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DIPLOMA THESIS

**Building Information Modeling in the Design
of Electrical Services for Building**

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Název diplomové práce anglicky: Building Information Modeling in the Design of Electrical Services for Buildings

Pokyny pro vypracování:

- Vysvětlení pojmů problematiky BIM a definice cílů
- Porovnání aktuálního stavu výstupů Revitu pro potřeby návrhu elektroinstalací a požadavků z hlediska českých norem a zvyklostí
- Úprava standardních šablon a nastavení prvků elektro dle českých standardů
- Aplikace jednotlivých změn v projektování

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- Eastman, Ch. et al.: BIM Handbook, John Wiley Sons, Inc., New Jersey, 2011. ISBN 978-0-470-54137-1.
- Reddy, K.P.: BIM for Building Owners and Developers, John Wiley Sons, Inc., New Jersey. 2012. ISBN 978-0470-90598-9,
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Declaration

I hereby declare that this thesis is my original work and I have completed it on my own with the contribution of my supervisors and consultants. I have specified all the sources of information which have been used in the thesis.

Prague/...../.....

Bc. Jiří Šindelář.....



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Abstrakt:

Autor rozebírá problematiku informačního modelování v oboru elektroinstalací. Cílem práce je poskytnout návrhy na správné a efektivnější vytváření modelu elektroinstalací. Hlavním tématem je tvorba rodin, jejich správné nastavení, nastavení projektu a následné vykazování. Pokud toto nastavení bude provedeno precizně umožní to uživatelům Revitu využívat další funkce a odbornější práci s daty. Pro zefektivnění práce je součástí také návrh několika skriptů v programu Dynamo a jejich vysvětlení.

Abstract:

The author deals with building information modeling in the design of electrical services for building. The goal of the work is to determine solutions to be more effective in electrical design. The main issues are families design and their proper settings, project definition and scheduling. If all these conditions are defined properly, the Revit users will be able to use more advanced data management. To work effectively, several Dynamo scripts have been designed and explained.

요약문:

본 논문에서는 건축 전기설계 단계에서의 BIM 적용에 대해 다루고 있다. 연구의 목적은 전기설계 단계에서의 효율적인 해법을 결정하는 것이며, 주요 쟁점은 패밀리 디자인과 이에 대한 설정 그리고 프로젝트의 정의 및 일정 계획이다. 본 연구에서 제시한 모든 조건들이 적절히 정의된다면 Revit 사용자는 보다 더 발전된 데이터 관리를 활용할 수 있을 것이다. 효과적인 적용을 위해, Dynamo Script의 설계와 이에 대한 설명이 제시되어 있다.

Klíčová slova:

BIM, TZB, Elektroinstalace, Revit, Dynamo, knihovní prvky

Keywords:

BIM, MEP, Electrical installations, Revit, Dynamo, libraries



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**Important abbreviations and terms:**

Abbreviation	Explanation
AC	Alternating current
BEP	BIM Execution Plan
BIM	Building Information Modeling
CAD	Computer-Aided Design
COBie	Construction Operations Building Information Exchange
DC	Direct current
FM	Facility management,
GDP	Gross Domestic Product
IFC	Industry Foundation Classes
LOD	Level of Detail/Development/Definition
MEP	Mechanical, electrical and plumbing



1 Introduction

The construction industry is a significant contributor to the worldwide economy. It is a producer of 6 - 7% GDP. About 9% of Czech population is employed in the construction industry. (1) That is why it can not be overlooked. First, the whole construction process must be properly defined. The process is influenced by many different factors and properties. Thus, creating and choosing the most efficient process is crucial. (2)

Nowadays, the best way how to work with data and define the process from designing to maintenance is Building Information Modeling.

“Improved processes in each phase of design and construction will reduce the number and severity of problems associated with traditional practices.” (3)

The use of BIM does not include only an architecture part. We have to perceive BIM processes as a tool for both all phases during the lifecycle of building and all parts of civil engineering such as piping or electrical circuiting. (3)
(2)

BIM utilization in MEP (Mechanical, electrical and plumbing) has a positive impact on clashes and collisions. Proper BIM model saves money for owners. However, the solution found in some guides is too general and is not suitable for everyone.

BIM is also topical in the Czech Republic. Czech government deals with law and national library for information modeling (4).

“According to results of the survey, it is necessary to implement BIM into legislation for public procurement and prepare standards for BIM libraries and outputs.” (5)

1.1 Main goals

This thesis deals with the MEP part of BIM process. The information modeling in MEP process is topical in most of the countries. (6) It improves the clash detection between professions. On the other hand, there are a lot of imperfections and problems. Several companies are solving these problems nowadays. We can ask ourselves what is the most suitable way. We can also find our most suitable process.



“In a 3D world, BIM is the glue that holds design and construction together. In my experience, there are a lot of firms out there that aren’t sure what goes into a successful BIM project.” (7)

A lot of articles and thesis have been written about whole BIM process. What this thesis describes is a direct way of designing in Revit 2018 with all the details of MEP settings especially in the “E” part of MEP, i. e. electrical. There are many ways and many software solutions for MEP designing, such as Autodesk Revit, Bentley or ArchiCAD. This thesis uses the Autodesk software Revit.

1.2 The benefit of this thesis

Electrical engineering services for buildings projects are a complex issue. Several branches of electrical design are included in electrical engineering services for buildings projects, such as Fire Detection and Fire Alarm Systems, Low Voltage Design, Extra-low Voltage Design or Building Management System.

The main goal is to make BIM process easier and more automatic. Revit offers various possibilities for electrical design. These days, there is a wide gap between fully automatic BIM modeling based on Revit software and Czech electrical designers, because the Revit native settings are based on the US standards. We are not able to change or improve some of these settings. The US standards, used by a default in Revit, can be replaced by new solutions formed by this thesis.

The thesis offers a project file as a result of proofing of all new solutions in use. This project file includes distributions systems, schedules and basic families, all provided with proper settings. Also, new Dynamo scripts are introduced in this thesis

The thesis is a guide for designers. It shows one of the proper ways how to improve the BIM experience in the MEP industry. It is suitable for all designers, not only for electrical designers. A lot of processes are similar in another part of Revit MEP. The findings of this thesis should help both beginners in the Revit world, as well as advanced users to improve or to reach a higher level of understanding.



2 Methodology

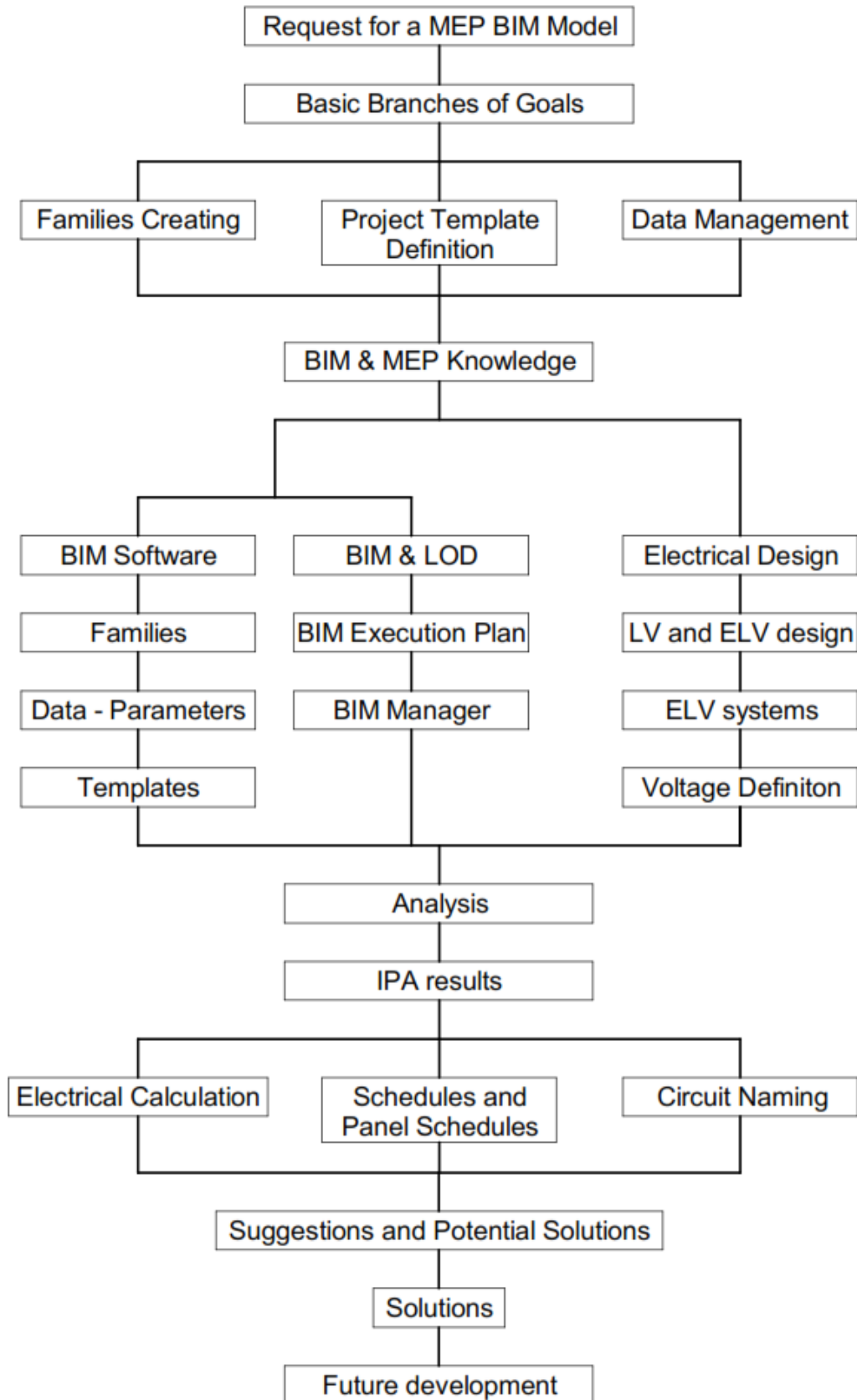


Figure 1 – Thesis workflow; source - author



Above is the general workflow of the thesis. IPA was used to analyze the chosen issues. The issues were chosen according to the previous experience of the author. The issues or the main goal will be defined and proved by the analysis. Generally speaking, three groups of goals have been set.

2.1 Final goals

The three goals are divided into two parts. First, the basic settings and understanding of Revit behavior including families creation and project definition. Second, the final data management. The knowledge of how the software works, has the highest priority for the user. There are several possibilities. Generally speaking, working effectively helps to save both money and a time.

2.1.1 Families creating

This part deals with families. There are many types of families for electrical engineers. They can be divided into hosted and non-hosted families according to a branch of the electrical design.

“Geometry and annotation play a large part in the construction documents for the electrical industry, but to take true advantage of the power of BIM, systems are the key.” (8)

The Revit system is a set of logically connected elements. Revit is able to provide information concerning circuit. Electrical system provides designers with the possibility to work with a group of elements together and to define their names and schedules. The system is also able to organize analysis and loads. The key point is to find advantages and disadvantages of this solution.

2.1.2 Project definition

Every part of the BIM process has to undertake several laws recommendations and BIM standards. Some of those differ in each project. However, the basic standards remain the same.

“If we talk about electrical part of BIM process, we have to talk about standards and manufacturers.” (9)

That is the difference between architecture and MEP part of BIM process. In architecture, a lot of parts, such as brick, has the same dimensions and it does



not matter who the manufacturer is. The system then enables users to combine many manufacturers. On the other hand, there are significant differences in dimensions and electrical standards between suppliers of electrical components. So, the project template has to be tailored to more combinations. That is why it is important to design distributions systems complying with Czech standards so that the designer is able to use circuits properly. Electrical engineers in the Czech building industry who use Revit to provide electrical drawings and panel schedules quickly discovered that the way Revit names circuiting information is not the most suitable one within the Czech standards (10)

The following part of thesis suggests an alternative solution. There are couple possibilities how to solve it. A useful tool can be for example Dynamo. It is an open-source software platform for computational design and building information modeling. It is based on object programming with using nodes.

“Nodes are the objects you connect to form a Visual Program.” (11)

Each node is able to provide an operation. Sometimes it is just a source of numbers or information or it may be a complex tool, such as one for defining and creating geometry. (11)

2.1.3 Data management

Data is the core business of BIM. Proper data management means a good BIM model. A good model must undertake the *Level of Development (LOD)* according to BIM execution plan and standards. (12)

Designers have to make sure that it is possible to upgrade the model into another phase. This is the point how we have to work with data. The thesis is focused on what is important for the project while the design is being created. It is necessary to understand how to manage data with circuits or without them and with using Dynamo for example.



3 Basic understanding of the building information modeling and MEP

“Building Information Modeling (BIM) is an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.” (13)

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.” (14)

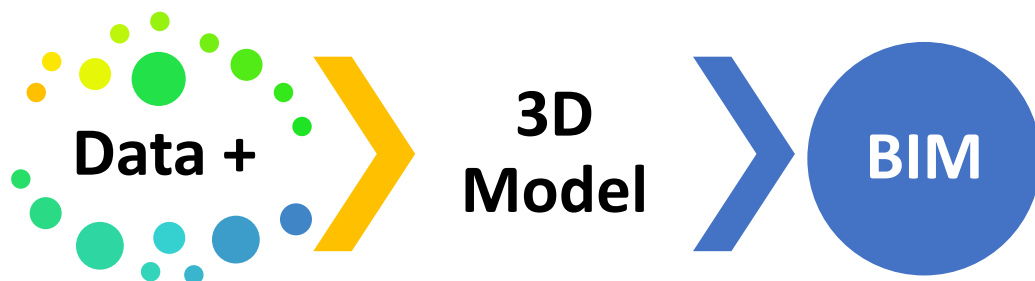


Figure 2 – BIM Formula; source - author

Building Information Modeling is a process of creating and maintaining data concerned with a building or with a part of the building during its lifecycle. It is not just a 3D geometry, although it is a basic part of information modeling. (2) BIM model is a database. Each object has as much information as it is required. The amount of information and the type of information sets BIM execution plan and BIM matrix. Final BIM model should be useful for using in all BIM software viewing platforms. That is why the *IFC (Industry Foundation Classes)* file format is required. This file format is not a substitution of an original editing format. *IFC* is not only for viewing and referencing, but also for information data managing.

3.1 IFC (Industry Foundation Classes)

The *Industry Foundation Classes* file format was developed by *BuildingSMART*. This organization was transformed from International Alliance for Interoperability and established in 2008. *BuildingSMART* is an open, neutral



nonprofit organization which is aiming to set a digital standard of the built environment. The four linked rings on the logo is the proof of interoperability. Each ring represents one of the major building phases: Design, Procure, Assemble and Operate. (15)

IFC provides an interoperability solution between different software. *BuildingsSMART* also established standards for import and export building objects and it defined basic parameters and information of models. (16) All software applications are able to read and create *IFC* file format. The file format improves collaboration between designers and enables using the model during the whole lifecycle of the building.

3.2 LOD

The *LOD* parameter is an information and graphics level of building information model. It is an *Informational richness* of the BIM model. Several standards define the *LOD* parameters. The most common types are the British and the US standards.

- *LOD* parameter as a *Level of Development*

This parameter is well known by US standard. AIA Document E202 BIM Technology Protocol

- *LOD* parameter as a *Level of Definition*

It is defined by British standard AEC UK BIM Technology Protocol – Practical implementation of BIM for the UK Architectural, Engineering and Construction

Level of Development is divided into 5 levels. Each level includes different type of information and different amount of graphics details. On the other hand, *Level of Definition* is divided into 6 levels. Each level is even divided into *Level of Detail (LOD)* and *Level of Information (LOI)*. (12) (17). According to the AIA, the *LOD 250* is similar to the detail level of Documentation for Building Permit.

