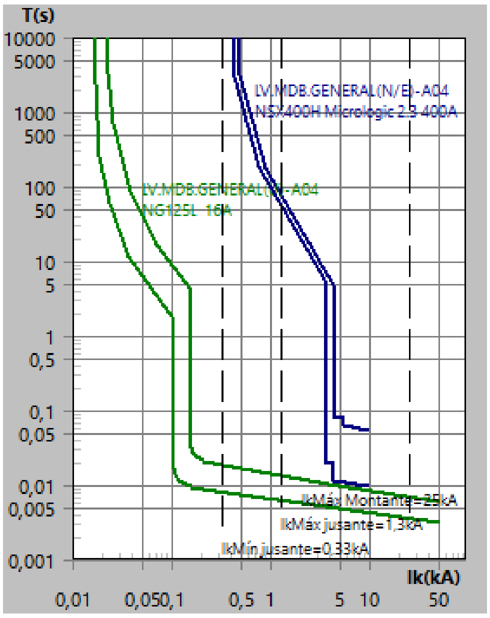


Figure 4.6: Example of the output from Caneco BT of the selectivity analysis for a circuit, where the upstream protection curves are represented in blue and the downstream protection curves are represented in green.

Importing the Caneco BT model back into Revit®, now that it had sized the cables' cross sections, in terms of cable trays, Caneco BIM knew which cables passed through which cable tray segments, so the plugin was able to suggest dimensions and generated cable tray profile images with occupation percentage calculation taking into account the definable spare room, which can be a useful element for justifying cable tray sizing to the client (Figure 4.8).

Then, as mentioned in Section 2.2.1, clash detection is being revolutionised by using BIM modelling programs, both due to it being possible to detect clashes in 3D, and because it can be done at any stage of the project, with the most recent models of all specialties, and without the need for information exchange through emails with PDF drawings that might become outdated the moment they are sent. In

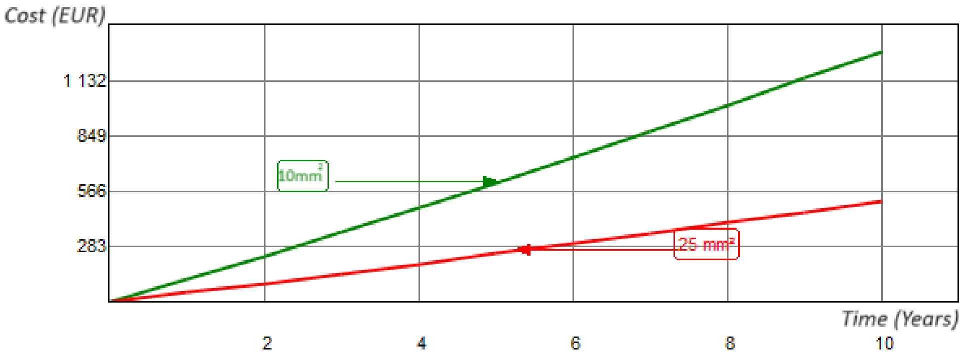


Figure 4.7: Example of a comparison between the Joule effect losses, translated to Euros, of the cable with the lowest cross-section that satisfies all conditions of cable sizing for a given circuit (10 mm^2), in green, and the Joule effect losses, translated to Euros, of a cable with a larger cross-section (25 mm^2), in red, over the course of 10 years of use.

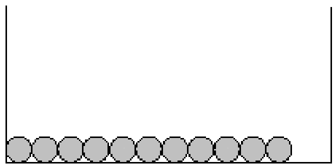
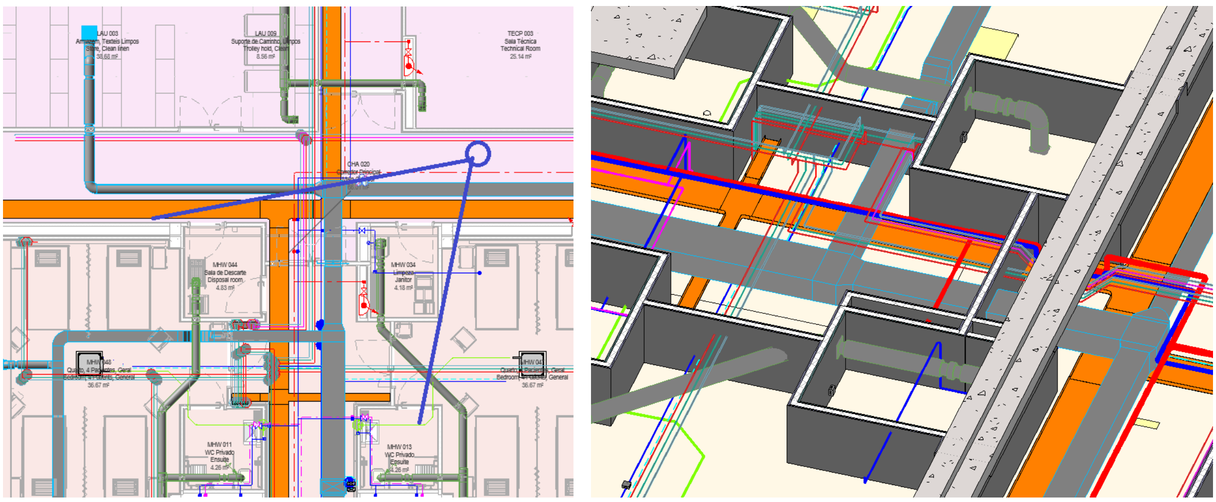


Figure 4.8: Example of a cable tray profile, where the grey circles represent the cross-section of the cables that go through that particular segment.

this project, the BIMcollab software was used for clash detection and coordination, which made use of the BCF standard. Figure 4.9 shows how difficult it would be to check for clashes in a particular area of the hospital and how 3D sections helped understand the heights of each element of every specialty better.



(a) Floor Plan (point of view of the 3D Section represented in blue).

(b) 3D Section.

Figure 4.9: Example of a specialty equipment dense area, showing how useful it is to have a 3D view to detect and avoid clashes when modelling cable trays (in orange).

Regarding the written deliverables, the most significant improvement is to the BQ, which can be generated as a schedule and exported as an Excel spreadsheet for delivery if necessary, though it requires a comprehensive development of a dedicated template. An example is sh. This way, every item reference number, every item description, every item quantity, every item unitary price and every item total price are always up to date and managed directly in the model, using project parameters, which used to be something to be very careful about in the usual project development as this is one of the most important documents of the project.

In terms of revising drawings before submissions, although it is always advisable to do it, and taking the example of the energy diagram, if it is exported from an electrical calculation software like Caneco BT, most of the changes that occurred over the development of the project will already be reflected in the diagram as the electrical calculations were dependent on the existing model, so the time spent revising these deliverables was greatly reduced by adopting the BIM methodology. Also, floor plans are simply different views of the same 3D model, so it was a matter of applying the right filters to the right floor plan, in some cases only the sockets and the architecture should appear, in others only the exterior lighting and the surrounding landscape should be visible, etc., which also meant that these drawings were automatically updated as the model changed. Note that, contrary to the traditional way of presenting floor plans of the electrical installation design specialty, the lines that represent wires are progressively disappearing, as this information can be communicated through the circuit tags each fixture has, and confirmed with the panel schedules, reducing drawing time and making the floor plans cleaner. An example of this is shown in a sockets floor plan in Appendix G.

To conclude, even after the deliverables' submission, all parts involved were expected to use the collaboration platforms provided by the modelling software developers to make comments, point out issues, and communicate in general using the most up-to-date IFC of the model as a basis for visual and parametric reference, so that everyone could access the latest information as smoothly as possible.

Chapter 5

Conclusions

In Section 1.2, the objective of this Thesis was defined as a comparison between the usual workflow of designing an electrical installation (Section 4.1) and the one following the BIM methodology (Section 4.2), so, in this chapter, the key takeaways from that comparison are presented, some of which related to the BIM workflow in general, and others specific to its application to the specialty of electrical installation design.

These takeaways may contribute to electrical design companies considering the adoption of the BIM workflow in their projects, as well as to raising awareness of the topic discussed, especially in the Electrical Engineering academic environment.

Then, a brief reflection on the possible direction of future in-depth work on this topic is presented in Section 5.2.

5.1 Key Takeaways

5.1.1 Drawbacks of the BIM Methodology

Regarding the BIM workflow, the extra time invested in internal meetings was very noticeable. Every process of every specialty must be, at least, acknowledged by the BIM coordinator of the project, ideally, coordinated between all specialties, since, in large projects, the model is usually split and linked by each of them, and that creates inter-disciplinary dependencies. An example of this in the hospital project was the creation of rooms in the architectural model, which determined the creation of spaces in the electrical model.

Another drawback identified was the unrealistic expectations it brings to the client. Understandably, from their perspective, as every specialty has the model from every other specialty linked in theirs, meaning they can see model updates in quasi-real time, it is possible to define a unique deadline for submitting the deliverables from every specialty. However, the chronological order of having the architectural main layout concluded before the MEP designers start modelling is crucial for avoiding unnecessary rework. Sure, an improvement in using BIM software to model the building expedites the accommodation of project changes, but these should nevertheless be considered as exceptions, otherwise this new workflow results in less efficiency. A suggestion for a future feature of BIM modelling software would be to have a page where each specialty could colour code the areas of the building according to their state of development, using a parameter in the room/space instances.