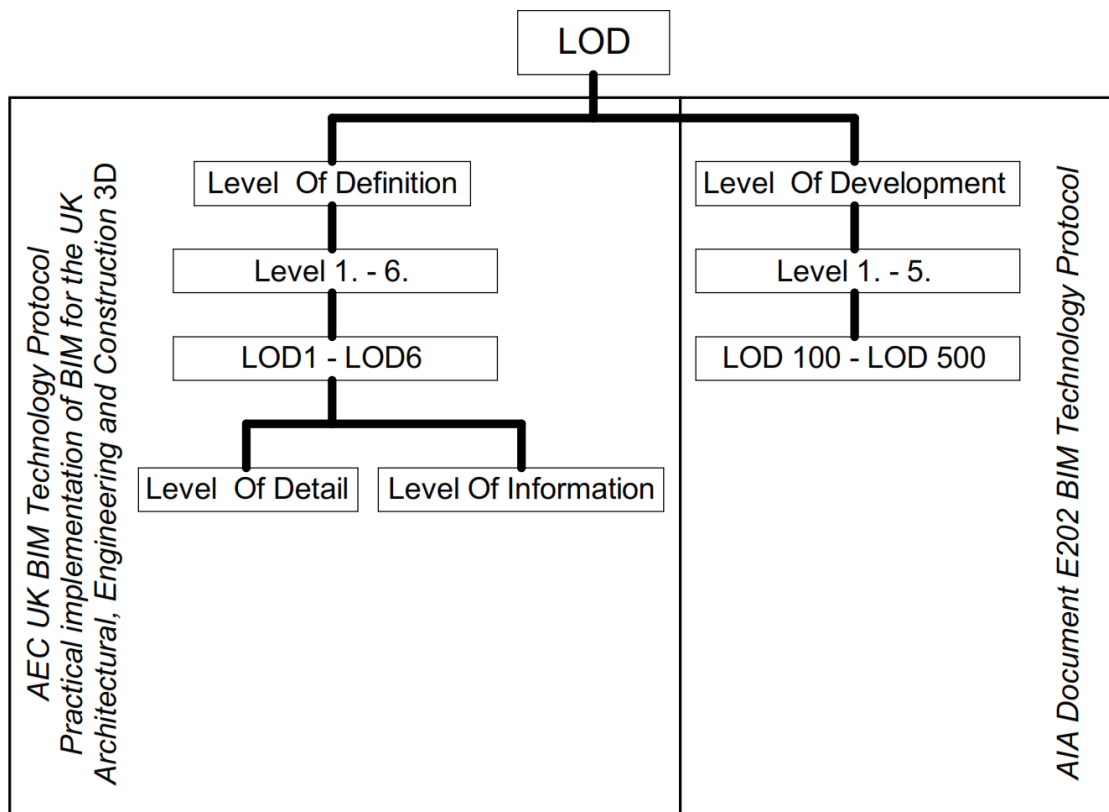


Figure 3 – LOD definition; source – author and (12) (17)

3.3 The new role of BIM model manager

Due to changes in the form of the model such as collaborating with several software and undertaking standards, the adoption of BIM has created new roles and relationships, as well as new work processes. The need for a proper coordination has led to establishing the BIM manager. The role of model manager is to deal with the whole design process, software applications and other project participants. The BIM manager should consider future BIM strategies and evolve them. To work effectively means to model properly and to save money. (18) The manager is the most important person in the BIM process. He is also a supervisor who must follow the BEP (*BIM Execution Plan*) and is responsible for the quality. The BIM manager is also able to change some part of the BEP, moreover, he should be one of the authors of the plan. Main issues for BIM manager are the following:

- To provide proper coordination between different branches of civil engineering



- To manage access right to model creating
- To keep BIM model up to date
- To manage proper naming of views and files (19)

3.4 BEP (BIM Execution Plan)

The basic document for the BIM project is BEP. This plan includes everything needed for the model creating. One of its parts is called *LOD* Matrix. It is usually a table with categories and *LOD* levels. However, the BIM execution plan is not only about *LOD*. It can be divided into four parts: Management, Planning and Documentation, Standard method and IT solutions. (20)

3.4.1 Management

- Roles, responsibilities and authorities.
- Deliverable strategy.
- Survey strategy.
- Approval of information.
- Authorisation process.

3.4.2 Planning and documentation

- Approved processes for collaboration and modeling.
- Approved matrix of responsibilities.
- Responsibility for delivery of information.

3.4.3 Standard method

- Origin and orientation.
- File naming convention.
- Construction tolerances.
- Drawing sheet templates.
- Annotation, dimensions, symbols.



3.4.4 IT solutions:

- Software versions.
- Exchange formats.
- Process and data management systems. (20)

3.5 Different views on BIM

The points of view on what BIM is depend on the particular actor. Expectations on BIM also vary depending on the profession of the user. (21) Simultaneously, the development of BIM to support facility management is lagging behind the development of BIM in the design stages of a project (3)

“Design professionals view BIM as an extension of CAD, while project managers and contractors see BIM as a more intelligent document management system suitable for extracting and analyzing data directly from a CAD package.”
(21)

The BIM model, too, varies according to the way it is used. There are many conditions which designers must face. Each type of the model includes different types of information. Different *“information richness”* is needed for the facility management BIM model or for a model suitable for the building construction. This is also another reason for considering all possibilities of use before the creation of the model begins.



4 MEP

“MEP” is an acronym consisting of three words: *Mechanical, Electrical, and Plumbing*. It is the most important part of building industry. (22) It is possible to imagine it as an engine of a car. Although the car has the beautiful shapes, it is not possible to use it without an engine. “*To move the building,*” it is the real reason of MEP. Mechanical, electrical and plumbing design makes building suitable for living and why it creates a comfortable environment inside. Every building in the world must deal with similar issues, i. e. to provide both cold and hot water, heating, electricity etc.

MEP engineers design safe and suitable buildings for a comfortable life with the almost unlimited amount of water and electricity. The more comfortable life people live, the more important role the MEP industry plays. For example, lighting. design helps us to be more productive and to bear tiredness during the day.

4.1.1 The mechanical aspect

“HVAC is the technology of indoor and vehicular environmental comfort. Its goal is to provide thermal comfort and acceptable indoor air quality.” (23)

The mechanical part of MEP is also known as HVAC - Heating, ventilation, and air conditioning. It is a subdiscipline of mechanical engineering, based on the basic physical laws and principles such as thermodynamics or fluid mechanics. It focuses on heating, cooling, and ventilation. Part of HVAC is also an electrical aspect focused on providing power to all outlets and appliances. (22) We can find HVAC system almost in every building.

A basic HVAC system consists of HVAC unit, ducts, and air terminal devices. This process of exchanging or replacing air is provided through the ducts and controlled by HVAC unit to provide high indoor air quality such as temperature control, oxygen replenishment, and removal of moisture, carbon dioxide, and other gases. HVAC unit and system are closely connected with *Building Management System*. This system operates with results of the air conditions.



4.1.2 Plumbing

Plumbing mostly deals with water. Water is the most important resource for living. That is why plumbing is the oldest part of MEP. Where the first sewer system was used for the first time is not quite clear, however, one of the best-known places is Skara Brae on Scotland's Orkney Island. The inhabitants of Skara Brae used the first form of stone toilet. Some sources say the first use of this infrastructure dates back as far as 8000 BCE. (24)

Modern plumbing industry uses more sophisticated materials, however, the principles are still the same. Today, every building has to deal with two main parts of plumbing – freshwater and wastewater treatment. Both are usually conducted in pipes made of plastic. In the past, earthenware or metals and its alloys were used as main materials. One subsystem pipes freshwater in, and the other takes foulwater out. The dimensions of pipes and fittings vary according to the country and its standards. The freshwater system is pressurized so its dimensions can be thinner. It is divided into several separated pipes systems – cold, hot and circulation water. The plumbing part also handles sprinkler systems, as well as gas delivery systems in medical and laboratory settings (25).

4.2 Electricity

Electricity is more crucial for us than we realize. Most people in the world cannot imagine a world without electricity. And it is true. Almost every device or thing we use is powered by electricity.

The history of the use of electricity is long and is connected to a lot of famous names and inventions. It is good to highlight a few of them.

- Benjamin Franklin

He was the first person to demonstrate that lightning is electricity.

- Henry Cavendish of England, Luigi Galvani of Italy

They wanted to find a practical use of electricity (26).

- Thomas Alva Edison

In 1879 invented a carbon filament that burned for forty hours. An inventor of a safe and the affordable oxygenless bulb. His invention was based on a patent from inventors Henry Woodward and Matthew Evans - 1875.) (27)



- Nikola Tesla

He contributed to the development of the alternating-current electrical system. AC system is the most common worldwide. He was one of the most influential inventors of all times. He is famous for “*Tesla coil*.” It is the foundation of the future wireless system and It is still a part of radio technology. (28) He had successfully filed several patents for AC-based inventions. He was also hired by Thomas Alva Edison for couple of years.

- Michael Faraday, Georg Simon Ohm, André-Marie Ampère, etc.

Most devices are controlled or supplied by electricity. The electrical part of building industry counts kilometers of cables and wires in every edifice.

The electrical part is not responsible only for outlets and appliances but also for lighting, switches, fire alarms, security systems, as well as lightning protection when necessary. However, all of these systems usually use different types of voltage.

4.2.1 Definition of basic terms

When people begin to explore the world of electricity and electronics, it is good to start by understanding the basic terms: voltage, current, and resistance. This is the most important part of electricity and it is necessary to know the terms. All of the three terms are closely related. *Table 1* summarizes the basic units and their unit symbols to support consistency in the use of these units. A lot of them were named after their inventors.

Variable	Unit	Unit Symbol
Electric current (I)	ampere	A
Voltage (V)/(U)	volt	V
Resistance	ohm	Ω
Energy	joule	J
Power	watt	W
Charge	coulomb	C
Time	second	s

Table 1 – Basic Units of Electricity; source - author



- Electric current

In general, it is the unit of a charge movement. The particles that carry charge through wires in a circuit are mobile electrons. The unit is called *Ampere*, part of SI base units. This unit was named after André-Marie Ampère (1775–1836), French mathematician and physicist. He is also considered the father of electrodynamics. One ampere is a movement of charge at the time.

$$I = \frac{Q}{t}, [A] \qquad 1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

Formula 1 – Electric current; source – author

Two types of current are used nowadays. alternating (AC) and direct current (DC). In DC circuits the electric charge flows only in one direction. The way to move is not sinusoidal. On the other hand, AC circuits are sinusoidal and the way of charge is changed periodically. Nikola Tesla is famous for using AC circuits.

- Voltage

Voltage is the difference in electric potential between two points per unit electric charge. It is also done work (W) per charge (Q). The water analogy can help with imaginations of it.

“Potential difference between two points corresponds to the pressure difference between two points. If the pump creates a pressure difference between two points, then water flowing from one point to the other will be able to do work, such as driving a turbine.” (29)

The *Volt* is the derived unit for electric potential, named after Italian physicist Alessandro Volta (1745–1827), the inventor of the voltaic pile, the first chemical battery.

$$U = \frac{W}{Q}, [V] \qquad 1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

Formula 2 – Voltage; source - author

- Resistance

Resistance is an ability of electrical conductors. It describes how easy or difficult it is to lead the electrical current. There are several influences. The level of resistance depends on the material of the conductor, its temperature, diameter and length of the conductor, for instance, wire. When the temperature grows, the



resistance increases, too. The inverse value is called the conductance. The unit of resistance is *Ohm* named after Georg Simon Ohm. He is the inventor of the relation between voltage and electric current.

$$R = \frac{U}{I}, [\Omega] \qquad 1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

Formula 3 – Resistance; source - author

- Power

Power or electric power is the rate of the electrical energy per unit time in an electric circuit. It is a part of SI unit. Its name is a *Watt* named after the Scottish inventor James Watt for his development of the steam engine.

$$P = \frac{W}{t}, [W] \qquad 1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$

Formula 4 – Power; course - author

Electric power is divided into three parts. *Apparent Power (S)*, *True Power (P)* and *Reactive Power (Q)*. It is suitable to imagine all types of power as vectors in the triangle. *Apparent Power* is the longest line of the triangle. It is a combination of *Reactive* and *True Power*. It is also total power in AC circuit both dissipated and absorbed/returned. (30)

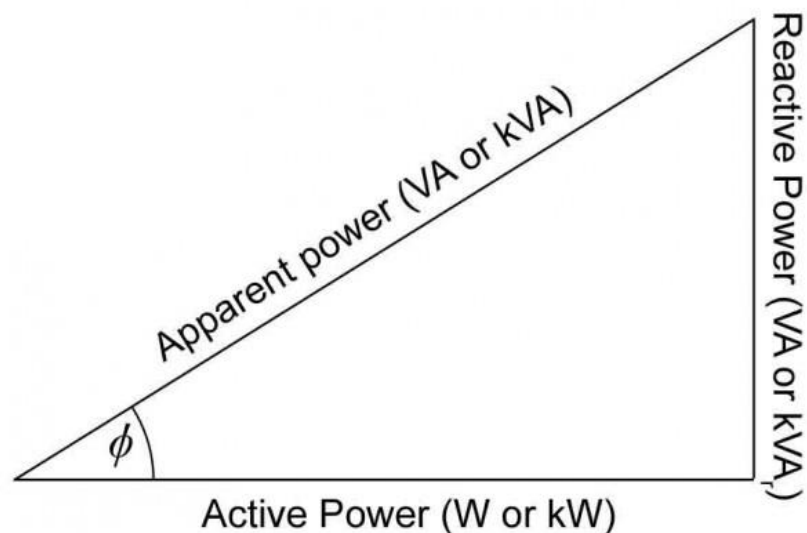


Figure 4 – Power (30)

$$\text{Apparent Power} = \sqrt{(\text{True p.})^2 + (\text{React. p.})^2}$$



$$P = UI, [W] \text{ (only DC circuits)}$$

$$P = UI \cos(\theta), [W] \text{ (only AC circuits)}$$

Formula 5 – Apparent Power; source - author

- Power Factor

It is necessary to understand the differences between AC and DC circuits to count the *True power*. In AC there is a new condition we must count that is called *Power Factor*. It characterizes the difference between *Voltage* and *Electric current*. *Power factor* is a number with a value from 0 to 1. It is described by $\cos(\theta)$.

Power Factor is divided into lagging and leading.

“In a predominantly inductive series circuit, where current lags voltage, the power factor is called a lagging power factor. Similarly, in a predominately capacitive series circuit, where current leads voltage, the power factor is called a leading power factor.” (30)

When the phase angle is 0 and *Power Factor* is 1 (unity) for purely resistive circuits when the phase angle is 90° and *Power Factor* is 0 for (inductive or capacitance) circuits. Most of the devices usually use predominantly inductive series circuit. That means the electric current is delayed after voltage.

4.2.2 Types of voltage

In electrical engineering, low voltage and its division is a relative term, the definition varying by context and use. These definitions vary by country and specific codes, regulations or agreements.

According to the International Electrotechnical Commission (IEC) voltage is divided into 3 different levels. The table shows levels with a different value for AC and DC current with the defining risks.



IEC voltage range	AC (V_{rms})	DC (V)	Defining risk
High voltage (supply system)	> 1000	> 1500	Electrical arcing
Low voltage (supply system)	50–1000	120–1500	Electrical shock
Extra-low voltage (supply system)	< 50	< 120	Low risk

Table 2 – IEC Voltage definition (29)

Each value of voltage has a tolerance. The value varies standard to standard.

EN 50160 allows, for example, that the supply voltage can be equal to $U_n - 10\%$ or $U_n + 10\%$ for a long period. (31)

Czech standards ČSN 33 0121 and ČSN 33 0120 define just nominal value of voltage. However, a former standard defined tolerance as a $+6/-10\%$ of nominal value. One of the Czech distributors of electricity set the tolerance as $\pm 10\%$ of nominal value for 95% of each week.

4.3 Low voltage design (LV)

Low voltage in this context still presents a risk of an electric shock, but only a minor risk of electric arcs through the air. In electrical power systems, low voltage most commonly refers to the main voltages as used by domestic and light industrial and commercial consumers. A low voltage system of (nominally) 230/400V and a frequency of 50Hz is the most common system in Europe.

This design includes a switchboard, a panelboard with circuits breakers and a residual current circuit breaker at the beginning of the circuit. A part of this LV design is also constructed of electrical sockets, lighting fixtures, switches and other devices such as ventilators in industry or another special device.

4.4 Extra low voltage design (ELV)

ELV is the terminology used in the construction world to electrically define all systems in a building which need the electricity to run or to be controlled, but are not parts of the building's main electrical system. ELV covers all the new



modern must-have technologies in every building. For instance, CCTV, fire detection SCS.

There are three other types of ELV. (32)

- SELV

Separated extra-low voltage system - the low-voltage output is electrically separated from earth and other systems. SELV can be generated from the battery.

- PELV

Protective extra-low voltage system - the low-voltage output is electrically separated from other systems. There is no separation from earth.

- FELV

Functional extra-low voltage system can be used only for functional purposes. There is no protection from contact with higher voltage.

4.4.1 SCS (Structured cabling system)

Structured Cabling System also known as LAN stands for *Local Area Network*. Another part of SCS is WLAN system. Wireless LAN which is the network of wireless access points that provide wireless network This type of CSC cabling is common for office buildings or apartment buildings to enable users to access the network with their devices and possibly access the internet.

This system consists of a number of smaller elements and separated structures and substructures. In a small building, this can be simple. The cabling is divided into categories according to use and conditions.

The basic system consists of:

- Patch panel - usually normal 19-inch rack mounted panel)
- Network switch – it can be designed as rack mounted or stand alone.
- Data socket – most common are socket wit RJ45 type.
- Routers
- Servers



The horizontal and vertical cabling is usually lead inside the separated cable trays or conduits.