The last (and most important) drawback identified in the BIM workflow implementation is that it gives rise to carelessly trusting the software. No program is 100% bulletproof, so, even though there are many automated functionalities and everything is synced, modellers and designers must double-check every deliverable as if it was done by hand, as before: sometimes a simple unchecked box in Revit® results in a blank floor plan.

Now, regarding the drawbacks specific to electrical installation design, as mentioned in Section 4.2, modelling in 3D takes longer than drawing symbols on floor plans, empirically and approximately three times longer.

Also, some programs only support calculations of electrical quantities for certain countries, due to the diversity in normative tables' values, for instance, for allowed current in cables, and in cable sizing definitions (e.g., Revit® only supports cable sizing according to the American Wire Gauge (AWG) cable sizing nomenclature), so a feature to be developed in the future could be either investing in the inclusion of international, European, and, eventually, national norm tables, as some programs already do, or allowing the user to define these values manually.

Finally, the previously mentioned careless trust in the software may lead to more serious project mistakes when the electrical calculations and sizing are not properly checked, in a worst case scenario it might lead to incorrect specification of protection devices and consequent risk of fire and/or electrical shock, putting to the occupants of the building in danger. Also, the continuous reliance on automatic calculations with no critical sense of the results obtained might lead, especially for those with less experience in electrical design, to developing a dependency on these calculation programs, forgetting the fundamentals mentioned in Section 3.1. Keep in mind that responsible use of BIM tools prevents the outcomes described in this paragraph.

5.1.2 Advantages of the BIM Methodology

Many improvements have been outlined throughout this document. In terms of BIM in general, it is worth mentioning again the revolutionary impact that 3D views and sections have on understanding the building itself, and on identifying and correcting clashes between specialties.

It also streamlines the collaboration process thanks to open standards, such as IFC, for model sharing, IDS, for requirement definition and transmission, and BCF, for issue communication and management, and thanks to dedicated collaboration platforms.

On the other hand, electrical engineers can benefit from software that provides certified and automatic calculations of all relevant quantities and installation characteristics, namely cable cross-section sizing, protection device sizing, and selectivity analysis. Note that these programs also update the values in the tables used in calculations according to the most up-to-date versions of the various norms, a common concern for electrical engineers who rely on spreadsheets for their calculations.

Furthermore, the nature of the automatic calculations is to choose the least expensive option that respects the regulations, which guarantees the final solution is as cost-effective as possible. Two examples of this were the cable tray size readjustments according to the cables passing through each segment, and the long-term return on investment analysis of choosing larger cable cross-sections to minimise the Joule effect losses.

Lastly, the quantity extraction capabilities of BIM modelling software greatly increase the accuracy of this process and contribute to avoiding incoherence between different deliverables (drawings, diagrams and BOQs).

All these improvements increase the client's trust that the project is as flawless and as cost-effective as possible.

5.1.3 Reasons for BIM Adoption Delay

Regarding BIM in general, two main reasons for BIM adoption delay were identified: the combination of lack of willingness to undergo proper training on the software, resulting in improper or incomplete usage of the tools available, plus some occasional bugs and/or data losses, might result in disbelief in the whole BIM methodology by the users; the second reason is a mismatch between the investment the company needs to make to implement this methodology — software licenses, personnel training and design time increase —, and the willingness of clients to raise the amount of capital allocated to the project development.

From the point of view of electrical installation design, on a slightly subjective note, the majority of people in the electrical installation design industry tend to be reluctant to adapt to new workflows, especially if they involve technological updates, arguably due to their nature of not wanting to take the risk of changing things or processes that are tried and tested, and known to work, for something they do not fully understand.

From a more objective perspective, unfortunately, in the electrical installation design marketplace, companies tend to compete in terms of price, instead of quality, as the clients rarely give importance to project quality and often choose between proposals exclusively based on its price. Nevertheless, there is a paradigm shift underway in Portugal as the government has recently passed a ruling [52] that establishes the obligation of every project to be delivered following the BIM methodology by 2030. Being one of the specialties lagging the most, this ruling instigates imminent further research and development of this Thesis' subject.

5.2 Future Work

Firstly, further studies may be done on how to incorporate the IDS standard in BIM workflows as it was not used in a practical way in this project. Also, the same type of work that was developed can be done for the other systems that the electrical installation designer is usually in charge of, namely the telecommunications and the Building Management Systems (BMS).

Secondly, with the emergence of renewable energy sources, it would be interesting to see how far the BIM programs are able to take the performance prediction of different project solutions in terms of solar energy, as they already perform natural lighting studies for architectural purposes considering accurate data of the sun path, depending on the buildings' geographic location.

Finally, an effort will have to be made to adapt to this type of workflow as companies will have to respect the previously mentioned 2030 goal, and the buildingSMART International is currently conducting studies on a new open standard, the so-called Normalised Electrical Model (NEM) [53], so, exploring its applications is a must for future research and investment in the field of electrical installation design using BIM software.

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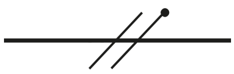
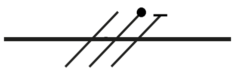
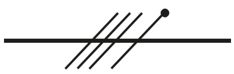
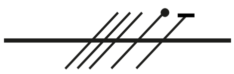
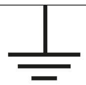
Appendix A

Symbology

Table A.1: Symbols used in this document's diagrams.

Symbol	Description
	1 wire — phase conductor.
	2 wires, single phase — phase and neutral conductors.
	3 wires, single phase — phase, neutral and ground conductors.
	4 wires, three phase — three phase conductors and one neutral conductor.
	5 wires, three phase — three phase conductors, one neutral conductor and one earth conductor.
	Point of connection of the electrical installation to the ground.
	Winding.

Appendix B

Cable Types

A table of cable nomenclature from the Portuguese Electrical Normalisation Technical Commission [54], in Portuguese.

ANEXO C - SÍMBOLOS UTILIZADOS NAS DESIGNAÇÕES DE CONDUTORES E CABOS, ISOLADOS, PARA INSTALAÇÕES ELÉTRICAS, SEGUNDO A NP 665:2012

EXEMPLO [(1)] ⇒												
		V				V		(frt)	5	G	6	0,6/1 kV

		SÍMBOLO
Material dos condutores	• Cobre	Sem letra
	• Alumínio multifilar	L
	• Alumínio maciço	LS
Grau de flexibilidade	• Condutores rígidos (classe 1 ou 2)	Sem letra
	• Condutores flexíveis (classe 5)	F
	• Condutores extra-flexíveis (classe 6)	FF
Material do isolamento	• Borracha de etileno propileno	B
	• Etileno acetato de vinilo	G
	• Papel isolante	P
	• Policloreto de vinilo - PVC	V
	• Polietileno - PE	E
	• Polietileno reticulado - XLPE	X
	• Composto reticulado à base de poliolefina, com baixa emissão de gases corrosivos e baixa emissão de fumos na combustão de cabos onde foi aplicada	Z
	• Composto termoplástico à base de poliolefina, com baixa emissão de gases corrosivos e baixa emissão de fumos na combustão de cabos onde foi aplicada	Z1
	• Composto reticulado à base de silicone	S
Blindagem	• Blindagem individual	HI
	• Blindagem coletiva	H
Condutor concêntrico	• Fios de cobre	O
	• Fios de aluminio	1O
Revestimentos metálicos para proteção mecânica	***Magnéticos:***	
	• Fitas de aço	A
	• Fitas de aço corrugado	2A
	• Fios de aço	R
	• Barrinhas de aço	M
	• Trança de aço galvanizado	1Q
	Não magnéticos:	
	• Fitas	1A
	• Fios	1R
	• Barrinhas	1M
	• Fitas corrugadas	3A
	• Trança de cobre	Q
Material das bainhas	***Não metálico:***	
	• Borracha de etileno propileno	B
	• Etileno acetato de vinilo	G
	• Papel	P
	• Policloreto de vinilo - PVC	V
	• Policloreto de vinilo com resistência a hidrocarbonetos - PVC	Vh
	• Polietileno - PE	E
	• Polietileno reticulado - XLPE	X
	• Juta	J
	• Composto reticulado à base de poliolefina, com baixa emissão de gases corrosivos e baixa emissão de fumos na combustão de cabos onde foi aplicada	Z
	• Composto termoplástico à base de poliolefina, com baixa emissão de gases corrosivos e baixa emissão de fumos na combustão de cabos onde foi aplicada	Z1
	• Composto reticulado à base de silicone	S
	Metálico:	
	• Fita de alumínio revestida com copolímero	L
	• Bainha coletiva em chumbo	C
Forma de agrupamento dos condutores isolados	• Cableados ou torcidos	Sem letra
	• Dispostos paralelamente (sem torção)	D
	• Cabos auto-suportados	S
Comportamento ao fogo e/ou proteção à propagação longitudinal da água	• Retardante à chama	(flr)
	• Retardante ao fogo	(frt)
	• Resistente ao fogo	(frs) [(3)]
	• Baixa opacidade dos fumos libertados	(ls)
	• Baixa corrosividade dos fumos libertados	(la)
	• Baixa toxicidade dos fumos libertados	(lt)
	• Isento de halogéneos	(zh) [(4)]
	• Condutor estanque	(ce)
	• Blindagem estanque	(be)
	• Condutor e blindagem estanque	(cbe)
Composição [(2)(5)]	• Número de condutores	(número)
	• Ausência de condutor verde/amarelo	x
	• Existência de condutor verde/amarelo	G
	• Secção do condutor (mm^2)	(número)
Tensão estipulada		Uo/U kV [(5)]

(1) - Cabo com condutores de cobre isolados a PVC, com bainha exterior de PVC, retardante do fogo, com 5 condutores de 6 mm^2, sendo 3 de fase, 1 de neutro e 1 de proteção, para a tensão estipulada de 0,6/1 kV: VV(frt) 5G6 0,6/1kV.
(2) - Deve ser indicada a secção do condutor envolvente a seguir à secção dos condutores do cabo separada por uma "/".
(3) - Um cabo (frs) é habitualmente também (frt), podendo-se por isso omitir a sigla (frt)
(4) - Os condutores e os cabos (zh) são, por natureza, também (la), (ls) e (lt).
(5) - Quando as secções dos condutores neutro e de proteção forem diferentes das secções dos condutores de fase, a composição deve caracterizar essa alteração. Por exemplo, para um cabo com condutores de fase a 35 mm^2 e condutores neutro e proteção a 16 mm^2, a composição deve ser representada por 3x35+2G16.
(6) - Uo - Tensão entre fase e terra ou entre fase e blindagem e U - Tensão entre fases.