4.4.2 Telephony system

This is the system used for quite a long time because analog telephone system is still in use in buildings by using multi-pair copper telephone cables connecting the PABX (*Private Automatic Branch Exchange*). Nowadays, they are almost totally replaced with VOIP (*Voice Over IP*) solutions that do not require separate cabling and depend on the building's SCS system.

4.4.3 CCTV

CCTV stands for *Closed Circuit TV*. In general, CCTV is a camera system set up inside and outside of buildings. CCTV provides monitoring of surroundings. Old analog cameras used a separate cabling of coaxial cables connecting each camera directly to the DVR (*Digital Video Recorder*). Nowadays, they are almost totally replaced with IP cameras utilizing LAN system of the building. (32)

4.4.4 (FDAS) Fire detection and fire alarm systems

FDAS is a system designed to provide warnings about an outbreak of fire and to allow proper firefighting action. The gain is to take the fire situation and dangerous under control as soon as possible and notify building occupants, so that they can escape the building.

It is a system with many components such as:

- Detectors

There are different types of detector in FDAS system. Heat detectors (for example, bimetal system), Smoke detectors (photoelectric, ionization), Gas detectors (CO detector)

- Magnetic smoke door holders

Door holders ensure that the fire doors close in a case of emergency to prevent the spread of the fire. They can be usually placed both on floor or wall mounted.

- Fire alarm control panel

It is the main point of controlling other devices in fire alarm system.



- Primary and secondary power supply system
- Notification appliances

It is also active fire protection. People can recognize by sound or it is a visible sign.

4.4.5 ACS

ACS is the abbreviation for Access Control System. This system allows access to different parts of the building.

ACS uses following devices:

- Stand-alone electric locks
- Card readers
- Biometric readers

ACS system usually relies on LAN infrastructure and low voltage as a power system.

4.4.6 PAS/PAGA

PAS (*Public Address System*) or PAGA (*Public Address and General Alarm*) is designed to make announcements to building users, to broadcast background music or to broadcast pre-recorded alarm notifications, sometimes automatically triggered by fire alarm systems. It uses separated cabling. It is not usually based on IP system. (32)

PAS/PAGA consists of:

- Speaker
- Amplifiers
- Microphones

4.4.7 Building Management System

This system is also known as a *Home Automation Systems* or *Building Automation System (BAS)*. It is a computer-based controlling and monitoring, designed to control building systems such as lighting, ventilation, fire system or security system.



All systems linked to BMS cause about 40% of energy usage of the building. The BMS system can monitor and control the air quality. The BMS is responsible for controlling the building environment to provide comfortable living conditions to its occupants.

4.5 BIM and MEP

Roots of Building Information Modeling are well known for about 30 years. MEP in civil engineering started to use 3D modeling only several years ago. The advantage of using BIM in MEP industry is significant. BIM in MEP provides customers and designers with calculations, better imagination in coordination and a proper and more specific schedule of material and subcomponents.

One of the biggest advantages is clash detection. It enables easy merging of separated models into one, so all the potential clashes can be solved. Clashes are the mistakes of modeling. For instance, clash occurs when elements of different models are located in the same position. Software market offers a lot of software solutions managing the clash detection. The most prevalent is Autodesk Navisworks.

4.6 Types of clashes:

- Geometric

Several instances occupy the same place such as pipe and cable tray or pipe and wall.

- Schedule based

Table of schedule is not separated according to part of building process such as MEP parts. For example, switch belongs to the wrong category.

4.6.1 Hard clash

Two objects pass through each other. Most BIM modeling software has the clash detection tool, but the question is how suitable it is and how useful is the setting of clash detection tools. Hard clash is also called geometric clash.



4.6.2 Soft clash

Soft clash allows finding objects encroached into geometric tolerances of other object or objects such as different types of cable trays.

4.7 BIM Software

The main tool for creating BIM model is the BIM software. The effort of the designer is to use just one software or to provide 100% correct interoperability between other products or software. Most of the software are able both to read and to create *IFC* format file. This open source format is an internationally used exchange file format in BIM industry, but it is suitable to use it as a linked reference. There is no possibility to continue with modeling based on this format. If the *IFC* format is created, a lot of information is lost. All BIM software use *IFC* parameters. These parameters are filled with information that cannot be lost.

Today, several companies offer BIM software and a lot of startups were bought by them to improve their BIM software, such as Autodesk and its BIM software Revit.

4.7.1 Architecture

- Autodesk Revit Architecture
- Graphisoft ArchiCAD
- Nemetschek Allplan Architecture
- Bentley Architecture

4.7.2 Structures

- Autodesk Revit Structure
- Bentley Structural Modeler
- Tekla Structures

4.7.3 MEP

- Autodesk Revit MEP
- Bentley Hevacomp Mechanical Designer
- Graphisoft ArchiCAD

4.7.4 Construction (Simulation)

- Autodesk Navisworks
- Solibri Model Checker
- Bentley ConstrucSim
- Tekla BIMsight
- Synchro Professional



4.8 Revit

The history of this BIM software has started on October 31, 1997, by founding Charles River Software in Newton, Massachusetts. This is the original place where the Revit was born.

“From the outset, Revit was intended to allow architects and other building professionals to design and document a building by creating a parametric three-dimensional model that included both the geometry and non-geometric design and construction information, which is also known as Building Information Modeling or BIM.” (3)

The first version of Revit 1.0 was released on April 5, 2000. Since then, the software has progressed rapidly, and the success has been significant. Autodesk Inc, well known for AutoCAD Software line of products, purchased the Massachusetts-based Revit Technology Corporation for US\$133 million in 2002. (33) The purchase allowed development and improvement of the software. During the years, Revit was spread. Nowadays, several versions of Revit are offered.

- Revit – Complex tool, Architecture, MEP and Structure parts are included.
- Revit LT – It is a light version lacked a lot of tools.

Revit is based on families. A family is a basic brick of Revit Software. BIM model is a set of many families. Revit is a complex software. It allows to design all branches of building industry for instance, architectural, MEP or structure part. Autodesk supports *IFC* as well as other BIM software. Autodesk supports *buildingSMART International*, the organization that develops and maintains the *IFC* standard, the leading interoperability standard.

4.9 Families

As mentioned before, a family is a basic building block of each Revit project. There are 3 types of families in Revit. Some of them are easy to replace, to upgrade or to remodel. However, there is one type called system families, which



is impossible to revise. Although Revit is a 3D modeling tool, 2D families can be created, too. Families are modeled in a *Family Editor*, using special modeling tools such as *Extrusion*, *Blend* or *Sweep*, that can be combined together with *Model Lines* or *Model Text*.

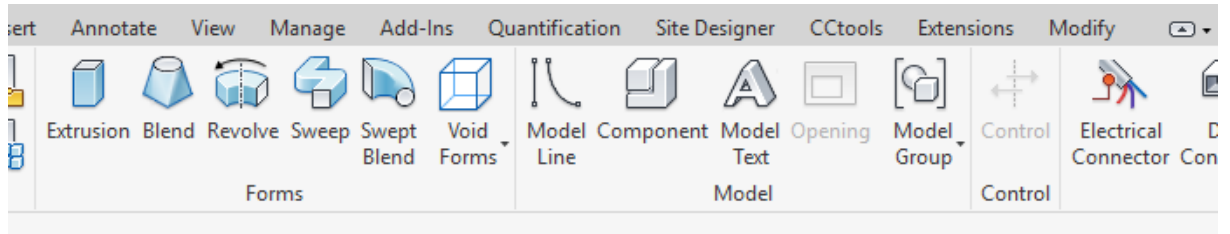


Figure 5 – Family Editor - Ribbon; source - author

4.9.1 Family Template

All families are based on a *Family Template* that creates a base specification of a family. This kind of template varies according to the future way of use of the family such as hosted/non-hosted family. For instance, the host can be a wall, floor or ceiling. Templates are also prepared separately for 2D and 3D families.

4.9.2 Family categories

Categories have almost similar graphics properties as the layers in AutoCAD. Their colors, lines properties or visibility can be changed. On the other hand, there is one big difference. There is no possibility to create new or to delete existing category. Each of them has different features. There are differing in five parts, with examples:

- Architecture – Walls, Doors, Windows, Stairs, Furniture, Curtain Wall Mullions
- Structure – Analytical Columns, Structure Columns, Structure Framing
- Mechanical – Air terminals, Duct Fittings, Mechanical Equipment
- Electrical – Fire Alarm Devices, Electrical Equipment, Electrical Fixture,
- Piping – Pipe Fittings, Pipe Accessories, Plumbing Fixtures, Piping Systems

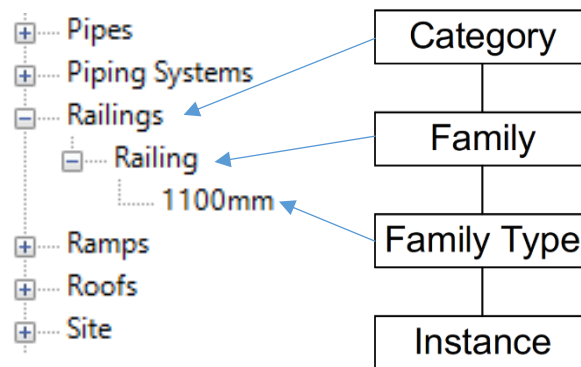


Figure 6 – Revit Family Hierarchy; source - author

Figure 6 is showing a part of the Project Browser. There is a *Family tree*. On the top is a Category as a basic specification.

4.9.3 Family name

Second is the Family Name. It is a name without special characters: \ : < > { } ~ ` | ? []. This is the name we find in windows browser below the icon with the format *RFA*.

4.9.4 Family type

The same naming conditions are used by Family Type. The family type defines different properties of the family. Types can differ only by parameters. These types can be defined inside of a family or as a text document in *TXT* file. For example, the manufacturer offers 2 same doors. The only difference is the width of the doors. So, 2 types with different values of width can be created in one family. However, the family must be modeled as a parametrical family controlled by parameters.

4.9.5 Family instance

It is the lowest level in the Family hierarchy. Generally speaking, it is each object in the project. This instance can vary only by instance parameters. It is a part of a group *Properties*. If some placed family is selected, an instance was selected.



Visibility of instances and families is possible to change according to *Detail Level*. There are 3 levels *Fine, Medium and Coarse*. Each level is able to have a different setting. The differences are set in the *Family Editor*.

4.9.6 System Families

These families are pre-defined families in Revit project. Their parametric, graphical, and documentation requirements and properties already exist. The user changes are limited. (34) They cannot be graphically edited, deleted or loaded. They do not use *Family Editor* for user changes. The possibilities are not so extensive. For example, there is no possibility to change the material for each type of the Cable tray. There is an opportunity to do it for the whole project in *Object styles*. System families are the basic elements of each branch of building industry such as

- Walls, roofs floors in architecture and structure model
- Ducts, pipes, cable trays or conduits in MEP industry

4.9.7 In-Place Families

In-place families are user-defined families in the project. This type is usually used for unique families used only once in a project. This type of family also support all tools as a normal *Family Editor*. (35) They have a similar feature as the system families they cannot be loaded into or saved out of a project. However, they can belong to every category as a loadable family. They can be also modeled within the context of the project. (34)

4.9.8 Loadable Families

Fully customize families can be called loadable. They are divided into hosted, non-hosted (horizontally rotating), symbols, annotates and built in an editing mode called the *Family Editor* using family templates.

Loadable families are families used to create the following:

- Building components that would usually be purchased, delivered, and installed, such as windows, doors,



- System components that would usually be purchased, delivered and installed in and around a building, such as boilers, water heaters, and plumbing fixtures
- Some annotation elements that are routinely customized, such as symbols and title blocks (35)

Because of their highly customizable nature, loadable families are created and modified in *Revit*. Unlike system families, loadable families are created in external *RFA* files and loaded in projects. They can be defined by types inside of the family or with external txt document or type catalogs with the same name as the family has. The type is created inside of Revit during the loading. This system allows loading only the types that are needed for a project. (34)

The system with external document uses the table during the loading the family when the user can pick only one type which is needed. It helps to the designer to work effectively with the amount of file data. Families file size with a lot of types can include about 10 Mb. if the project includes about 20 families with this size the result would be critical.

4.9.9 Type/Instance parameter

One of the differences necessary to know for a designer or Revit user is to know the difference between an Instance and a Type Parameter. One family type can include a lot of parameters both instance and type. A different value of instance parameter means a change of features or dimension just one or all placed families. The change of type parameter changes all instances of the family type in the whole project without any influence of a number of selected objects.

Imagine two same glasses. One will be full of water and the second one will be half empty. The amount of the water will be instance parameter because its value belongs only one glass and each glass can have a different amount of water. On the other hand, type parameter defines all glasses of one type such as their high or material. If someone changes its value, all glasses will be changed.

- Type - All parameters which are under control *Edit Type* button and *Type Properties* table
- Instance - All parameters which can be changed in *Properties* table.



4.9.10 Kinds of parameters

- System Parameter

Pre-existing Parameters defined inside of a family. Most *System Parameters* can appear in *Schedules* and *Tags*. These parameters are also known as a *Multiple Categories Parameters* such as *Comments*, *Mark*, *Description* or *Assembly Code*.

- Family Parameter

Parameters created in the *Family Editor* mode. This type of parameters cannot appear in *Schedules* or *Tags*. *Family Parameters* live inside the family to control the family and its dimensions. They can be used in formulas. On the other hand, their value can be changed in the project in *Type Properties* or *Properties* table. A family parameter can also be used to control a parameter in a nested family. The family parameter can be associated with the family parameter the nested family.

- Project Parameter

Project parameters are a specific parameter used project to project file. They are added to the project file and added to elements by assigning them to one or multiple categories, sheets, or views. Their values cannot be shared between project files. It is just for one project. However, these parameters are suitable for scheduling, sorting, and filtering. They can appear in *Schedules* but not in *Tags*.

- Shared Parameter

These parameters are good to use if the parameter in a family or project needs to be scheduled or tagged, that parameter must be shared and loaded in both the family (project) and the tag family.

All shared parameters are saved in the external document. This is a protection to make a change or mistake with using this parameter. If the user wants to schedule a lot of parameter from several different families. It is highly recommended to use the *Shared Parameter*. All shared parameters are suitable for scheduling, sorting, and tagging. That is why *Shared Parameters* are parameter definitions that can be used in multiple families or projects. (34)



Shared Parameters can be associated with dimensions of a family geometry or used in external document types of the family.

- Global Parameter

These parameters are specific to a single project file. However, cannot be assigned to categories. *Global Parameters* can be simple values, values derived from formulas or parameters from Revit linked global parameters. These parameters make easier parametric design inside of project file.

“You can also set the position of one element by the size of another element. For example, beams can be driven to consistently offset from the floor they support. If the floor design changes, beams will respond accordingly.” (36)

4.9.11 MEP System/Circuit Type

MEP families can be sorted into the system. When Revit user selects a component with electrical, duct, or pipe connectors that is not a member of a system automatically. He can create or add it to selected system or circuit. Each connector in the project is recognizable with a special symbol. This symbol is shown after selection of the family.

In Revit, there are 3 standard systems.

- Electrical

Electrical systems have three options for three different independent systems. There are separated from Cable Trays, Conduits and for devices in Revit. Conduits and Cable trays systems are created automatically by placing the cable tray or conduit with fittings. The last one has to be created after the device families are placed in the project. When a component with an electrical connector is selected, the Create Systems panel displays. This panel allows the user to create a specific electrical system: Power, Switch, Data, Telephone, Fire Alarm, Nurse Call, Communication, Control or Security. (37)

- Duct

This type is used to create a specific HVAC system: Supply Air, Return Air, Exhaust Air. It uses a Duct or Flex Duct to create the system. When a component with a duct connector is selected, the Create Systems panel displays the Duct tool to create a specific HVAC system



- Pipe Connector

Pipe connectors are used with hydronic systems, plumbing systems, and fire protection systems. (38) When a component with a plumbing (pipe) connector is selected, the Create Systems panel displays the Piping tool, to create a specific plumbing system: Sanitary, Domestic Hot Water, Domestic Cold Water, Other.