Nota: *Esta tabela substitui a tabela do ANEXO IIB da parte 5 das RTIEBT:2006, dada a alteração entretanto verificada na NP 665.*

Appendix C

Bathroom Volumes

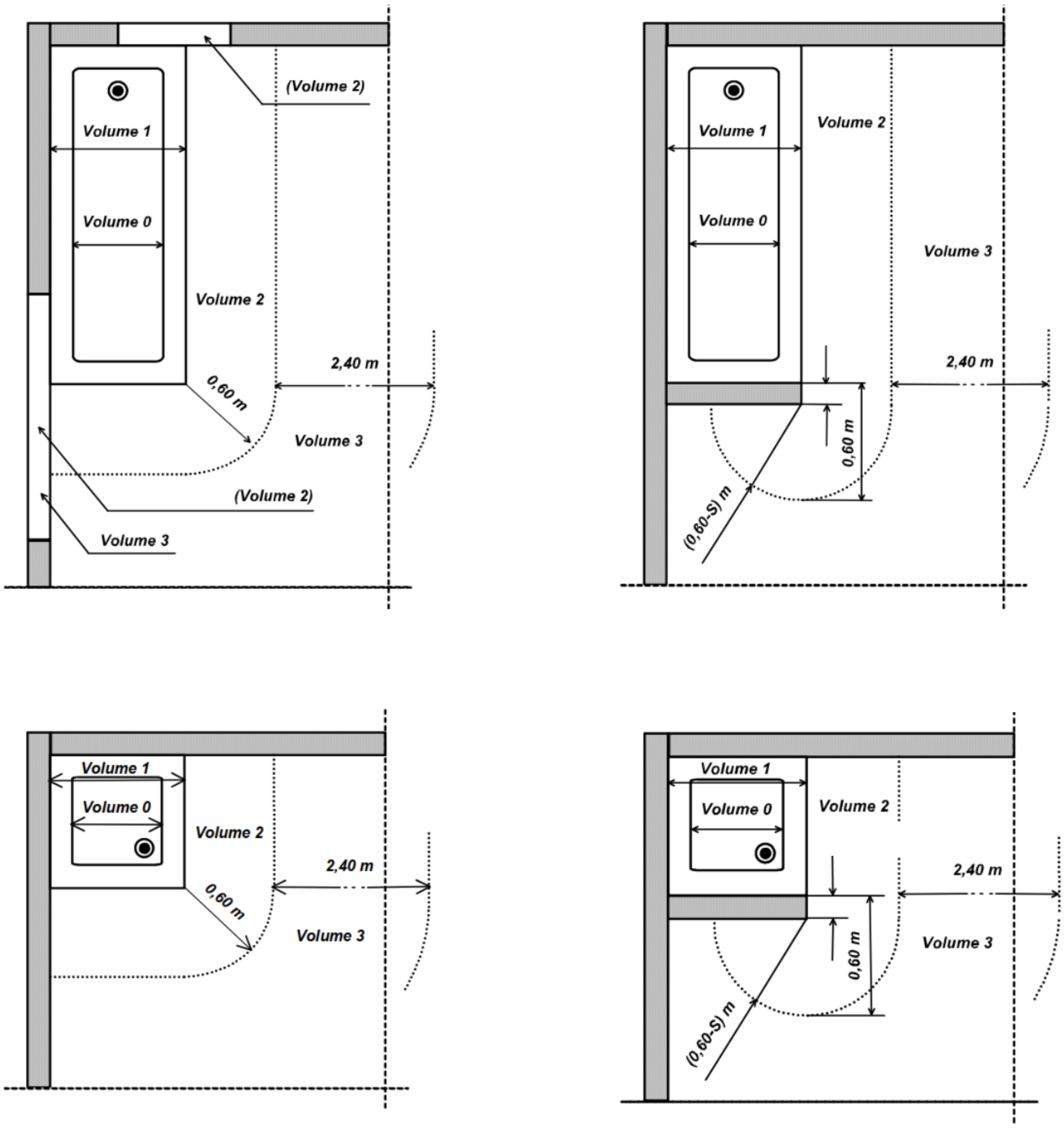


Figure C.1: Examples of how volumes are determined in bathrooms (adapted from [13]) (1).

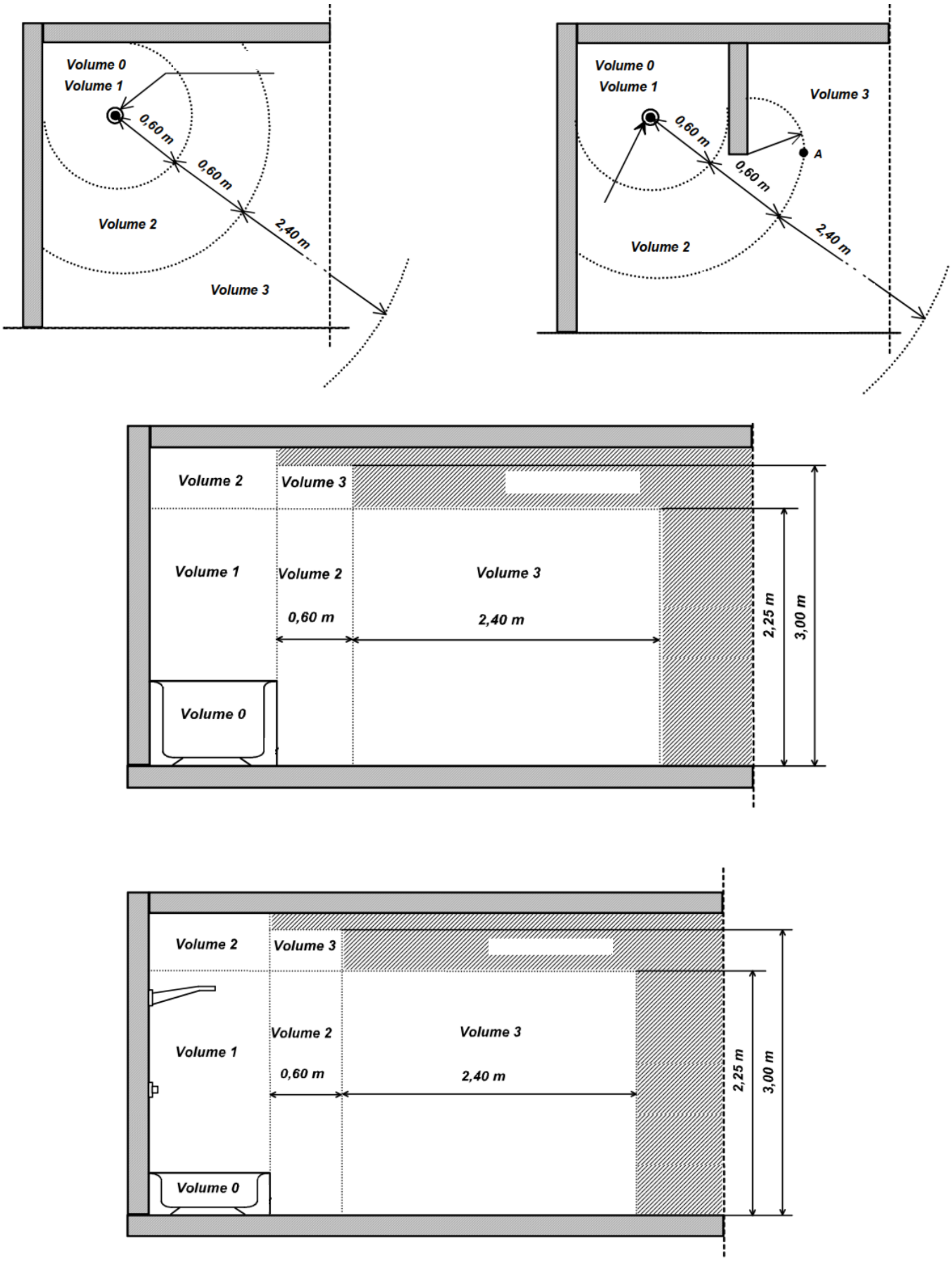


Figure C.2: Examples of how volumes are determined in bathrooms (adapted from [13]) (2).