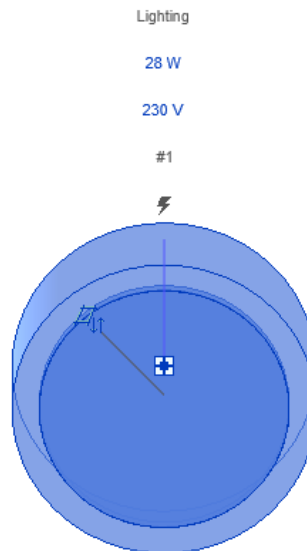


Figure 7 – Connector; source - author

4.9.12 Connectors

Connectors are placed in *Family Editor* to connect the family to the duct, piping, electrical, and other systems in the project file. Even the in-place families can include a connector. There are several types of connectors:

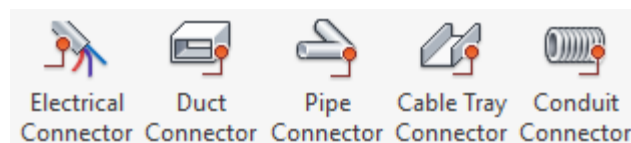


Figure 8 – Connectors Ribbon; source - author

- Electrical connectors

They are used for any type of electrical connections: Power, Switch, Data, Telephone, Fire Alarm, Nurse Call, Communication, Control or Security

- Duct connectors

They are associated with ductwork, duct fittings, and other elements such as Mechanical equipment category or Air Terminal.



- Pipe connectors

They are used for piping, pipe fittings, and other piping categories for transmitting fluids.

- Cable tray connectors

are used for cable tray, cable tray fittings to create a cable tray system for LV or ELV design.

- Conduit connectors

are used for conduit, conduit fittings, and other components that are used for wiring.

A conduit connector can be an individual connector or a surface connector. The individual connector allows just one conduit connection. The surface connector is used for connecting more than one conduit to a surface and allows to pick the specific place where to connect it.

- Connector placing

There are two options. Place on Face or Place on the Work plane. Placing on Face allows connectors point to place the middle at the center of the edge loop. In most cases, this is the preferable method for placing a connector with the low preference of placing the connecting point.

Place on Work Plane helps to be independent of connector placing. This option allows the user to change the geometry of the family without any influence on connector placing. However, this method generally requires advanced knowledge of Revit, extra parameters and constraints to use.



5 Survey

Quality has become an important subject of discussion among BIM. One of the main ways to set the goals is to determine the satisfaction with the BIM tool performance, to compare what they expected when they introduced the BIM tool. (39)

There are two major research instruments. Both of them have been developed over the years to analyze the quality and consumer satisfaction. (40) The first one is the Importance-Performance Analysis (IPA) and the second is SERVQUAL. For this research, the first method was applied.

To determine the current BIM practices and experience in their companies, electrical design engineers and project/design managers were interviewed. This survey is very important for the proper definition of main goals. All of the companies interviewed use Revit as a BIM tool. The survey focused on electrical design engineer.

5.1 Importance-Performance Analysis (IPA)

“An easily-applied technique for measuring attribute importance and performance can further the development of effective marketing programs.” (41)

This definition from Journal of Marketing is the main inspiration for using IPA in this thesis. If something is effective and practical, no marketing is needed, so the BIM software has to be effective and well developed.

The first idea concerning Importance-Performance Analysis was proposed by Martilla and James (1977). (39) According to them, it was a tool by which measuring the client satisfaction with a product or service can be provided. (41) This method has proven to be a widely applicable tool for researchers in general. The IPA consists of importance and performance axis, Importance (y-axis) and the Performance (x-axis). Each of the quadrants combines the importance and the performance value. Every interviewed designer or manager set the different value to the terms or statements (41) (39)

- Good work - high importance, high performance:

This quadrant is an indicator of advantages and major strengths; no other work is needed.



- Point of concentration - high importance, low performance
A high priority of attention. Immediate need for improvement is required.
- Not so interesting to solve - low importance, low performance
Points in this quadrant are minor weaknesses. No need is required unless other problems appear.
- Overkilled work - low importance, high performance:
Solutions of this problems are overkilled. Too much effort has been done for the solution.

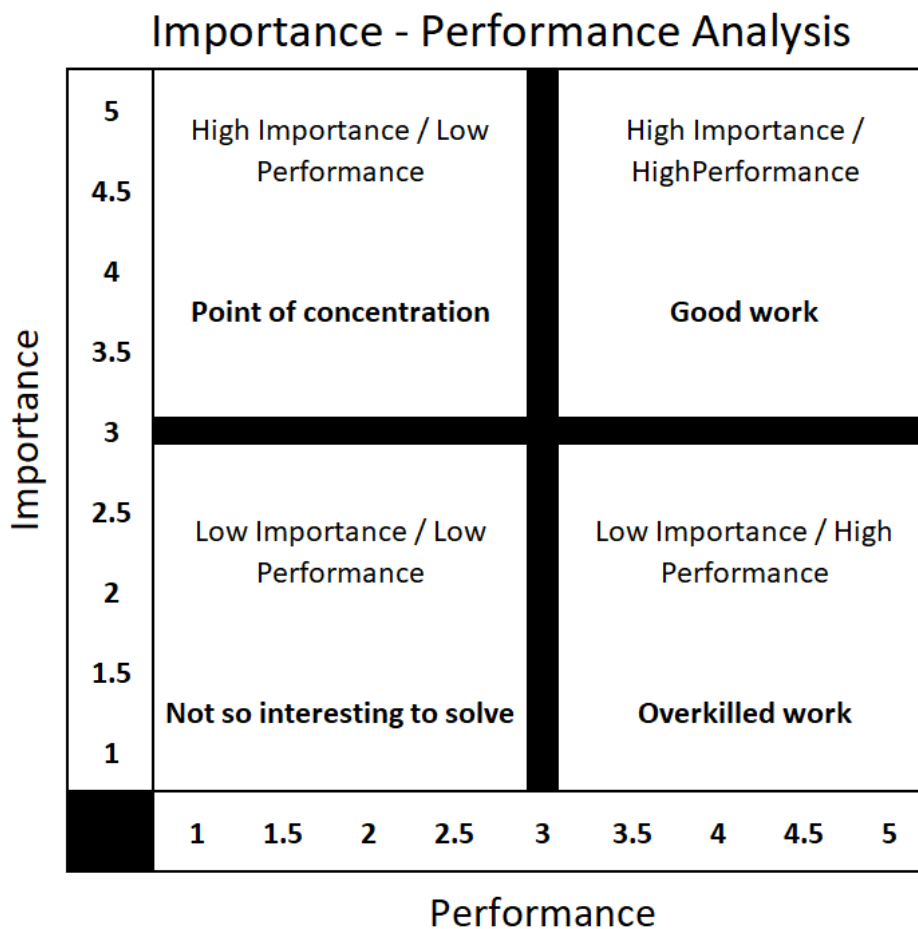


Figure 9 – Importance-Performance Analysis; source - author

5.2 Sample and Questionnaire

The survey was conducted from the 5th of September until the 10th of November in 2017. A total of 26 valid questionnaires were received. Most of the participants were designers (46%), the second biggest group consisted of



consultants (39%) and the last one was students (15%). All the respondents had experience with modeling or making electrical project or families.

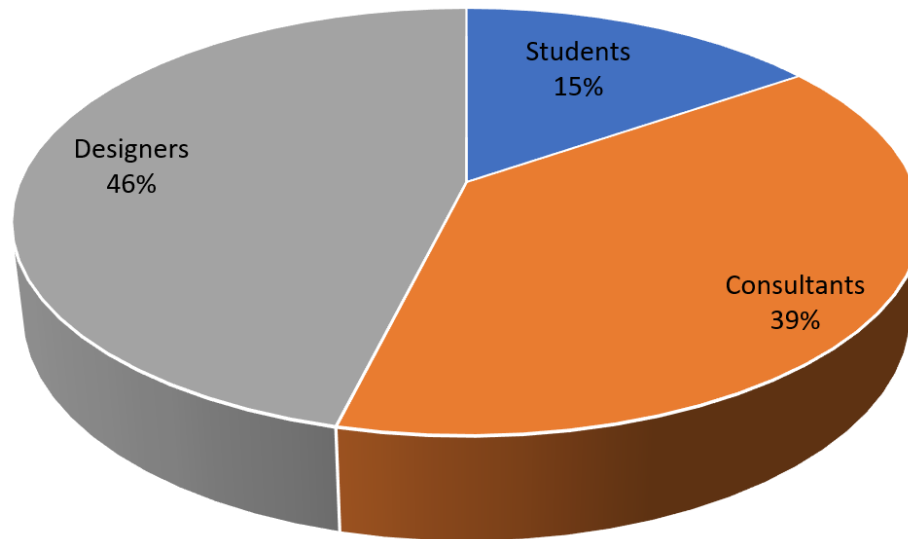


Chart 1 – Research participants; source - author

The used instrument was divided into two sections: section one refers to the importance and performance of key attributes concerning in BIM process. The section two allows people to write more about problems with BIM solution. The attributes under consideration are:

- Quality of General Aspects of BIM,
- Revit features for MEP,
- Quality of time-saving,
- Quality of families.

The data for this study was collected by email. All the evaluations were measured on a five-point scale (1=lowest, 5 highest). (39)

5.3 Survey results

Chart 2 shows the real results of the importance-performance analysis. The survey consists of 15 statements. The list of them is shown in the Table 3. There are also average values of each statement. The thesis should focus on the statements with the bold text. The result of the survey sets more specific goals to focus on. Statement number 12 shows the biggest difference between Importance and Performance.



	Questions	Importance	Performance
1	BIM makes design process easier	4.65	3.05
2	BIM reduces the amount of imperfection in documentation	4.85	4.65
3	Revit makes faster designing of documentation for building permit	3.4	2.15
4	Revit makes faster designing of project implementation documentation	3.8	3.7
5	Revit Electrical Circuit System makes creating of circuits faster	2.95	3.05
6	Revit Electrical Circuit System reduces the amount of imperfection of circuits naming	4.05	3.45
7	Circuits naming is suitable for Czech standards and your requirements	3.5	1.65
8	MEP Families are available in sufficient quantity and good usability	4.1	3.95
9	Creating of 2D documentation is easy after the model has been designed	3.85	3.7
10	Visual possibilities of 2D documentation is suitable for Czech standards	4	3.45
11	Revit makes easier some electrical calculations	3.95	1.65
12	Revit allows creation of schedules, panel schedules	4.45	1.9
13	Host families make easier checking of Revit Links	2.45	3.05
14	Revit allows the measurement of cable lengths	3.35	2.45
15	Designing with Revit is pleasure	4.35	3.4

Table 3 – General results; source - author

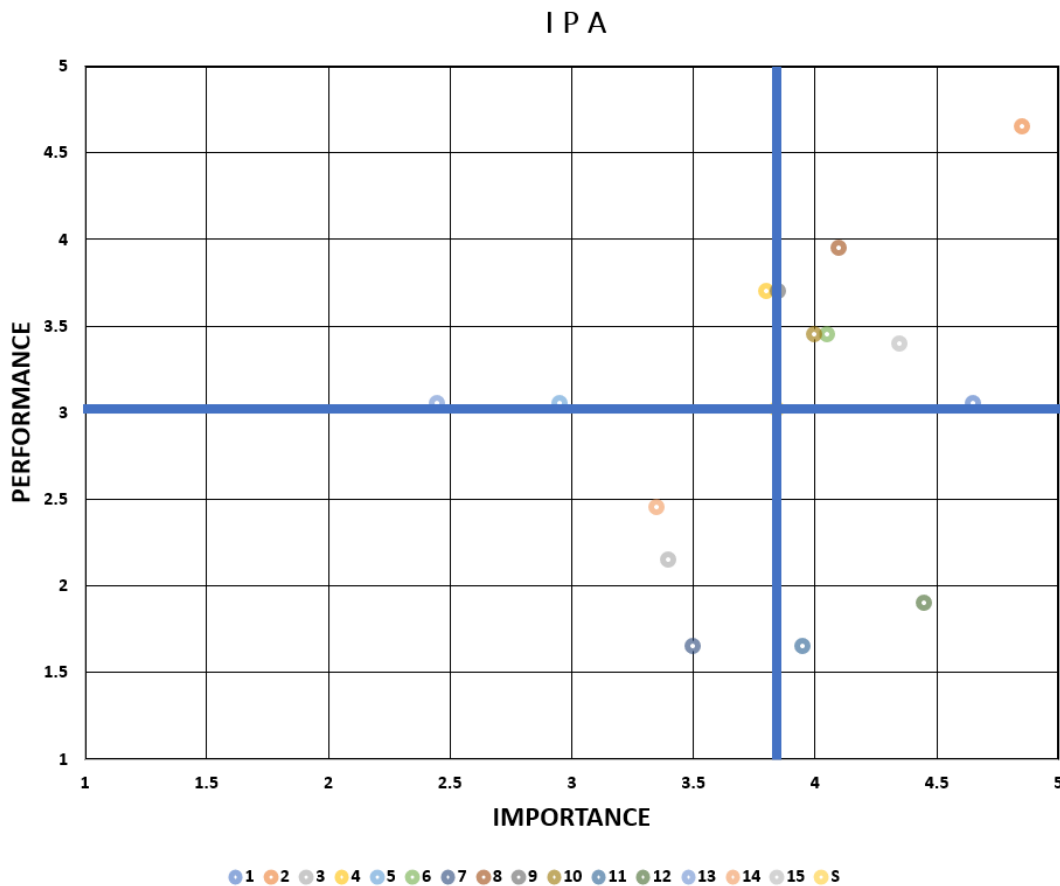


Chart 2 – IPA Results; source - author

5.3.1 Revit allows creating of schedules, panel schedules

The current solution is to use CAD software such as Autodesk AutoCAD and the sheet processor Microsoft Excel. As the main goal is to have all data in one file, the current solution is a problem mainly for contractors and designers. The new solution, based on the BIM model, will be more advanced. The biggest problem of using Revit solution is the difference between Czech and American standards. However, there are several other possibilities how to upgrade the solution of panel schedules. It is also possible to use schedule instead of panel schedule function in Revit. It is necessary to compare all advantages and disadvantages and choose the best solution.

5.3.2 Revit makes some electrical calculations easier

Revit offers a lot of quantity calculations such as:

- Cable Lengths
- Total Connected Load.



- Demand Factor
- Power Factor
- Load classification

All of these values in Revit are set according to foreign standards. It is not possible to change the rules of Load Classification for example. However, it is possible to define them by prepared scales of values. The creation of templates of load classifications and demand factors for all electronic devices is also possible.

5.3.3 Circuits naming complies with Czech standards and your requirements

This is the biggest issue for creating circuits. Each branch of electrical engineering services for buildings projects has different standards. It is easy to find differences even in circuits naming. Generally, it is possible to use four types of circuits naming. The most suitable possibility is Prefixed. It allows to show circuit number and prefixed value in one parameter Circuits Number. However, it is not enough. Designers have to be able to make circuit number more specific. One of the possible ways is to use some other parameters to spread this solution.



6 Suggestions and solutions

As mentioned before, families are the basic of Revit. That is why it must be the first step of settings the workflow with Revit. Precisely made families help users to work effectively.

If a user is not enough experienced to professionally check or repair family, it may cause a lot of problems with modeling. In architecture discipline of Revit, there is usually a problem with a file size of the family. The bigger size, the bigger level of detail. A lot of not properly made families are full of line patterns, groups or imported objects. The goal is to minimize the file size.

MEP families are affected by other problems. The common issue is the absence of connector or wrong set of connectors or their order. There is the different point of view on the level of detail. There is no need to design families in detail. The biggest volume is usually enough. However, it depends on BIM execution plan and LOD matrix.

6.1 Electrical Families Creating and Settings

The first step in creating families is choosing the template and the right category. These templates vary according to future way of use of the family. Some templates are automatically with the host. There is no easy way to change the host of the family after the family is created. That is why it is important to know how the family will be used because the impact in project file can be serious.

There are types of the most suitable templates in electrical services for building:

- Family template wall based
- Family template roof based
- Family template floor based
- Family template face based
- Family template ceiling based
- Non-hosted Family template



6.1.1 Hosted Families

The style of hosting is required when choosing a template, and then category selection is changeable all the time. Additionally, some types of families require a special family template. In electrical discipline, there is one category *Mass*.

The question is which template is the one for users. There is no easy answer. If the hosted template is chosen, there is no possibility to place the family without the host.

Electrical model is usually created at the same time as the architecture part is modeled. So, there is a probability that the architecture model is not finished during that time. Some hosts (walls, ceilings...) cannot be modeled yet.

The face based family template is different. Instances of these families can be placed on any surface, regardless of its orientation. On the other hand, the host must be present in the model or can be replaced by *Reference Plane*.

Reference Plane is an invisible object in Revit project which can be used as a host. It can be placed in every orientation. This is a suitable solution for just a few cases in a project.

The biggest advantage of hosted families is that families can react to changes in architecture/structural model. In most cases, these changes of an architectural model are solved by *Warnings* and user must check all warnings and solve the problems. This solution is possible but takes a lot of time.

Family type	Disadvantages	Advantages
Hosting on family category	When the host is deleted, the family instance or instances are also deleted	Proper reaction on changes of reference link (host movements)
	Only one host category is allowed, more hosts categories mean more separated families. The more similar families, the more same families to manage	All families can automatic change the level they occupy.



	If there is no suitable host in the user needed space, no placing is allowed.	The short list of hosts cause always correctly placed family
	This solution does not allow every family category placing (columns, doors)	
Hosting on face	User has to change the level position after copying manually	Can be hosted by every family
	Possibility of mistakes by setting <i>Schedule level</i>	Can be hosted on reference plane
	Host is not changed after the family is copied	
	When the host is deleted the family is not deleted too but dissociated. <u>Dissociated</u> element is free to move irrespective of a work plane or former host. On the <i>Properties</i> palette, the dissociated element's <i>Hosts</i> parameter value is <i><not associated></i> .	
Non-Hosted families	No automatic reference model changes checking	No problems with copying
	Connections between host and family must be made by <i>Dimensions</i> or by <i>Lockers</i>	Possibility of unlimited placing
	Possibility of mistakes caused by reference model changing without <i>Warnings</i>	
	No possibility of <u>vertical</u> rotation	

Table 4 – Family types differences; source – author



6.1.2 Categories

The second step in family creating is category choosing. Each category has own preset group of parameters, moreover special properties. Especially MEP categories vary category to category. It is very important to understand the behaving of each category and even to the differences in their settings.

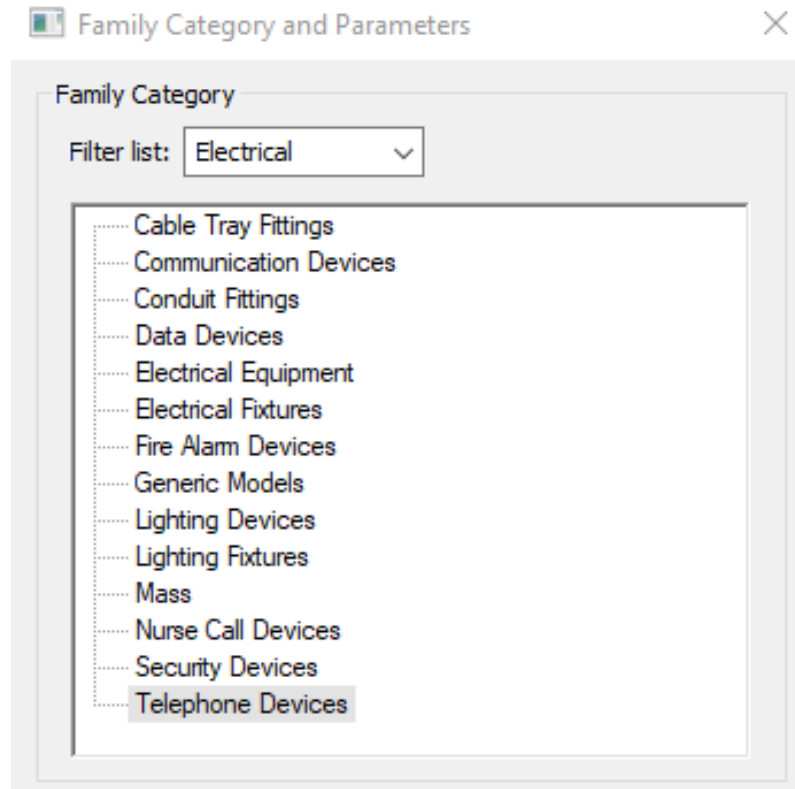


Figure 10 – Categories List; source – author

Some categories have 4 or more different types. This parameter is called a *Part Type*. The *Part Type* parameter provides additional sub-classification of a family category and determines the behavior of the parts in the family. These differences between types can be very significant.

The *Part Type* serves two functions:

- To reduce replacing a different *Part Type* family.

There are times when this is not appropriate. For instance, for fittings, it would be wrong to replace a cross with a transition. Generally speaking, it is a filter inside of category which is not available in the project file.

- To allow calculating or wiring.

For instance, *Electrical Equipment* has 4 *Part Types* options. These options are set in properties dialogue in parameters group *Mechanical – Equipment*



Switch, Other Panel, Panelboard, Switchboard and *Transformer*. This can be the key of the proper function of the family. To create LV system the *Transformer, Panelboard* or *Switchboard Part Type* is needed. The others are not suitable for *Distribution System* definition.

If a family category provides a *Part Type* parameter, the *Part Type* values available depend on the family category. The following table shows which *Part Types* apply to which family categories:

Family Categories	Part Types	Example & Explanation
Cable Tray Fitting	Channel Elbow, Channel Vertical Elbow, Channel Cross, Channel Tee, Channel Transition, Channel Union, Channel, Offset, Channel Multi-Port, Ladder Elbow, Ladder Vertical Elbow, Ladder Cross, Ladder Tee, Ladder Transition, Ladder Union, Ladder Offset, Ladder Multi Port	<p>This category is changeable only with the same <i>Part Type</i> specification. Project file allows <i>Part Type</i> definition as the fittings in every cable tray type properties.</p> <p>Fittings families can include material parameter but, cable trays have no type differ material definition, only general material definition is possible in <i>Object Styles</i> window</p> <p>Cable tray fittings cannot be shared family</p>
Communication Devices		The category is used for PAS (<i>Public Address System</i>) or PAGA (<i>Public Address and General Alarm</i>). This



		category includes all devices such as speakers and other units to make announcements to building users, sometimes triggered by fire alarm systems. This category is not used for distribution amplifiers or control equipment because of lack of connection more than 2 devices.
	Normal	Devices such as speakers or microphones
	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
Conduit Fittings	Elbow, Cap, Union, Multi-Port, Tee, Cross, Junction Box Elbow	<p>This category is changeable only with the same <i>Part Type</i> specification. Project file allows <i>Part Type</i> definition as the fittings in every conduit type properties.</p> <p>Fittings families can include material parameter but, conduits have no type differ material definition, only general material definition is possible in “Object Styles” window</p> <p>Cannot be shared family</p>
Data Devices		The category is used mainly for SCS (<i>Structured Cabling System</i>). This system consists of many smaller elements and separated structures and substructures, that is why good knowledge about wiring is needed.



		<p>Nowadays, a lot of systems use LAN technology. So, even ACS, CCTV or Telephones could be part of Data Device category because only one connector can be shown in the schedule. The more specific category sorting depends on the used system.</p>
	Normal	<p>Devices such as data sockets, switches, routers or servers.</p>
	Junction Box	<p>Wiring is generally drawn through this device and automatically generate wiring branches in Revit</p>
Electrical Equipment		<p>This category can define distributions systems of each Revit electrical system or can be a panel for connections for all electrical categories devices</p> <p>The reason why the user should know these differences are the relations with panel schedules. Each <i>Part Type</i> has own predefined schedule template</p>
	Equipment Switch	<p>This is the only <i>Part Type</i> in this category which works like a load</p> <p>It is usually an equipment of power panel, or BMS (<i>Building Management system</i>) device</p>
	Other Panel	<p>Works as a panelboard for all ELV system. That means to use it for data, security, telephone, communication panels and so on. The value of system type parameter in <i>Family Editor</i> set the type of panel.</p>



		So, the other panel <i>Part Type</i> must use at least one electrical connector, but the only connector 1 defines the type of the panel
	Panelboard	<p>This family use power electrical connector. Power distribution panel can be <i>One column</i> or <i>Two column</i> types of <i>Panel schedule</i>.</p> <p>They usually host the breakers of each circuit.</p> <p>These panelboards are connected to switchboards families.</p>
	Switchboard	<p>Power distribution panel, mainly used for three-phase circuits and this <i>Part Type</i> has no choice of panel schedule template. Switchboard schedules display information about the connected units such as panelboards.</p> <p>Panelboards are connected to these switchboards.</p>
	Transformer	<p>It is used for transformers since the user can set two <i>Distribution systems</i>.</p> <p>No panel template choice is possible</p>
Electrical Fixtures	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	<i>Part Type</i> suitable for all outlets, including receptacles
	Switch	This <i>Part Type</i> has the same behavior as a Switch <i>Part Type</i> in lighting devices



		category. There is one important difference. There is no <i>Switch ID</i> parameter which allows logically set the relation between the lighting fixture and the switch.
Fire Alarm Devices	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	Devices such as detectors, magnetic smoke door holders.
Lighting Devices	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	Devices such as lighting accessories or sockets.
	Switch	This <i>Part Type</i> has been defined to create switch families. This category includes <i>Switch ID</i> parameter which allows logical relation between the lighting fixture and the switch. On the other hand, there is no solution for connecting more than 1 switch to the lighting fixture family.
Lighting Fixtures		This category includes all types of the lighting fixtures and its accessories. This category is the only one which allows switch connection, but this connection is possible only with suitable category and <i>Part Types (Lighting devices and Electrical fixture)</i> . Every lighting fixture family is able to use <i>Light Source</i> both predefined or from an external file in *.ies format.



		<p>Because lighting fixtures can be placed in every position (ceiling, wall floor) <i>Room Calculation Point</i> can be turned on to set its position in the project file.</p> <p>This is the invisible point placed in <i>Family Editor</i> in space to set his level position in the project.</p>
	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	Devices such lamps, emergency lights, outdoor lightings
Nurse Call Devices	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	All devices connected with nurse call system such as emergency buttons.
	Switch	This <i>Part Type</i> has the same behavior as a <i>Switch Part Type</i> in lighting devices category. There is one important difference. There is no <i>Switch ID</i> parameter which allows logically set the relation between the lighting fixture and the switch.
Security Devices		<p>Several parts of building industry can involve the use of this category. Generally, ACS and CCTV families are part of this category.</p> <p>In some smaller buildings models, even fire alarm can be part of the security system, that is why some families are</p>



		created twice with different connector 1 and with a different category.
	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	All devices such as stand-alone electric locks, card readers, biometric readers
	Switch	This <i>Part Type</i> has the same behavior as a Switch <i>Part Type</i> in lighting devices category. There is one important difference. There is no <i>Switch ID</i> parameter which allows logically set the relation between the lighting fixture and the switch.
Telephone Devices	Junction Box	Wiring is generally drawn through this device and automatically generate wiring branches in Revit
	Normal	All devices in this category telephones and its accessories.

Table 5 – Family Part Types definition; source – author

6.1.3 2D Families – Symbols

Most of the electrical engineers are used to use symbol characteristic of each device such as receptacle. The symbolism in families can be incorporated using symbolic lines to which user can attach visibility and lines style. There are options depending on the level of detail. To use this option, there are a few conditions that the user should know.

- The symbol will adjust according to the scale. It means only one scale is suitable for this solution.
- The symbol can change its dimensions according to the 3D geometry of the family easily.
- The changes in the family are more difficult because of the relationship between geometry and symbolic lines.



That is why this is not the most suitable solution, however, two more advanced solutions are possible. To nest a *Detail component*, based on family category called *Detail items* and to use *Annotation Symbol*, based on family category called *Generic Annotations*

Family Category	Change in scale	Shows real drawings dimensions	Symbol offset
Generic Annotations	No changes, the families have a printing size.	No, the dimensions are same all the time. The solution is fully independent out of scale.	Symbol offset has still same printing value. No changes needed after scale is changed
Detail Item	Yes, the behaviour is same as 3D geometric behavior. They have model dimensions	Yes, the dimensions show real values of the geometry.	The offset value has modeling value. If the scale is changed the value of the offset must be changed to keep the same difference between 3D geometry and symbol on the sheet.

Table 6 – Symbols families; source – author

The decision on which way is better depends on the type of the families and their geometry. Most electrical outlets should use *Generic Annotation* method. There is even a handy solution of symbol horizontal and vertical offset. This offset must be created inside of generic annotations, because of proper behavior in scale changing.

To be able to control offset parameters in the project file, all parameters inside the nested family must be linked with host family parameters.



6.1.4 Switch symbol based on generic annotation template family

The best example is a switch. Following text describes workflow of making symbol family based on generic annotation category. This text presumes the symbol has been drawn and the knowledge of creating 2D geometry was managed. For making more symbol types in one family visibility parameters should be used to differ symbols in *Family Types* tab.

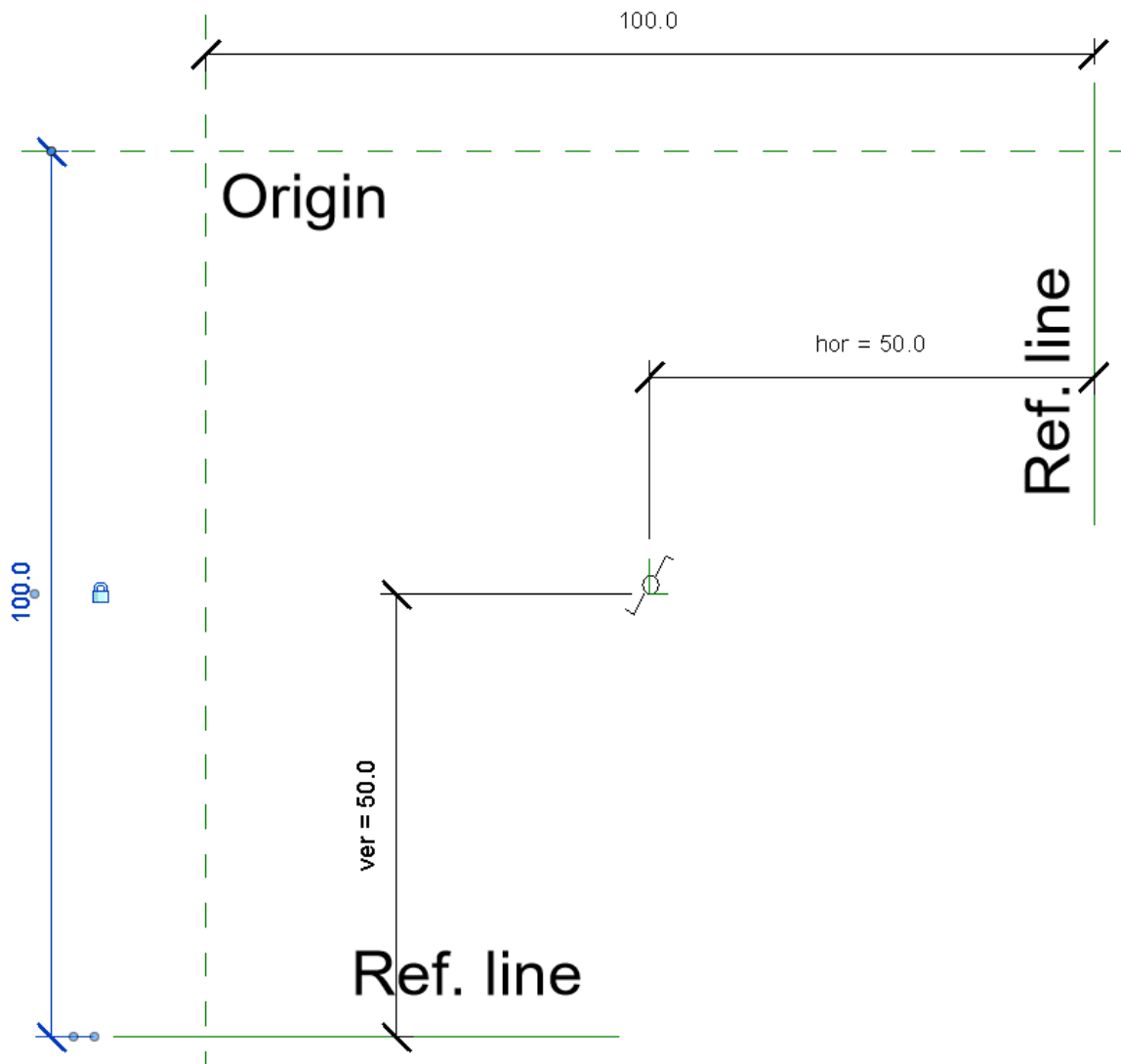


Figure 11 – Generic Annotation; source – author

If the symbol had been created already and the designer knows that the origin of the symbol is suitable for his family, it is time to start design the offsets.

The solution consists of reference lines. The longer reference lines are the borders. These lines set the limits of offsets. In this case 100mm. It is suitable in most cases. All dimensions values are in millimeters. This value is a real printing value. Although 100 millimeters seems to be a small value, it is not. Most



electrical sheets are in scales 1:50 or 1:100. That means 100mm is 10,000mm in the model. It can be sometimes even width of the whole building.

The longer ref lines were created and locked by dimensions to the reference planes.

Two reference lines must be created even with the intersection in the origin of the symbol and grouped. This causes the offsets of the group as one object. Dimensions between reference lines and instance parameters will control the offset.

This can be the final solution, but it is no comfortable for the user. The better solution is to set step with the default value 0, not 100.

New parameters must be created: Horizontal and vertical offset. Definition of them set as an integer. Integer values are defined as a number that can be written without a fractional component. Also, a negative number is included.

With IF formula is the last step to define this parameter. This is the simple definition of IF formula in Revit.