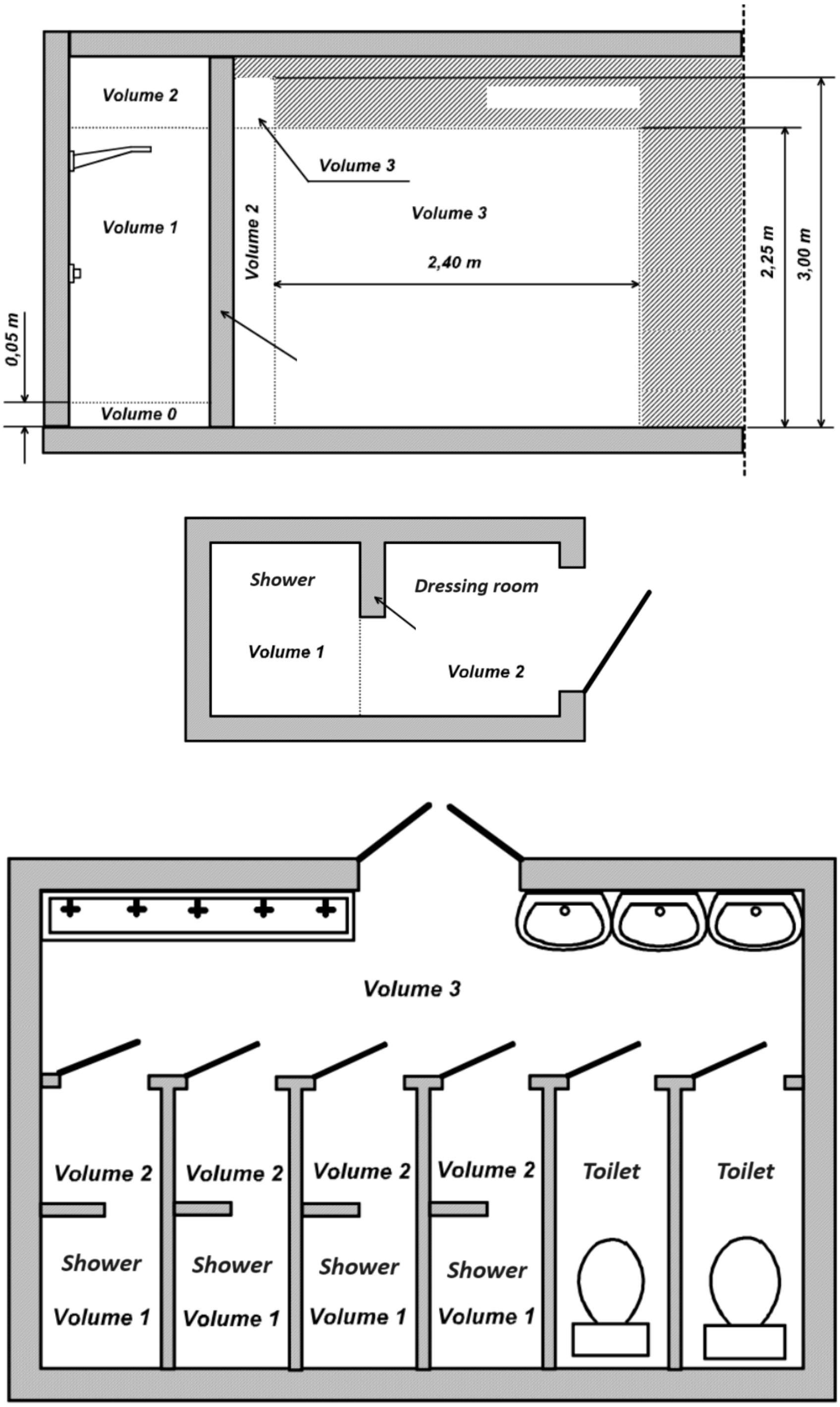


Figure C.3: Examples of how volumes are determined in bathrooms (adapted from [13]) (3).

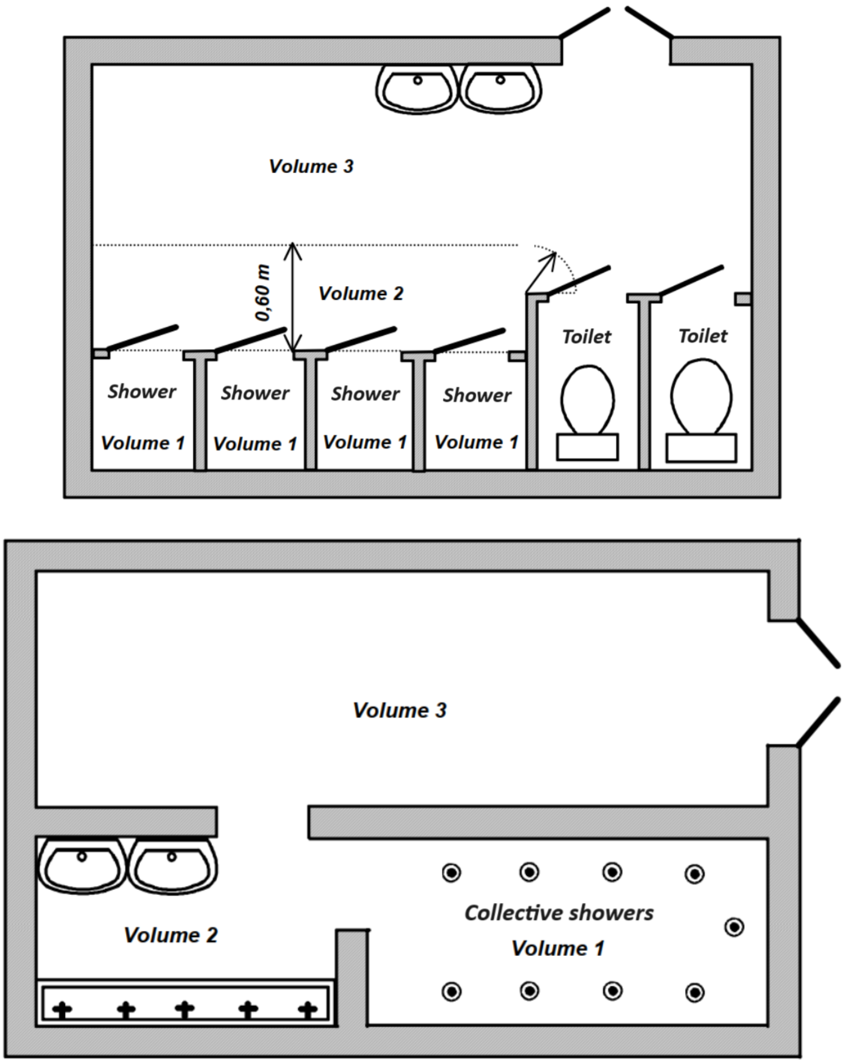
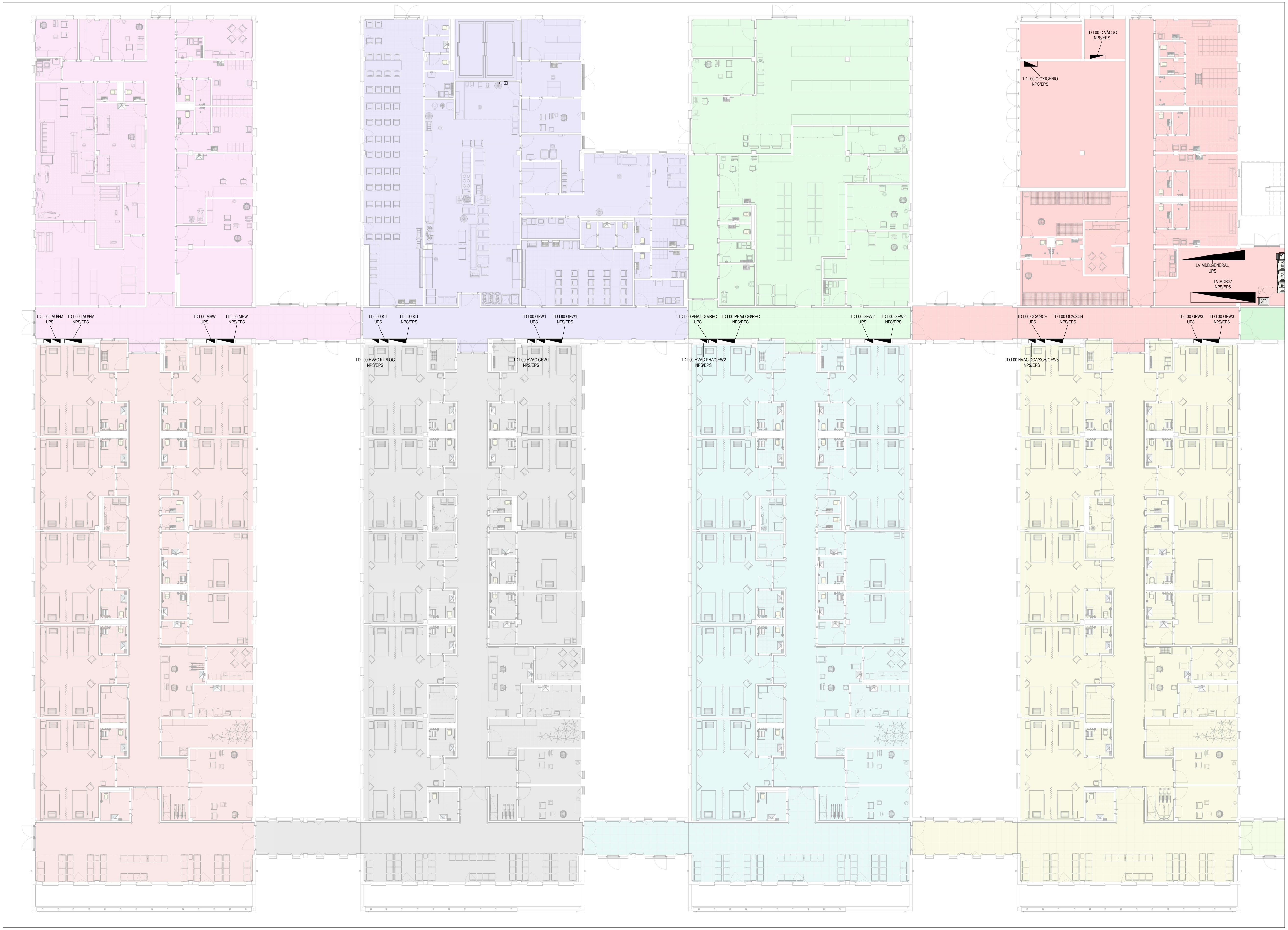


Figure C.4: Examples of how volumes are determined in bathrooms (adapted from [13]) (4).