- IF: =IF (Condition, True, False)

In this case is a little complicated

- Horizontal offset:

Hor = if(Horizontal offset > 0, 100 mm - Horizontal offset * 1 mm, 100 mm - Horizontal offset * 1 mm)

- Vertical offset:

Ver = if(Vertical offset > 0, 100 mm + Vertical offset * 1 mm, 100 mm + Vertical offset * 1 mm)

Nested instance parameter Horizontal and vertical offset must be linked to lighting device family. The visibility is solved in electrical device family. This solution is shown in Figure 13.



family Types

Type name: _____

Search parameters

Parameter	Value	Formula
Graphics		
Horizontal offset (default)	50	=
Vertical offset (default)	-50	=
Other		
hor (default)	50.0	= if(Horizontal offset > 0, 100 mm - Horizontal offset * 1 mm, 100 mm - Horizontal offset * 1 mm)
ver (default)	50.0	= if(Vertical offset > 0, 100 mm + Vertical offset * 1 mm, 100 mm + Vertical offset * 1 mm)
Identity Data		

Figure 12 – IF formula in Family Editor; source – author

6.2 Electrical connectors

The electrical connector is the most important part of the electrical family. It allows connecting the family to another, for example such as a panelboard. However, this type of connector is not the only one. Because three kinds of connectors for electrical systems are defined.

- Conduit connectors
- Cable tray connectors,
- Electrical connectors

These connectors have many parameters, especially the Power part of connectors. These parameters are key for calculation and some of them even for definition of *Electrical Equipment*

Electrical Equipment category has a *Part Type* called Other panel. This is the *Part Type* defined for all panelboards except with electrical connector Power – unbalanced and balanced. This connector number one defines the type of ELV panelboards such as data panel or telephone panel. Following table shows the names and explanations of connector parameters.



Parameter name	Description	Unit	Parameter type
Electrical - Loads			
True Load Phase 3	Calculated based on (Apparent Load Phase 3) x (Power Factor).	Watt	Power
True Load Phase 2	Calculated based on (Apparent Load Phase 2) x (Power Factor).	Watt	Power
True Load Phase 1	Calculated based on (Apparent Load Phase 1) x (Power Factor).	Watt	Power
Power Factor	Percentage of power attributed to this connector. Active only when Power is specified as System Type.	-	Number
Apparent Load Phase 3	Calculated based on (Voltage) x (Current - Phase 3). Active only when Balanced Load is False and System Type is Power, and Number of Poles >2.	VA	Apparent power
Apparent Load Phase 2	Calculated based on (Voltage) x (Current - Phase 2). Active only when Balanced Load is False and System Type is Power, and Number of Poles >1.	VA	Apparent power
Apparent Load Phase 1	Calculated based on (Voltage) x (Current - Phase 1). Active only when Balanced Load is False and System Type is Power.	VA	Apparent power



Apparent Load	Calculated based on (Voltage) x (Current). Active only when Balanced Load is True and System Type is Power.	VA	Apparent power
Voltage	The voltage specified on the connector. Active only when the System Type is Power.	V	Voltage
System Type	Possible values are: Data, Power - Balanced, Power - Unbalanced, Telephone, Security, Fire Alarm, Nurse Call, Controls, Communication.	-	-
Load Classification	Possible values are: HVAC, Lighting, Power, Other.	-	Load Classification
Power Factor State	Possible values are: Lagging, Leading.	-	-
Number of Poles	Possible values are: 1, 2, or 3.	Integer	Number of Poles
Identity Data			
Index	A unique identifier for a connector in a family (read only).	-	-
Primary Connector	Possible values are: True or False (read only). A single connector of each discipline is allowed to be primary in each family. The family's electrical data that displays in a schedule is derived from the primary connector.	-	-



Connector Description	A description of the connector.	-	Text
Utility	Indicates whether the connector is exported on a site utility to an Autodesk Exchange file (ADSK).	-	Yes/No

Table 7 – Connectors parameters; source – author and (42)

6.2.1 Conduit Connectors

These connectors can be added by clicking the *Conduit Connector* button on the *Create tab* in the *Family Editor*. The *Options Bar* provides two choices for conduit connectors. (37)

- Individual Connector

This option is for placing a single connection point in a specific location on the equipment. The location is in the center of the face. These connectors allow user to adjust the angle and to set the radius or diameter of the connector according to the family category settings.

- Surface Connector

It is a unique and powerful option because it allows for the connection of multiple conduits at any location on the top of the panel. These connectors allow user to adjust the angle of the surface to which the connector is attached.

This parameter is typically used in fitting families. The second use has an application in an *Electrical Equipment* family. In a project, the conduit can be drawn to or from the surface. The placing is easy. Selecting the surface will activate the Surface Connection mode, which allows you to drag the connector location to any point on the surface. (37) This process is repeatable several times for the same surface connector.

6.2.2 Cable Tray Connector

The *Cable Tray Connector* button on the *Create tab* in the *Family Editor* allows you to place a point of connection for cable tray. These connectors are like the individual conduit connector. Properties can involve the angle and the setting



the height and width of the connector. (37) Width and Height are set by cable tray in the project.

6.2.3 Electrical Connector

Clicking on the *Electrical Connector* button on the *Create tab* in the *Family Editor* allows you to place the connection for wiring. This type defines which of the *Electrical Equipment* systems can be used. The properties table allows the user to define the system of the connector prior to the connector being placed.

All extra low voltage system electrical connectors have no properties settings. The only settings use power connectors.

6.3 Project Definition and Scheduling

“Modeling power systems with a building information modeling (BIM) solution such as the Autodesk Revit MEP 2015 program is just as important to project coordination as modeling systems that contain large amounts of physical data, such as HVAC systems.” (37)

The key component of an electrical systems model is the data within the model elements. This information determines how systems can be put together. Properly used data can be extracted for use in analysis.

Most of the electrical components are relatively small such as receptacles and junction boxes compared to other system components (HVAC model), but a large number of them is placed in a project and the larger number of items the bigger potential for interference. Nowadays, building ELV systems have become more complex with advances in modern technology (37). The need of some electrical system is defined by law and national standards.

6.3.1 Distributions systems

There are two points of view in BIM and Revit. The first is space requirements. It enables users to coordinate the hard lashes. On the other hand, BIM also allows the user to build intelligence into the model by establishing *Distribution Systems* and relations between electrical families. The profit is the future scheduling. Although Revit enables calculations there are many limits, especially for European users.



Another advantage is the ability to keep track of loads from the smallest circuit panels all the way to the main electrical equipment. This is the importance of assigning a *Distribution System* to your electrical power equipment. These intelligent connections are invisible, so no conduits or cable trays are needed. To create a *Distribution System*, the following process must be done before.

About 90% of all settings in Revit project file is in Manage part of ribbon and MEP Settings icon and Electrical Settings. At first voltage, definition must be defined. There are 4 columns:

- Name - 230V this name will be shown in *Distribution System* table
- Value - 230.00V default value of the voltage
- Minimum - 207.00V minimal value according to the standard specification (-10%)
- Maximum - 243.8V maximal value according to the standard specification (+6%)

Electrical Settings ? X

- Hidden Line
- General
- Angles
- Wiring
 - Wire Sizes
 - Correction Factor
 - Ground Conductors
 - Wiring Types
 - Voltage Definitions
- Distribution Systems
- Cable Tray Settings
 - Rise Drop
 - Single Line Symbology
 - Two Line Symbology
 - Size
- Conduit Settings
 - Rise Drop
 - Single Line Symbology
 - Two Line Symbology
 - Size
- Load Calculations
- Panel Schedules

	Name	Value	Minimum	Maximum
1	0 V	0.00 V	0.00 V	0.00 V
2	230 V	230.00 V	207.00 V	243.80 V
3	400 V	400.00 V	360.00 V	424.00 V

Figure 13 – Voltage Definition; source - author

Several voltage definitions can be set. Every project template should allow connecting all electrical devices and system in the specific country. The *Distribution Systems* table defines *Distribution Systems* that are available in your project.

- Name - A unique name that defines a *Distribution System*.



- Phase - Three or single, selected from the drop-down list, no another choice is possible
- Configuration - Drop-down list to select *Wye* or *Delta*, three-phase systems only, no another choice is possible
- Wires - The number of conductors 3 or 4 for three-phase, 2 or 3 for single-phase.
- L-L Voltage - Selection of a voltage definition that represents the voltage measured between any two phases, related to the phase and wire selections, not available for single phase 2 wires system.
- L-G Voltage - Selection of voltage definition that represents the voltage measured between a phase and ground. L-G is always available.

	Name	Phase	Configuration	Wires	L-L Voltage	L-G Voltage	^
1	400/230V, Delta	Three	Delta	4	400 V	230 V	
2	400V, Wye	Three	Wye	4	400 V	400 V	

Figure 14– Distribution System; source - author

6.3.2 Circuits Creating

Electrical circuit is a standalone category. This category cannot contain any loadable families. By connecting the family to the panel this family category instance is created. It is the important category used in panel schedules.

Although *Distribution Systems* are created, there is no possibility to use it without properly created family. The only family category which can use it is *Electrical Equipment* category with correct *Part Type*.

- Electrical component and branch circuit panel circuit

The first step is selecting one of loaded low-voltage branch circuit panels and assign a *Distribution System* to the panel from the drop-down on the *Options Bar*. The thesis of circuiting is upstream, from component the branch circuit panels to the transformer.

By selection of any component *Modify, Electrical Equipment* contextual tab appears on the ribbon with all possibilities of circuiting, such as Power button to allow users creating a system. Click on this button to create a power circuit and select the branch circuit panel.



There are two ways a user can select a panel: either by clicking on the panel in the drawing area or by selecting it by name from the Panel drop-down list on the Options Bar. The drop-down shows all available panels with the same *Distribution System* in whole project file

- Panelboard and transformer circuit

The steps for creating a circuit have been repeated for the transformer. The transformers families must be defined with *Part Type*: Transformer, to allow the family to connect *Secondary Distribution System*. This secondary system is the default value for another components or panel. The primary *Distribution System* is the default value for the transformer to connect.

6.3.3 Power Diagrams

The common way to communicate the *Distribution Systems* is by a riser or one-line diagram. This is the schematic representation which displays the relationships between electrical distribution equipment in a clear and easily readable manner.

Unfortunately, there is no automatic way. On the other hand, it does not mean that user cannot create a diagram in a project file. The drafting tools can help to create diagrams. The issue is there is no connection with 3D components. It is the same as to do this schema in another CAD platform.

6.3.4 Wirings – cable lengths, cable naming

Once created, users can edit circuits to add or remove components or connect another circuit panel, add wiring runs, and view circuit and panel properties. Wiring is not necessary, but it can help to show wiring that concealed within other elements such as walls (43). Wirings can define the used types of cables. The project allows a lot of wires types which can be defined by the user. The first type specified in the wire types table dialog is the default in the project. This type should be used for the majority of wirings in the project for higher effectivity.



The fields in the Wiring Types table are as follows:

- Name - user-defined string
- Material - Copper, Aluminum
- Temperature Rating - project specific temperature rating
- Insulation - Depending on the material selected
- Max Size - This is the maximum conductor size
- Neutral Multiplier

Using this field, the user can specify how the neutral conductor of a system is sized. (37)

- The Neutral Multiplier

It is applied after the neutral size is calculated, either by sizing the same as the hot conductors or according to unbalanced current.

- Neutral Required

If selected, all wiring runs using this wire type will include a neutral, even in the case of a balanced 3-phase load, where a neutral may not be required by the load itself. If not selected, a neutral will be omitted for balanced loads and will be included for unbalanced loads

- Neutral Size

In this field, you can specify whether the neutral is sized by Hot Conductor Size (the baseline for the size of the neutral will be the same as the hot conductor) or by Unbalanced Current (the neutral will be sized based on the amount of current flowing in the neutral).

- Conduit Type

It is used for the voltage drop calculations: Steel or Non-Magnetic. (37)

	Name	Material	Temperature Rating (°C)	Insulation	Max Size	Neutral Multiplier	Neutral Required	Neutral Size	Conduit Type
1	THWN	Copper	60	THWN	2000	1.00	<input checked="" type="checkbox"/>	Hot Conductor Si	Nemagnetické
2	XHHW	Copper	60	XHHW	2000	1.00	<input checked="" type="checkbox"/>	Hot Conductor Si	Nemagnetické
3	AYKY	Aluminium	90	XHHW	2000	1.00	<input checked="" type="checkbox"/>	Hot Conductor Si	Ocel
4	CYKY	Aluminium	90	FEP	<input type="checkbox"/> 2000	1.00	<input checked="" type="checkbox"/>	Hot Conductor Si	Ocel

Figure 15 – Wiring; source - author



The new part of Revit 2018 is designed to count cable length and the user can design the path. The button Edit Path is situated in Electrical Circuits part of the ribbon. The Edit Path allows customizing the path both in floor plan and in 3D views. There are 3 preset path modes in Revit:

- All Devices

It contains the path from the farthest device to the closest. This solution follows the offset values of each device.

- Farthest Device

Use just the farthest device and panel.

- Custom

User-created solution. This solution is hard and takes a lot of time.

This solution is suitable for very precise values of cable lengths. On the other hand, *Edith Path* function is still the invisible lines. There is no way to use them in the floor plan or for one-line schedules.

6.3.5 Circuits naming

Circuits naming varies country to country, that is why broad user possibilities should be allowed, but they are not

. There are 4 types of naming. In the instance properties of a panel, the user can set and fill parameters values about it that appears in the schedules or panel schedules. To define how the circuit name tags will appear in your drawings user fills Circuit Naming parameter and Panel Name parameter, also other settings concerning calculation is set in panel properties tab.

- Panel Name

Panel Name is not just a type of naming and even standalone text parameter. This option places the name of the panel in front of the circuit as a prefix, after the number of the circuit is written. The user can use a separator between the panel name and circuit number by using the Circuit Prefix Separator parameter.

- Prefixed

This option has similar properties as panel name type has. To place the prefix defined circuit naming the Circuit Prefix parameter must be used. This



parameter takes place in front of the name, Circuit Prefix Separator separate prefix by a value such as dash, dot or slash from circuit number when a wire or device is assigned to the panel.

- Standard

This option is the simplest way. It does not add any additional information to the circuit name and to the tags that display the circuit number on the drawings.

- By Phase

This option displays the Circuit Naming by Phase label. The definition of each phase can be defined in the Electrical Settings. These values are shown in front of the circuit number

Circuit Naming	Circuit number					
	1	2	3	4	5	6
Panel Name	RH.1	RH.2	RH.3	RH.4	RH.5	RH.6
Prefixed	S/1	S/2	S/3	S/4	S/5	S/6
Standard	1	2	3	4	5	6
By Phase	R1	R2	S1	S2	T1	T2

Table 8 – Circuit Naming; source - author

6.3.6 Special use of system solution

As it is shown in *Table 8* several different types can be created. This naming is the definition for all connected circuit on the panelboard. There is no choice to set for example prefix S for first 10 circuits and later set another prefix, for instance, V with values from 1 to 10 again. This is a complex problem in Revit which makes this naming tool not as much advanced as it should be. The circuit naming is the key for all participants of building industry even for inhabitants.

There is one possibility. To use By phase circuit naming definition and sort it according to phase from 1 to 10 on each phase, for instance. Although this can be used as a solution for naming, the calculation part is not correct. The panel would be unbalanced. No calculation results would be valuable to use. However, the sorting is not automatic. The user must connect all circuits and after create the panel schedule which allows to sort each circuit and set it own position on the panel. By the positioning of circuits, the names would be changed. If anyone does not want to use calculation it is a way. On the other hand, only 3 different naming



types are available. That is why this solution is not recommended too and to do not use calculation because of naming is not a good BIM solution.

6.3.7 New solution with the use of shared parameters

This solution has been designed for low voltage system. Generally, more information is needed than just number and one another value such as prefix with a separator. Another information is defined as a shared parameter, because of using them in the schedule.

Huge problem is to define names of 3 phase devices. Czech standard is to name 3 phase devices with one number as normal 1 phase devices are named. Revit system solution is to define them with 3 numbers such as 1, 3, 5 or 2, 4, 6.

All shared parameters are created with capital letters. It is a good habit to do it like this. Every user can clearly recognize which parameter is system or project parameter and which is shared parameter.

- Panel name - System parameters used in schedules
- Circuit Number - System parameters used in schedules
- CIRCUIT NUMBER - New shared parameter, can be used instead of system parameter Circuit number, because of 3 phase wrong naming standard
- LIGHTING FIXTURE TYPE - New shared parameter, define the use of lighting fixture (emergency or standard)
- CIRCUIT TYPE - New shared parameter, define circuit type such as receptacles, lighting fixtures, switches.
- LIGHTING CONTROLLER - define type of switch or controller.
- CIRCUIT NAME – final parameter. This parameter is full name parameter designed for dynamo script.
- Examples of tags - PN/L1s

“Panel name”/“CIRCUIT TYPE”“CIR. NUMBER”“LIGHTING CONTROLLER”

Or the more useful option for future use is:

“Panel name”/“CIRCUIT NAME”



Revit allows combining parameters into one parameter. This works just in schedules and there is one big disadvantage. This combining always create new parameter which is not shared. This parameter is only inside of the schedule. It helps a lot if user want to create simply schedules with minor number of columns. Also, this information are connected with original values and react to the changes of values.

This functionality CIRCUIT NAME must gain too. To design it Dynamo script has been designed, because Dynamo allows the easiest interoperability with Revit software.

6.3.8 Dynamo script - Combining parameters

Dynamo is a graphical programming interface that customizes building information workflow both geometrically and informationally. It is an open source visual programming platform for designers, similar to Grasshopper, that works under Rhinoceros. Nowadays, Dynamo is installed as part of Revit. To use Dynamo user must click *Manage tab* where *Dynamo* and *Dynamo Player* is situated. *Dynamo Player* provides a simpler way to execute Dynamo scripts.

- Filtering visible scripts and loading new scripts
- Viewing current script status
- Launching the script
- Editing the script in Dynamo

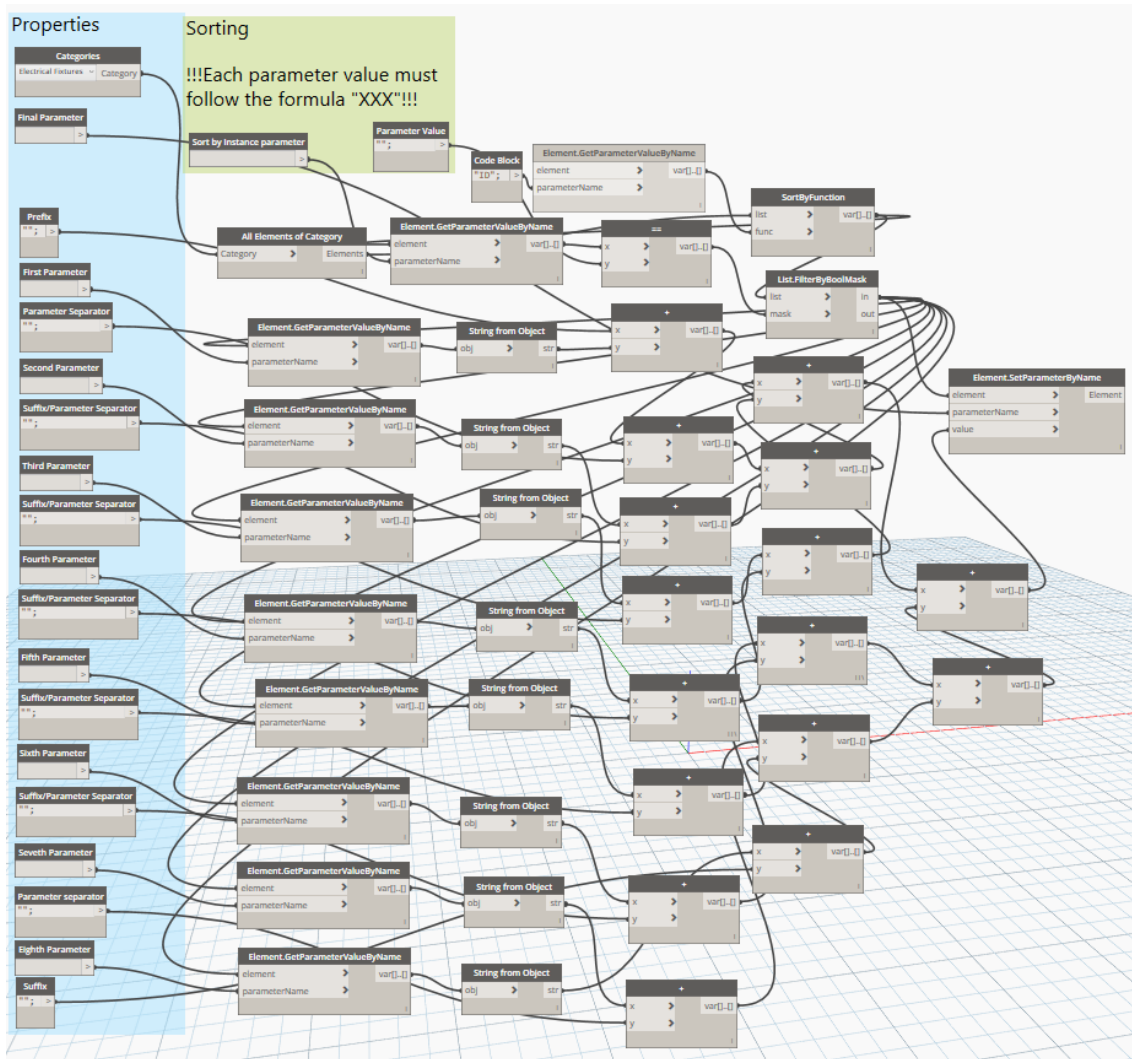


Figure 16 – Combining parameters; source - author

With the Dynamo, Revit has become stronger BIM tool than others. *Dynamo Player* allows using dynamo scripts without advanced experience. Shown scripts called Combining parameters allows users to combine parameters from one category. The sorting has been designed also. There are two sorting options according to type or instance parameter. The user can define these nodes:

- Sorting by instance parameter
- Sorting instance parameter value
- Family category
- Final parameter
- Prefix, parameter separator, suffix
- Combining parameters

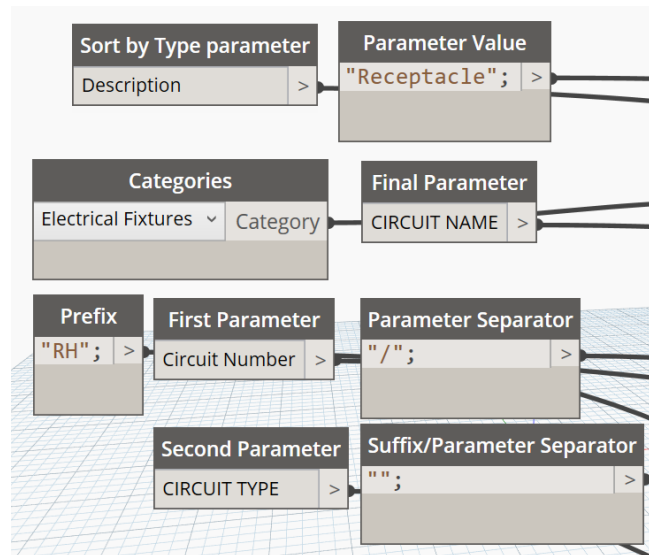


Figure 17 – Combining parameters - Properties; source - author

Eight parameters can be combined at most. There is a prefix before first parameter, suffix at the end and separator nodes between them.

All text values (prefix, separators and suffix) have to be defined with quotation marks. Without them, Dynamo cannot combine any parameter. Even when user does not use these nodes, empty quotation marks must be used.

The user can define several types of this script which he needs to use. After that, *Dynamo player* will easily solve his parameters issues.

The use of these scripts is unlimited. Even instance parameters such as offset can be combined or just copied to another shared parameter.

6.3.9 Example of another use of this script:

The electrical designer can check the offset of receptacles in the project just to create the filter with the copied values of offset parameter. This parameter is invisible in the drop-down list in the filter table. That is why this script must be used to automatically copy the values to a new shared parameter or to another system parameter such as *Comments* to make it filterable. These filters can differ receptacles colors according to the copied offset value.

6.4 Schedules

Many angles or viewpoints at building model are in Revit. Schedule views are simply another view of the model. In this way a schedule allows the user to



view the data within the components in an organized easy to manage table instead of looking at the physical 3D elements of the building. The description of schedule is a tabular display of information, extracted from the family properties in a project. These parameters can be both instance and type.

The most important thing to know is that all scheduled data still collaborate with model families. Each change of value is the change of the model. For example, by schedule user can change dimensions of windows. This way of data management is truly efficient, and the future use of BIM model increase and even its accuracy, and coordination within Revit project.

On the other hand, not all parameters can be scheduled. This is the limit of use. That is why the Dynamo script had to be created. Only some system and all shared parameters can be scheduled. The ability to track and manage objects can help with cost estimation and material takeoff. (37) It can also sort, filter or collapse multiple instances onto a single row

Six types of schedules are defined in Revit:

- Schedule/Quantities
- Graphical Column Schedule
- Material Takeoff
- Sheet List
- Note Block
- View List

For electrical design, the Schedule/Quantities is the best option. These schedules allow select one category to be scheduled. In the following design this option has been used.

6.4.1 Circuit naming possibilities with separated panelboards

To avoid a clash or information data duplication, system solutions are highly recommended. As mentioned before, only one prefix can be set in *Electrical Equipment* category which is the only suitable category for the panelboard design.

The first step to improve this bad feature of Revit is to set the final conditions. The most advanced part of creating circuits must be scheduled. One



proper design schedule template is enough for most designers, but Revit allows Panel schedule and schedule of quantities. All of them can be used with limitation.

The main goal of this part of the thesis is to make information modeling accurate, effective and to avoid mistakes. This solution is possible. The user has to use both types of the schedule. To make a more advanced schedule with several prefixed with one-panel schedule/quantities has to be defined.

The key to this use is Panel name. Schedule of quantities does not make difference between ID of each element. The user can choose just sorting according to panel name and all elements will be sorted, furthermore, Revit does not highlight the duplication of the panel names.

All schedules update automatically when user modify the project. For example, if the user changes the prefix value, all circuit numbers update in the schedule.

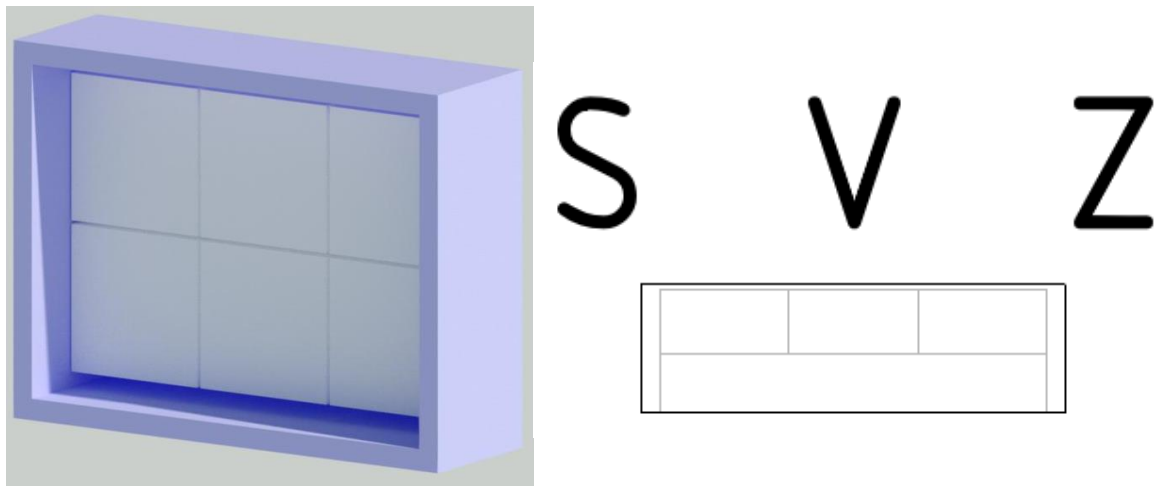


Figure 18 – New Panelboard Render and Floor plan; source - author

Figure 23 shows two different views on newly designed panelboard. This panelboard is, in fact, an assembly of 7 panelboards. The cover or frame can be called switchboard. This frame hosts all “bricks” of panelboards. There are 7 separated families connected by system circuits. The inner panelboards can be also defined as the circuits breakers. This template uses simple bricks as an example.

The floor plan shows separated parts of *Electrical Equipment* in fine detail level. There are also 3 separated letters. These letters are optional in value and in offsetting. The “brick” family include annotation as most of the electrical families. The controlling of annotation is same as was shown in thesis before.



The values of annotations are linked with circuit prefix parameter. If the value of circuit prefix is modified the same value will be in the annotation. These letters also help the designer to select the correct switch.

6.4.2 Panel schedule

Revit uses 3 default templates which can be user upgraded. These templates are defined in *Family Editor* only in *Electrical Equipment* category.

- Two Columns, Circuits Across

This type uses imperial units and is recommended for using in the U.S.

- Two Columns, Circuits Down

This type uses imperial units and is and considered as generic

- One Column

Branch panel template with metric unit and one column for European use.

Table 9 defines parameters of panel schedules template.

Panel Feature	Description
Branch Panel	Panel name (defined in properties table of each panel)
Volts	Distribution system supported by the panel
Phases	Number of phases available from the panel. Project example use NUMBER OF POLES shared parameter, defined as a type parameter.
Wires	Number of wires specified for the distribution system definition assigned to this panel
Mains Rating	Rating of the mains feeding the panel
Mounting	Type of mounting (Surface etc.)
Enclosure	Type of case enclosing the panel. It is a cabinet for electrical equipment, seen by users to prevent electrical shock to equipment users. It is also protection from the environment.
Location	Room where the panel is installed
Supply from	Name of the connected panel or switchboard



Trip	Rated trip current for a circuit breaker
Poles	Number of poles on the circuit breaker
CKT	Whole value of the parameters <i>Circuit Number</i>
MCB Rating	Values of miniature circuit breaker used to protect lower current
Phase A Phase B Phase C	Apparent load (VA) for each of the phases
Total load	Total apparent load for all three phases
Main Type	Manufacturer or type
AIC Rating	The value of amperes interrupting current AIC, also referred to AIR -ampere interrupting rating.

Table 9 – Panel schedule parameters; source – author and (44)

The panel schedules have one useful feature. The user can move the circuits positions. That means the numbers of circuit can be independently changed by *Move up* and *Move down* buttons. It is a big advantage when other circuits are added in the final phase of project or even in facility management.

Manage tab offers to edit own template based on one of three templates. *Edit a Template* button switch the user to schedule editor. This editor allows to use all parameters assigned to *Electrical Circuits* category. It is a big limitation. So no information from connected electrical devices cannot be easily copied to the panel schedule. Although new shared parameters can be assigned to *Electrical Circuits* category, no feature to copy information is not offered. Even to create the sub schedules from circuits breakers or from the parts of panelboard are not possible.

The Dynamo script has been designed to solve this problem and to allow the copying between categories. The script is shown in Figure 20. This script can be defined for each panel and used with dynamo player to be still up to date with electrical information. It is a simple script which copy one value from one category to *Electrical Circuits* category. If user needs to copy more than one parameter, he can use another script designed in this thesis.

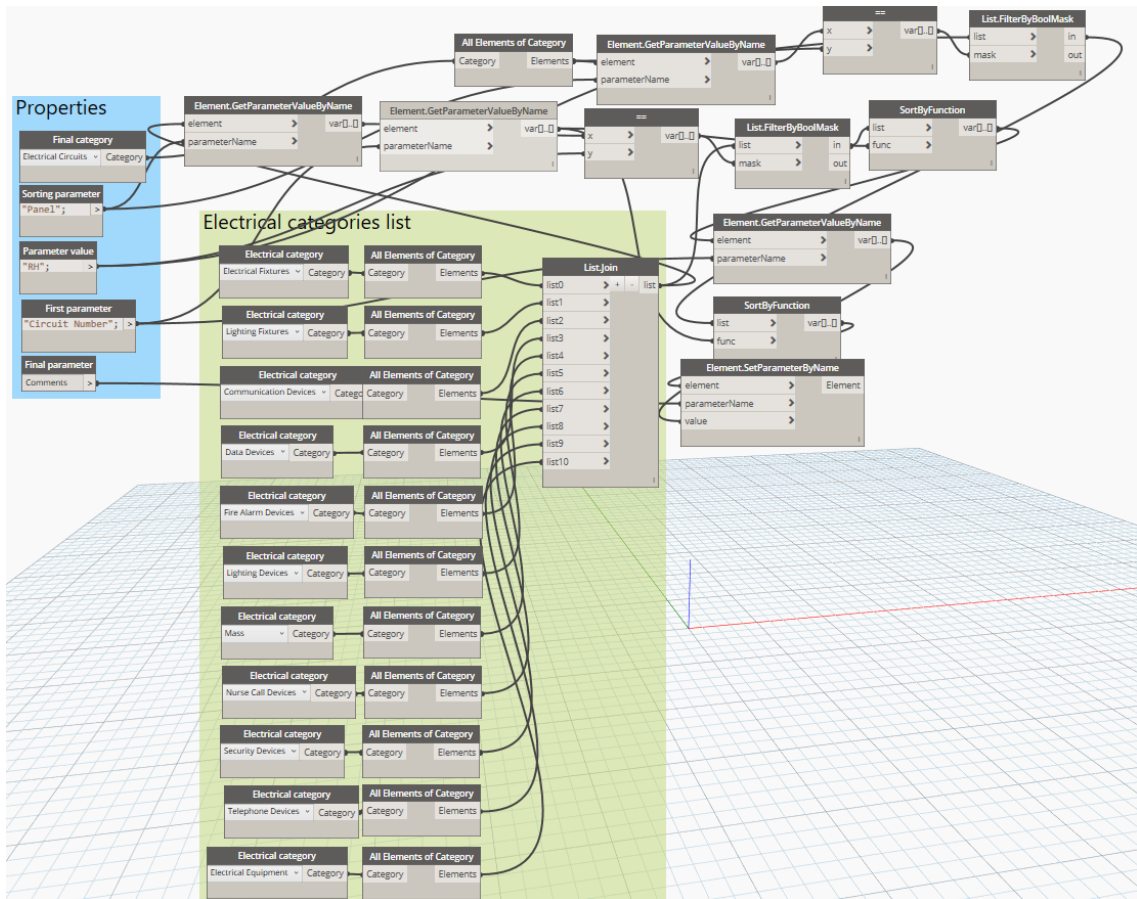


Figure 19– Copy parameters between categories; source - author

6.5 Families and scheduling

The last part of this thesis is concerned with families. It is an example of the basic electrical families and their circuiting and scheduling. These families contain all different categories, both ELV and LV systems. ELV categories and their families are easier to use in the project.