Appendix D

Areas of Influence Floor Plan

A floor plan from the hospital project that exemplifies the use of colouring rooms according to the panelboard that feeds the electrical equipment in those rooms.

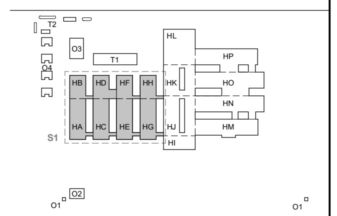


LEGENDA / LEGEND

SIMBOLOGIA - DISTRIBUIÇÃO DE ENERGIA / SYMBOLOGY - ENERGY DISTRIBUTION	
	Quadro elétrico / Switchboard or Panelboard.
UPS	UPS Geral / Main UPS.
UPS	Armário Bypass UPS / UPS Bypass Cabinet.
CFP	Bateria de Correção do Fator de Potência / Baterry Correction Power Factor.
C	Botoneira de Corte Geral de Energia dos Aparelhos de Cozinha / General Electricity Cut-Off Push Button for Kitchen Appliances

ÁREAS DE INFLUÊNCIA / AREAS OF INFLUENCE

- TD.L00.LAU/FM NPS/EPS/UPS
- TD.L00.MHW NPS/EPS/UPS
- TD.L00.KIT NPS/EPS/UPS
- TD.L00.GEW1 NPS/EPS/UPS
- TD.L00.PHA/LOG/REC NPS/EPS/UPS
- TD.L00.GEW2 NPS/EPS/UPS
- TD.L00.OCA/SCH NPS/EPS/UPS
- TD.L00.GEW3 NPS/EPS/UPS
- LV.MDB01 NPS/EPS
- LV.MDB02 NPS/EPS
- LV.MDB03 NPS/EPS
- TD.L00.ADM NPS/EPS/UPS
- TD.L00.CSS NPS/EPS/UPS
- TD.L00.CTE NPS/EPS/UPS
- TD.L00.DCW/ENDO NPS/EPS/UPS
- TD.L00.DIA NPS/EPS/UPS
- TD.L00.EME NPS/EPS/UPS
- TD.L00.ENT.HP NPS/EPS/UPS
- TD.L00.ENT.WorE NPS/EPS
- TD.L00.ICU NPS/EPS/UPS
- TD.L00.IMG NPS/EPS/UPS
- TD.L00.LAB NPS/EPS/UPS
- TD.L00.MOR NPS/EPS/UPS
- TD.L00.MPW NPS/EPS/UPS
- TD.L00.NICU NPS/EPS/UPS
- TD.L00.OBS NPS/EPS/UPS
- TD.L00.OP1 UPS
- TD.L00.OP2 UPS
- TD.L00.OP3 UPS
- TD.L00.OP4 UPS
- TD.L00.OP5 UPS
- TD.L00.OP6 UPS
- TD.L00.OP7 UPS
- TD.L00.OPD NPS/EPS/UPS
- TD.L00.PUB.EXT NPS/EPS
- TD.L00.PUB.INT NPS/EPS
- TD.L00.REH NPS/EPS/UPS
- TD.L00.SPARE1to4 NPS/EPS
- TD.L00.SPARE4 NPS/EPS
- TD.L00.SUR NPS/EPS/UPS
- TD.L00.WASTE NPS/EPS
- TD.L01.HVAC.ADM/CTE/DCW/OPD 2 NPS/EPS
- TD.L01.HVAC.CSS/SUR NPS/EPS
- TD.L01.HVAC.OBS/NICU/ICU/IMG/OPD1 NPS/EPS



REV.	DESCRIÇÃO / DESCRIPTION	DESENHOU / DRAWN BY	VERIFICOU / VERIFIED BY	DATA / DATE

PROJETISTA / *DESIGN TEAM*:

TPF - CONSULTORES DE ENGENHARIA E ARQUITETURA

CLIENTE / *CLIENT*:

PROJETO / *PROJECT*:

FASE / *PHASE*:

ESPECIALIDADE / *TRADE*:
Electricidade / Electrical System

TÍTULO DO DESENHO / *DRAWING TITLE*:

Quadros Elétricos - Áreas de Influência - Planta do Rés-do-Chão - S1 /
Switchboards - Areas of influence - Ground Floor Plan - s1

PROJETOU / *DESIGNED BY*:

DESENHOU / *DRAWN BY*:

ESCALAS / *SCALE*:
1 : 100

VERIFICOU / *CHECKED BY*:

APROVOU / *APPROVED BY*:

DATA / *DATE*:

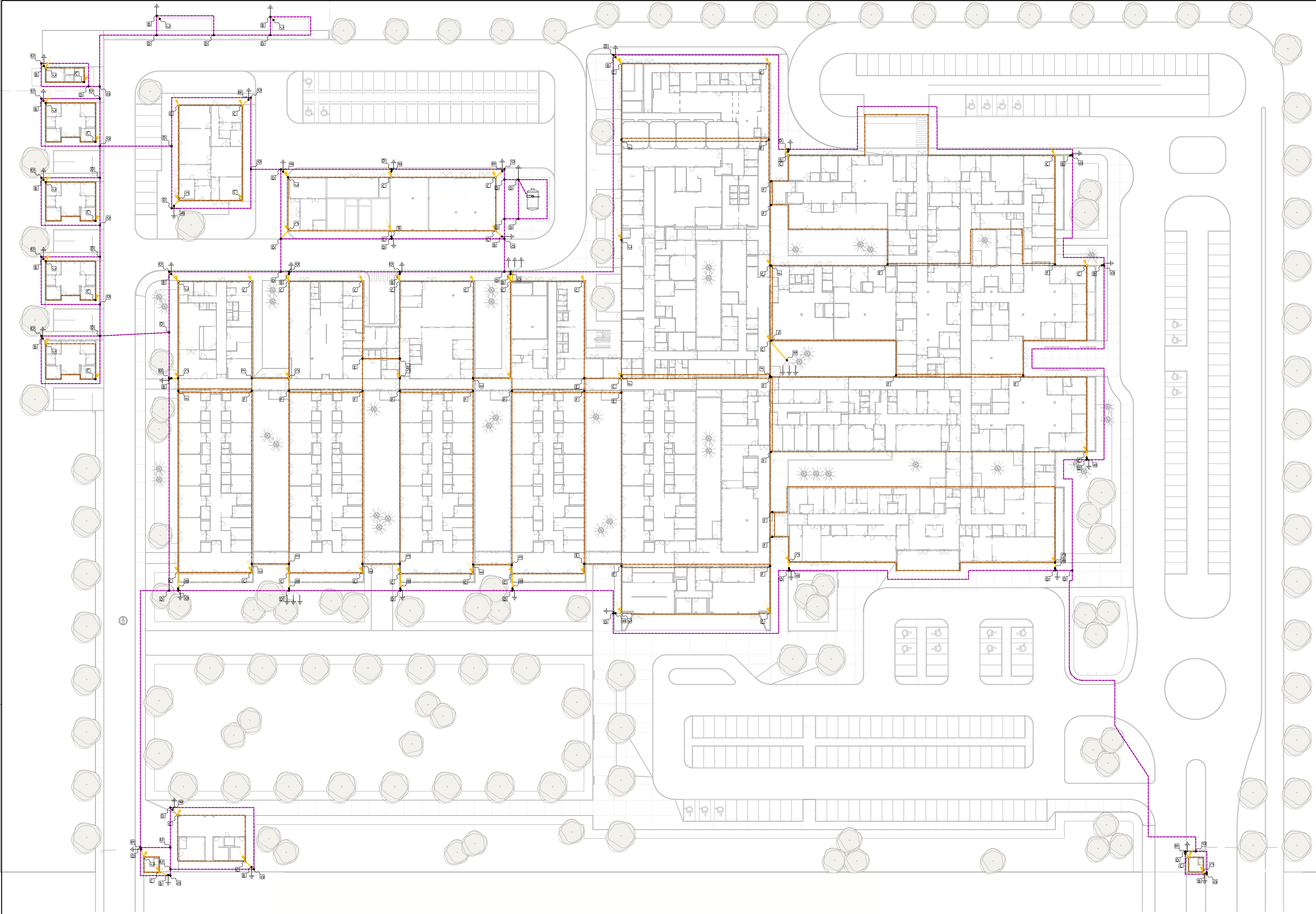
CÓDIGO DE PROJETO *PROJECT CODE*	FASE *PHASE*	ESPECIALIDADE *TRADE*	TIPO DE DOC. *TYPE OF DOC.*	TÓPICO/TEMA *TOPIC/THEMATIC*	NÍVEL *LEVEL*	SECTOR *SECTOR*	NÚMERO *NUMBER*	REVISÃO *REVISÃO*

FICHEIRO / *FILE*:

Appendix E

Earthing Grid Floor Plans

Two floor plans from the hospital project that represent the buried earthing grid and the one installed on the roof of each building.



Rede de Terras e Pára-Raios - Planta Geral /
Earthing Network and Lightning Protection - General Site Plan
Esc. 1 : 300

LEGENDA / LEGEND

SIMBOLOGIA / SYMBOLOGY

- Varão de aço galvanizado Ø10mm, instalado à vista nas coberturas, fixado por abraçadeiras /Ø10mm galvanized steel rod, installed in the building roof, fixed by clamps.
- Fita de aço galvanizada 30x3mm enterrada, instalada na viga de fundação / Burried galvanizedsteal tape 30x3mm, installed in the foundation beam.
- Cabo cobre 70mm2 instalado em vala envolto em composto / 70mm2 copper cable installed inditch wrapped in composite.
- Ligação ao ferro da estrutura do edifício em varão de aço galvanizado Ø10mm / Connection tothe structure iron with a Ø10mm galvanized steel rod.
- Para-raios ionizante, instalado em mastro / Ionizing lightning rod, mast mounted.
- A Ligação Varão - Varão /Rod - Rod connection.
- B Ligação Cu - Varão / Connection Cu - Rod.
- C Ligação Fita - Varão / Tape - Rod connection.
- D Ligação Cu - Cu / Cu - Cu connection.
- E Ligação Fita - Fita / Tape - Tape connection.
- F União entre lajes de fundação em fita de aço galvanizada enterrada, envolvida em betão pobre/ Joint between foundation slabs in buried galvanised steel strip, wrapped in lean concrete.
- Elétrodo de terra em caixa de medição de terras em alvenaria / Earth electrode in masonryearth measuring box.
- Elétrodo de terra tipo pata de ave, em caixa de medição de terras em alvenaria / Bird-pawearth electrode, in masonry earth measuring box.
- Varão de Aço galvanizado Ø10mm (descida pelo interior do pilar) / Ø10mm galvanized steelrod (descending through the pillar interior).A ligação do varão ao ferro da estrutura deverá ser feita no mínimo de 2 em 2 metros / The rodmust be connected to the iron of the structure at least 2 in 2 metres.

REV.	DESCRIÇÃO / DESCRIPTION	DESENHOU /DRAWN BY	VERIFICOU /VERIFIED BY	DATA /DATE

PROJETISTA / *DESIGN TEAM*:

TPF - CONSULTORES DE ENGENHARIA E ARQUITETURA

CLIENTE / *CLIENT*:

PROJETO / *PROJECT*:

FASE / *PHASE*:

ESPECIALIDADE / *TRADE*: Electricidade / Electrical System

TÍTULO DO DESENHO / *DRAWING TITLE*:

Rede de Terras e Pára-Raios - Planta Geral - Planta de Fundações / Earthing Network and Lightning Protection - General Site Plan - Foundations Plan

PROJETOU / *DESIGNED BY*:

DESENHOU / *DRAWN BY*:

ESCALAS / *SCALE*: As indicated

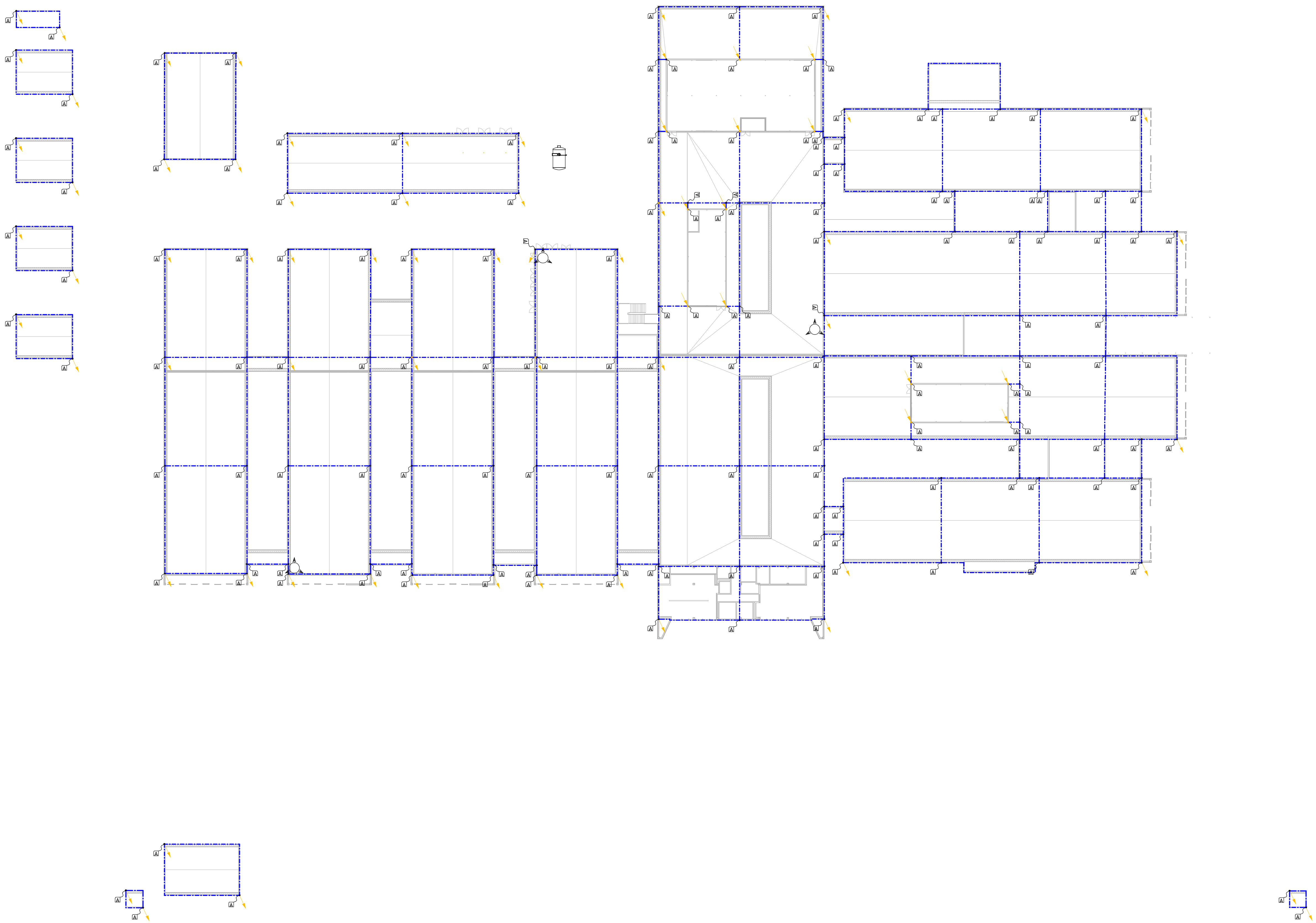
VERIFICOU / *CHECKED BY*:

APROVOU / *APPROVED BY*:

DATA / *DATE*:

CÓDIGO DE PROJETO *PROJECT CODE*	FASE *PHASE*	ESPECIALIDADE *TRADE*	TIPO DE DOC. *TYPE OF DOC.*	TÓPICO/TEMA *TOPIC/THEMATIC*	NÍVEL *LEVEL*	SECTOR *SECTOR*	NÚMERO *NUMBER*	REVISÃO *REVISÃO*

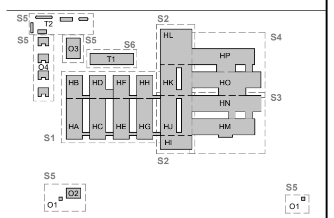
FICHEIRO / *FILE*:



LEGENDA / LEGEND

SIMBOLOGIA / SYMBOLOGY

- Varão de aço galvanizado Ø10mm, instalado à vista nas coberturas, fixado por abraçadeiras / Ø10mm galvanized steel rod, installed in the building roof, fixed by clamps.
- Fita de aço galvanizada 30x3mm enterrada, instalada na viga de fundação / Burried galvanized steal tape 30x3mm, installed in the foundation beam.
- Cabo cobre 70mm2 instalado em vala envolto em composto / 70mm2 copper cable installed in ditch wrapped in composite.
- Ligação ao ferro da estrutura do edifício em varão de aço galvanizado Ø10mm / Connection to the structure iron with a Ø10mm galvanized steel rod.
- Para-raios ionizante, instalado em mastro / Ionizing lightning rod, mast mounted.
- A — Ligação Varão - Varão /Rod - Rod connection.
- B — Ligação Cu - Varão / Connection Cu - Rod.
- C — Ligação Fita - Varão / Tape - Rod connection.
- D — Ligação Cu - Cu / Cu - Cu connection.
- E — Ligação Fita - Fita / Tape - Tape connection.
- F — União entre lajes de fundação em fita de aço galvanizada enterrada, envolvida em betão pobre / Joint between foundation slabs in buried galvanised steel strip, wrapped in lean concrete.
- Elétrodo de terra em caixa de medição de terras em alvenaria / Earth electrode in masonry earth measuring box.
- Elétrodo de terra tipo pata de ave, em caixa de medição de terras em alvenaria / Bird-paw earth electrode, in masonry earth measuring box.
- Varão de Aço galvanizado Ø10mm (descida pelo interior do pilar) / Ø10mm galvanized steel rod (descending through the pillar interior).
  A ligação do varão ao ferro da estrutura deverá ser feita no mínimo de 2 em 2 metros / The rod must be connected to the iron of the structure at least 2 in 2 metres.