These families do not contain all the parameters necessary to use. Only parameters used for connector sets are included, as well as a few basic parameters, such as electrical current. To load a lot of new parameters with own titles is not recommended. The proper way is to set all need parameters for each category as the project parameters.

If these parameters are shared, they will be shown in schedules and annotations and thus prevent mess in the project definition. Families should be versatile, which means free of redundant parameters, materials, and line patterns or even not used families.



6.5.1 Low voltage wiring combinations other panel and families

This ELV design performs a similar behavior. As explained before, all ELV connectors have no other setting. Because of that, only one family has been designed.

On the other hand, most ELV families have several type options. This issue is quite unrecognizable in the first part of the BIM design. The problem is a clash detection.

If the family has more types with different geometry and the difference is controlled by visibility parameter of each solid, the clash will be detected. It is not caused by a mistake of a designer usually, but the family creator's fault instead. Although another types geometry is not visible, it is still detectable.

As an example, a speaker's family has been created. It is a communication category family with 2 different types:

- Rectangular speaker – 150 x 150 x 110 mm (Width x Height x Depth)
- Circle speaker – 200 x 300 mm (Diameter x Depth)

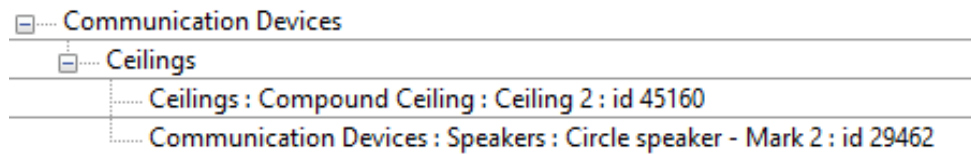


Figure 20 – Interference report (Communication device); source - author

Figure 25 shows the issue in a more precise way. The dark blue part represents the used type of the speaker and the light blue part stands for an invisible type defined by visibility parameter. In this case, the clash would be detected by Revit Interference report tool. This is not correct and must not be used.

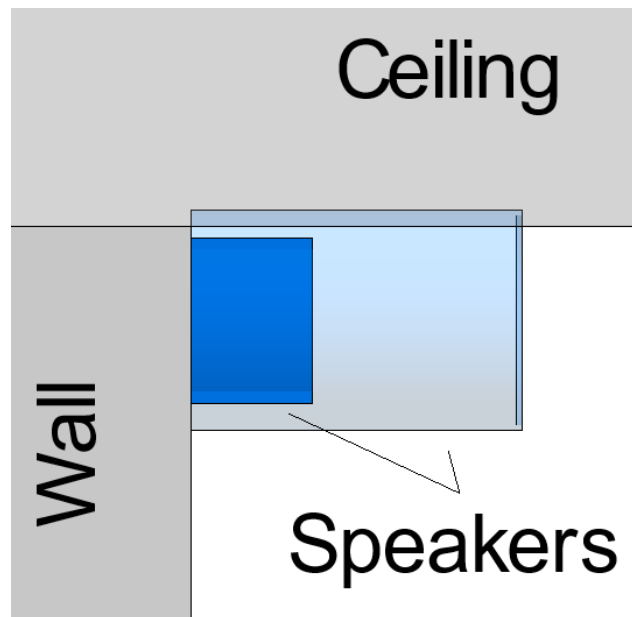


Figure 21 – Speakers; source - author

The proper solution is more elegant, and it works correctly. The key is to use nested families. A nested family is not detectable in the project when another family type is used.

This Speakers family includes 3 different families. First, an annotation category family. This is not detectable in any way. This family is visible only on floor plan controlled by its visibility setting.

The next two families are communications category family with no connector and special parameters. They are set to be only in fine detail level and allow the user to rotate them. The selection of type is defined by the parameter. No other visibility solution is needed in final *Family Editor*. Only the connector has to be set.

To control this family, ELV panelboard has been designed too. It is *Electrical Equipment* category with Other panel *Part Type*. Its number one connector defines the communication category ability. The circuit naming and creating of the circuit is the same as in LV design.

6.5.2 Electrical fixture (switch and socket)

The most significant objects of electrical design are switches and sockets. This is something that every edifice includes. There are many types and many ways of wiring. For this thesis, 230V socket and 230v switch were used.

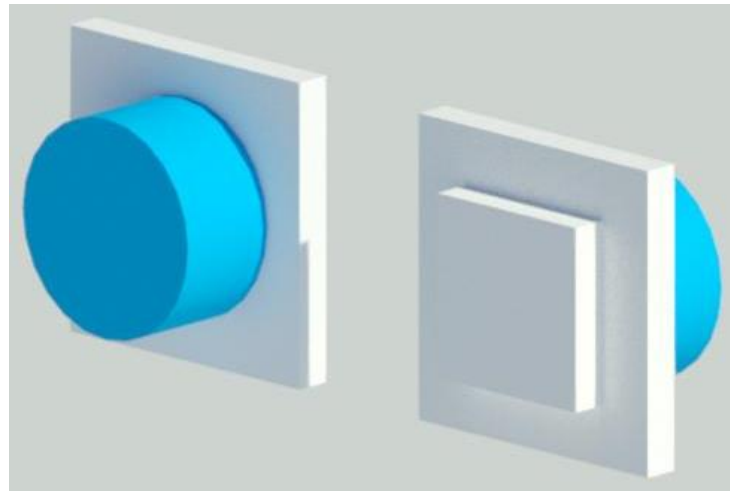


Figure 22 – Switch 230V; source - author

These families have the same dimensions and even some parts.

- Socket box

These boxes vary according to a multi-gang installation. A lot of manufactures provide these boxes and usually are not a part of the switch. It is another article with own article number.

- Mechanism

It can be one part with the cover plate. If it is a separated article, then there is a need to design it as a separate family to be able to schedule it.

- Cover plate

Cover plate can also be a separated family because of different properties such as material or color. Another option is to create it as one family with the mechanism.

- Clipping plate

The separated object of switch or socket system. Can vary according to multi-gang installation. Should be modeled separately with own article number.

If there are similar objects for more Revit categories such as the clipping plate, only one category can be used. The best solution is to set all parts of this system as an electrical fixture and the mechanism or mechanism with clipping cover define as a proper category.



6.5.3 Lighting Fixtures

The last part is lighting fixture family definition and its wiring, because this category has special features. It can be controlled by switch *Part Types* of any category. But only lighting device category allows naming of the switch according to the circuit.

This category can occupy almost every spot in the building. The lighting fixtures hang from ceilings and structures or are mounted in floors and stairs. Some of them can just stand alone. This is the reason why wide variability is needed. There is two disciplines lighting fixture fulfill.

- Geometric

The geometric part allows you to design all types of shapes needed. All types of hosting can be used for lighting fixture category. However, the shape is not the main part of these families. Usually, most buildings use several shapes of lighting fixtures. That is why a few well created parametric families can be enough for the basic use.

Geometry relates to room calculation point. This point helps the designer to define the belonging to the level because the placing of the family can cause clashes. For example, floor mounted light can have reference level under the level of the building. That is why room calculation point must be used. It is an invisible point which can occupy every place in *Family Editor* according to the recommended final position of the lighting fixture.

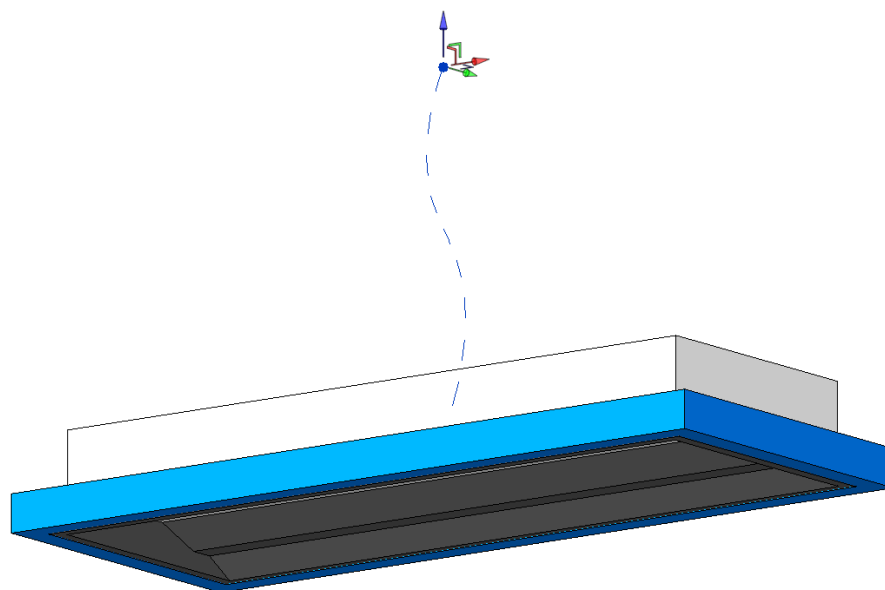


Figure 23 – Room calculation point; source - author



- Photometric

Two same families can define 2 different output behaviors by different photometric setting. This is the second part of lighting fixture definition. The lighting source definition can be set numerous directly to family types table and set to each type separately. There is also a parameter allowing load light source with an external file in *IES* file type.

Most *IES* files are defined by manufacturers and provided to designers. However, only *ies* format is possible to use in Revit. The photometric data for a specific lighting fixture can be applied to a lighting fixture family regardless of the geometry of the family. (37)

Lighting fixture should be a part of the electric circuit and families can also contain electrical data, which allows for a connection with *Distribution Systems*. These parameters are included in the family made as a part of this thesis. There are no other parameters which can be added as project parameters. The only connector for the basic light is Power.

- Switch ID

Every properly defined lighting fixture family has a special feature, possibility of switch connecting. The switch circuit is created as a normal power circuit in the project. It helps to automatically define the name of the connected switch. The switch naming the parameter is called *Switch ID*. This parameter must be defined in switch family. After connecting the name, the parameter will be set in lighting fixture automatically, too.

There is one issue. Only one switch can be used. The only solution is to define all used switches with a same *Switch ID* and sort switches in schedule according to these values.



7 Conclusion

BIM is the future of building industry. The profit is clear and the profit for us is related to our experience and the way of use. That was the reason behind writing this thesis. The goal was to suggest a solution and to create a complex guide for all MEP designers, especially for the electrical ones. This is the first complex document dealing with electrical design which has been written and offers such a deep know-how. After reading the thesis, Revit user with a basic experience will be able to work alone including family creating and template setting.

Revit is a strong tool and allows many options of usage. It is still just a software designed mainly for the US market. Although a lot of tools are suitable for most of European countries, the MEP part has some limits. The use of results of this thesis solves several problems and makes Revit a more advanced must have software for BIM engineers. This thesis can motivate people to accept Revit software and BIM as a truly profitable solution.

Although the thesis has already predicted issues, more specific goals, and problems were determinate with IPA research and some of them were founded even during the designing of the Dynamo scripts. The verified results predicted issues and helped to establish main goals, but the number of interviewed people was limited to 26 people. On the other hand, all of them have rich experience with Revit and electrical design. This proof makes the research more advanced.

7.1 Families creating

Families creating is the most important part in Revit. That is why the thesis has offered several points of view. All differences between categories, family templates and connectors have been explained. Because the understanding families is the key to effective work, almost all settings had to be determined.

- Categories

All possibilities of categories were researched and explained. The table shows all differences. The most important part of categories in electrical design is *Part Types*. That is why the focus on *Part Types* was on the higher level, even



3 types of *Electrical Equipment* were designed to explain possibilities and inspire another interested people.

- Templates

This part explained differences between hosted and non-hosted families. This is a topical issue. Although thesis explained the differences no decision which way is the best can be determined. There will be always a question what is better. Generally speaking, hosted families are more suitable for the smaller model. The non-hosted ones are better because of freedom in space.

- Modeling

The third part of this goal contains geometric modeling rules and problems with clashes. One of the possible solutions was explained and several families have been created, furthermore, a schematic characteristic was determined and designed. There are 2 ways how to create the symbol. The used tables show the differences and profit of both solutions.

The modeling of the family's examples is included to help designers create their own families or to improve them. Of course, there are several ways how to model the family, but the used way is the most suitable according to the research, available information and the author's experience.

7.2 Project definition

Proper determined families must collaborate with advanced project template. That is why the most important setting has been described and tested. This part was mainly about the understanding of all possibilities. To have the possibility does not mean to use all of them. For example, cable lengths.

It is still necessary to know that some solutions can be useful, but they are not effective due to its limitations. Some of them take a lot of time and the result is not the best. This part explained all settings necessary to define own standards in voltage definition for instance.



7.3 Data management

True BIM is just a work with information and making schedules. There are some limits in Revit. Thesis suggested the solution with circuit naming by using more prefixed circuit names. It is just a 50% of the solution, because to make the useful schedule is the key. That is why even Dynamo scripts have been designed. It shows how easy can be schedule defined with a little Dynamo help. Thesis created only a few Dynamo scripts, but it is only the first step for future BIM and Revit solution. With Dynamo, even all calculation will be provided in Revit and no matter which standard user undertake.

User who will be able to use one software as a complex tool for BIM electrical design will be the most profitable in future. This part was the most interesting and more important for users. As was mentioned with Dynamo, even panel schedules are now a strong tool in Revit.

7.4 Other future possibilities of electrical design in Revit

There are still many things to do in the BIM industry. The future work should deal with project file with prepared families and their groups. That is meant to prepare panelboards with bricks inside to be able to use more than one prefixed circuit name for all branches of electrical design both ELV and LV or to convert this solution to circuit breaker. This solution is highly recommended because there is no other way how to do it faster.

Another future suggestion is the solution of multi-gang switches, sockets and all other devices used by this solution. To have all basic combinations of multi-gang devices would be definitely useful in the first phase of project designing. To set these devices takes always a lot of time. The best solution is to define project file with all these assemblies.

Another future work can compare the ways of creating families and their file sizes. That means to define which modeling tool is more suitable for smaller file size and to also compare the effectivity of modeling and file size saving. Some families are used hundred times in a project, so the file saving would be significant.



There will be many possibilities what to do and many things to improve. The best way to define what is good is by gaining experience. That is why the solutions can change in the future due to software change or maybe Dynamo.

Parametric scripting tools like Dynamo are definitely the future of BIM. The possibilities of this software are underrated. The designer still does not know what a strong tool Dynamo is. It is the easiest way how to improve own work in Revit and how to be more advanced.



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12 Apendix

12.1 Families

- Communication Panelboard.rfa
- Lighting fixture.rfa
- Panelboard.rfa
- Panelboard component.rfa
- Socket 230V.rfa
- Speakers.rfa
- Switch 230V.rfa

12.1.1 Nested families

- Circler speaker.rfa
- Lighting fixture annotation.rfa
- Panelboard annotation.rfa
- Panelboard detail item.rfa
- Rectangular speaker.rfa
- Socket.rfa
- Socket annotation.rfa
- Speaker annotation.rfa
- Switch - single frame.rfa
- Switch - socket box.rfa
- Switch annotation.rfa
- Switch button.rfa



12.2Dynamo scripts

- Combining parameters_instance sorting.dyn
- Combining parameters_type sorting.dyn
- Copy parameters between categories.dyn

12.3Other documents

- Shared parameters.txt
- Project example.rvt