REV.	DESCRIÇÃO / DESCRIPTION	DESENHOU / DRAWN BY	VERIFICOU / VERIFIED BY	DATA / DATE

PROJETISTA / *DESIGN TEAM*:

TPF - CONSULTORES DE ENGENHARIA E ARQUITETURA

CLIENTE / *CLIENT*:

PROJETO / *PROJECT*:

FASE / *PHASE*: Projeto de Execução / Detail Design

ESPECIALIDADE / *TRADE*: Electricidade / Electrical System

TÍTULO DO DESENHO / *DRAWING TITLE*:

Rede de Terras e Pára-Raios - Planta da Cobertura / Earthing Network and Lightning Protection - Roof Plan

PROJETOU / *DESIGNED BY*:

DESENHOU / *DRAWN BY*:

ESCALAS / *SCALE*: As indicated

VERIFICOU / *CHECKED BY*:

APROVOU / *APPROVED BY*:

DATA / *DATE*:

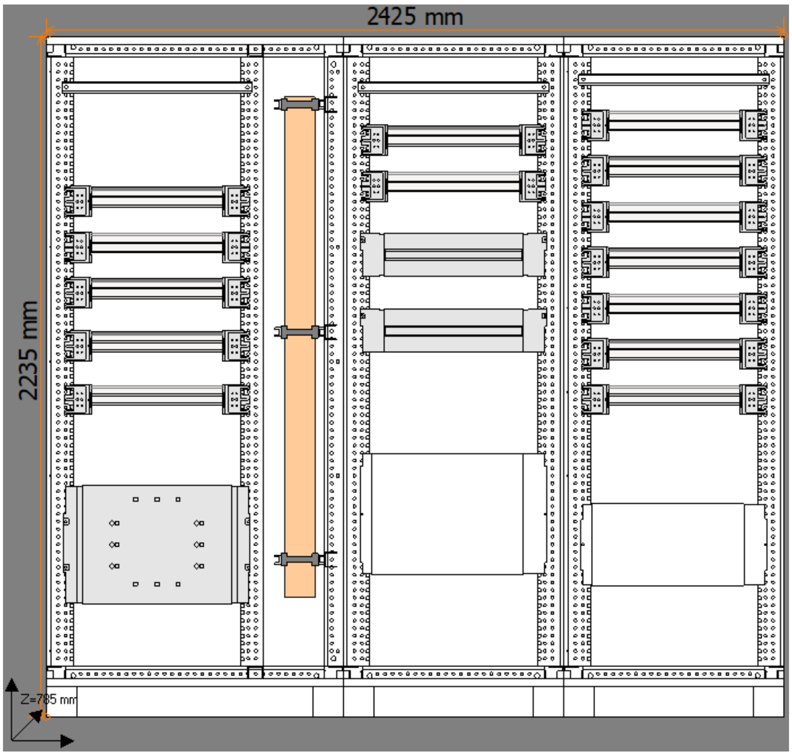
CÓDIGO DE PROJETO / PROJECT CODE	FASE / PHASE	ESPECIALIDADE / TRADE	TIPO DE DOC. / TYPE OF DOC.	TÓPICO/TEMA / TOPIC/THEMATIC	NÍVEL / LEVEL	SECTOR / SECTOR	NÚMERO / NUMBER	REVISÃO / REVISÃO

FICHEIRO / *FILE*:

Appendix F

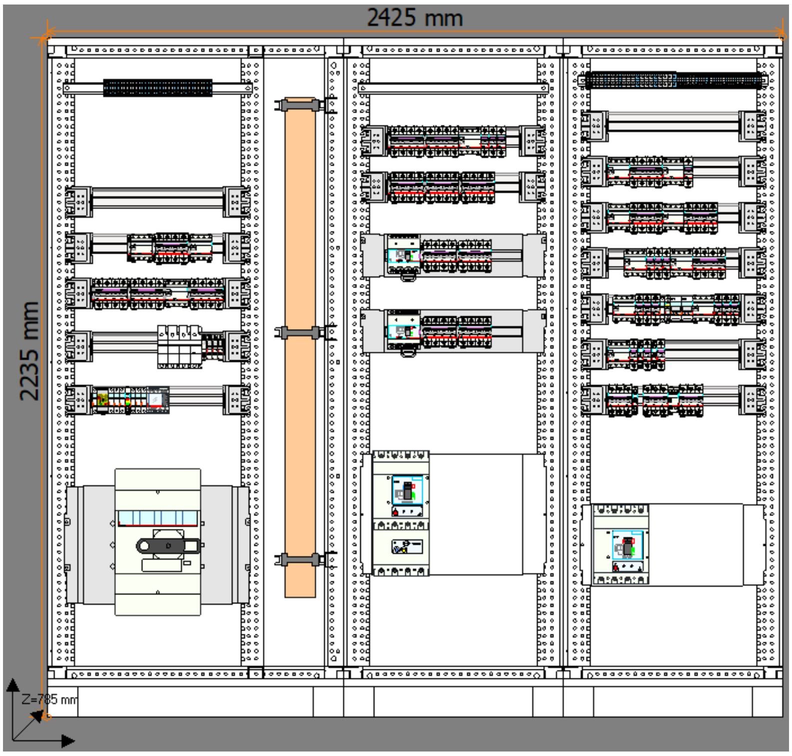
Panelboard

Schematic views of a panelboard across its design phases:

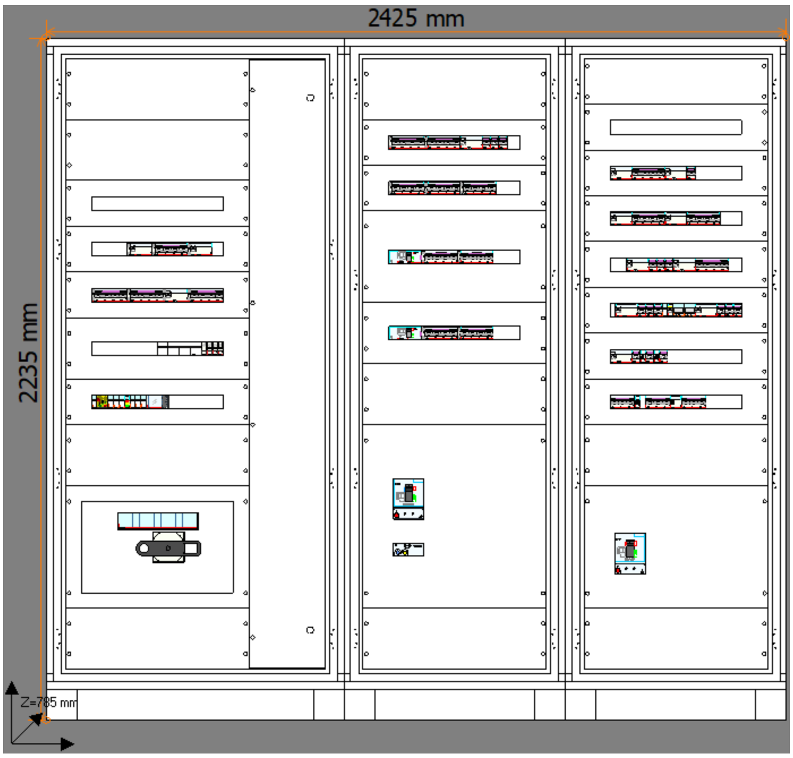


(a) Chassis.

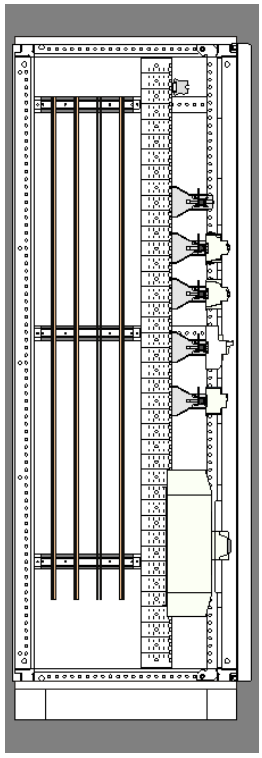
Figure F.1: View of the chassis (a) layer inside a panelboard.



(a) Devices.



(b) Devices with panels.



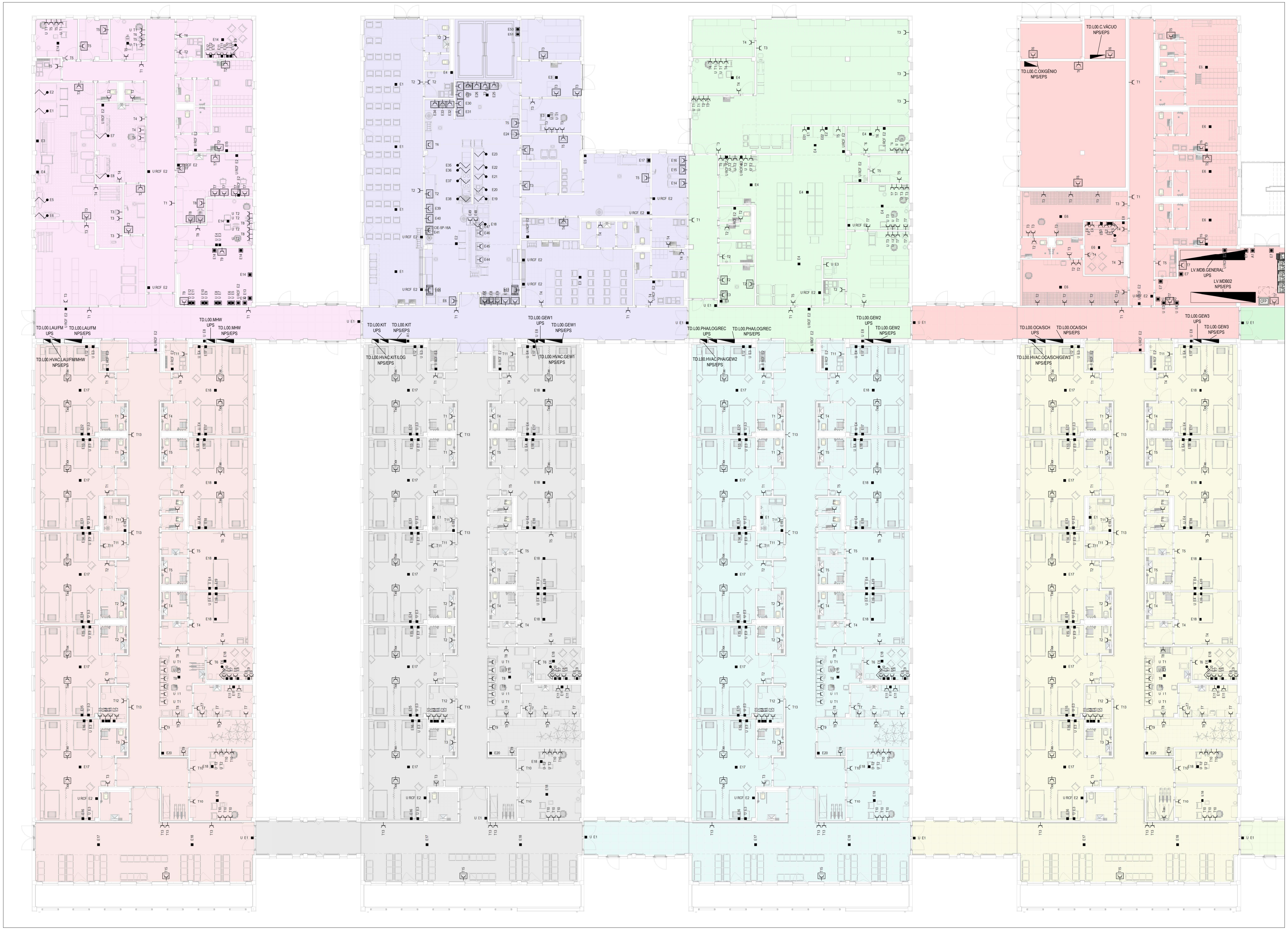
(c) Side view.

Figure F.2: View of the devices (a) and the devices with panels (b) layers inside a panelboard, as well as a side view (c).

Appendix G

Sockets Floor Plan

A floor plan from the hospital project that indicates where each socket is to be installed.



Blocos HA a HH / Blocks HA to HH

Esc. 1 : 100

LEGENDA / LEGEND

SIMBOLOGIA - TOMADAS E ALIM. EQUIP. / SYMBOLOGY - SOCKETS AND EQUIP. POWER SUPPLY		
REDE		
N/E	UPS	
Cxxx	U Cxxx	Tomada Schuko, embebida / Schuko socket, recessed. Altura de montagem: 0,30m / Mounting height: 0,30m. Ver nota 2 / See note 2
Cxxx	U Cxxx	Tomada Schuko, em calha / Schuko socket, in trunking. Altura de montagem: A confirmar com a altura de montagem da calha de rodapé / Mounting height: To be confirmed with the mounting height of the cable trunking. Ver nota 1 / See note 1
Cxxx	U Cxxx	Tomada Schuko, embebida, com tampa / Schuko socket, recessed, with cover. Altura de montagem: 0,30m / Mounting height: 0,30m. Ver nota 2 / See note 2
Cxxx	U Cxxx	Tomada Schuko, embebida, com tampa, estanque. / Schuko socket, recessed, with cover, watertight. Altura de montagem: 0,30m / Mounting height: 0,30m. Ver nota 2 / See note 2
Cxxx		Tomada Schuko, em calha, com tampa. / Schuko socket, in trunking, with cover. Altura de montagem: A confirmar com a altura de montagem da calha de rodapé / Mounting height: To be confirmed with the mounting height of the cable trunking. Ver nota 1 / See note 1
Cxxx	U Cxxx	Tomada Schuko, saliente, com tampa / Schuko socket, wall mounted, with cover. Altura de montagem: 0,30m / Mounting height: 0,30m. Ver nota 1 / See note 1
Cxxx	U Cxxx	Tomada Schuko, saliente, com tampa, estanque / Schuko socket, wall mounted, with cover, watertight. Altura de Montagem: 0,30m / Mounting height. 0,30m. Ver nota 1 / See note 1
CIE-5P-16A Cxxx		Tomada CIE trifásica 5 polos (3P+N+T), 16A, IP44, montagem saliente estanque / Three-phase CIE socket 5 poles (3P+N+T), 16A, IP44, surface mounted, watertight. Altura de Montagem: 0,30m / Mounting height. 0,30m. Ver nota 1 / See note 1
Cxxx		Caixa de derivação. / Junction box.
Cxxx		Caixa de derivação, estanque. / Junction box, watertight.
Cxxx		Caixa de derivação, saliente, estanque. / Junction box, surface mounted, watertight.
Cxxx		Ponta de cabo / Cable end.
Cxxx		Identificação do Circuito, nnn - número / Circuit Identification, nnn - number.

NOTAS / NOTES:

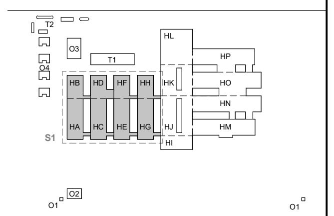
1 - Todas as cotas de montagem indicadas deverão ser confirmadas em obra com a fiscalização. / All mounting heights indicated must be confirmed on site with the work supervision.

2 - As tomadas de energia destinadas à alimentação de TV estão à cota de montagem de 2,10m. / The power sockets for TV power are at the mounting height of 2,10m.

3 - Onde estiverem 8+ símbolos de tomadas na mesma parede, estes poderão não estar colocados de acordo com a posição real das tomadas. Por favor consultar o modelo e/ou os pormenores das salas tipo. / When there are 8+ socket symbols on the same wall, these might not be placed according to the sockets' real position. Please refer to the model and/or sample rooms details.

4 - Os elementos embebidos nas paredes exteriores (tomadas de energia e calhas médicas) deverão ter os roços para os tubos executados assim que possível. Por norma os roços são executados na vertical a partir do teto falso, no entanto poderá ser na horizontal onde a proximidade de uma parede acessível o justifique. / For exterior wall embedded elements (power sockets, BHU) execute the cable conduits and pipes chases in the earliest possible phase. Normally the chases are vertical from false ceiling, but can be horizontal when close to an accessible gypsum wall.

5 - As secretárias/bancadas isoladas de paredes serão equipadas com calhas técnicas. As tomadas de energia serão embutidas nas calhas. O caminho de cabos para a calha será embutido na laje de enchimento. / A cable trunking will be added under the desk. The power sockets are embedded into the trunking. The cables are connected to the trunking through the cable conduit embedded in the floor screed from the closest accessible wall.



REV.	DESCRIÇÃO / DESCRIPTION	DESENHOU / DRAWN BY	VERIFICOU / VERIFIED BY	DATA / DATE

PROJETISTA / *DESIGN TEAM*:

TPF - CONSULTORES DE ENGENHARIA E ARQUITETURA

CLIENTE / *CLIENT*:

PROJETO / *PROJECT*:

FASE / *PHASE*:

ESPECIALIDADE / *TRADE*: Electricidade / Electrical System

TÍTULO DO DESENHO / *DRAWING TITLE*:

Tomadas de Energia e Alimentação de Equipamentos - Planta do Rés-do-Chão - S1 / Power Sockets and Equipment Suplies - Ground Floor Plan - S1

PROJETOU / *DESIGNED BY*:

DESENHOU / *DRAWN BY*:

ESCALAS / *SCALE*: 1 : 100

VERIFICOU / *CHECKED BY*:

APROVOU / *APPROVED BY*:

DATA / *DATE*:

CÓDIGO DE PROJETO *PROJECT CODE*	FASE *PHASE*	ESPECIALIDADE *TRADE*	TIPO DE DOC. *TYPE OF DOC.*	TÓPICO/TEMA *TOPIC/THEMATIC*	NÍVEL *LEVEL*	SECTOR *SECTOR*	NÚMERO *NUMBER*	REVISÃO *REVISÃO*

FICHEIRO / *FILE*: