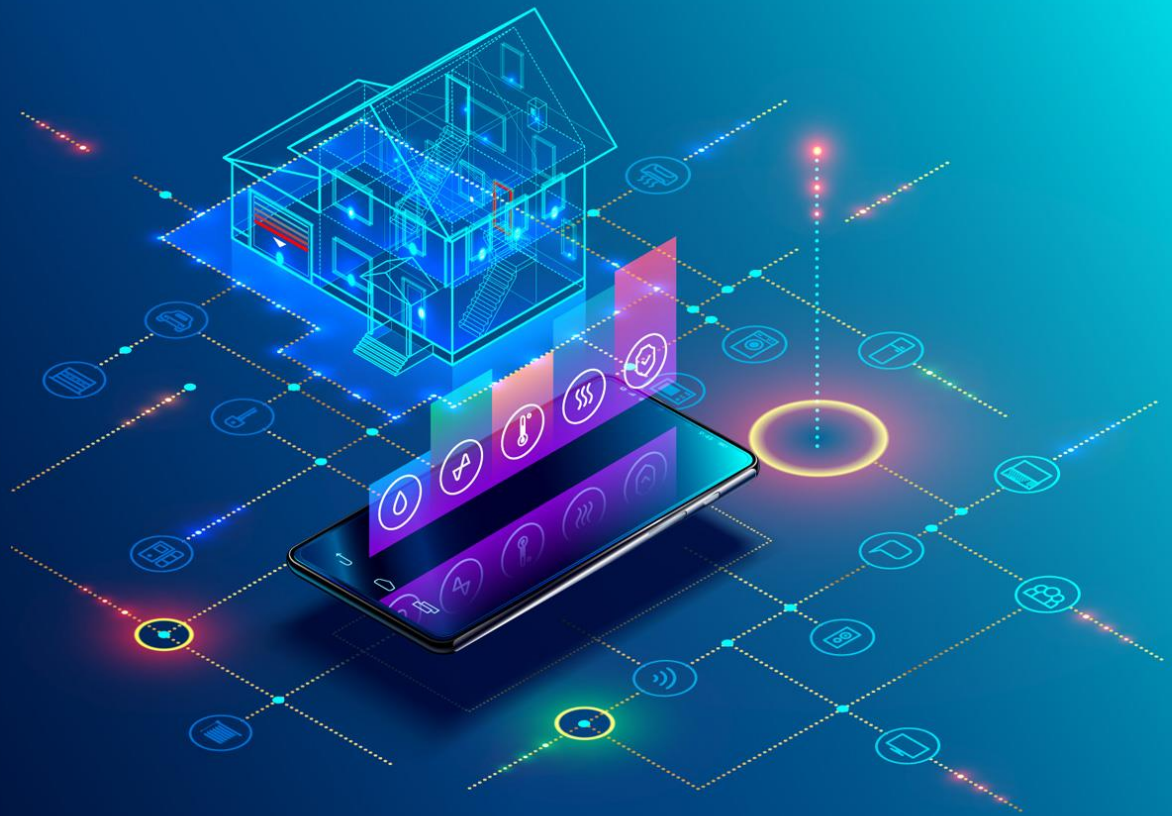# Guidelines for as-built BIM modelling of existing buildings

Deliverable 2.4

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BIM-SPEED

Harmonised Building Information Speedway for Energy-Efficient Renovation

Disclaimer

BIM SPEED

Guidelines for as-built BIM modelling of existing buildings

Deliverable 2.4

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Publishable executive summary

This guide aims to establish a set of general recommendations and rules that BIM modellers and companies can implement to ensure that a proper workflow is made for renovation projects. Depending on the considered BIM Use case, the modeller will adopt certain techniques to ensure the model is adequately made for the chosen use case and to avoid over/under-modelling. The document will refer to two main 3D modelling software applications; REVIT and ARCHICAD. The proposed guidelines highlight what are the practical steps to take when modelling using these two applications and guarantee that the model is in accordance with the BIM Use Case selected.

The general rules have a broader view over the BIM modelling in relation to the items that a user might face while working on projects. This can be for example risks of switching from older to a newer version of the software, the importance and requirements of a project template, the necessity of setting coordinates of the project, creating levels, and adopting the correct level of development of the model, how to manage the model, as well as splitting a BIM model and making a proper export of IFC and other formats.

Since renovation projects require a lot of data collection and BIM Models are built based on the collected data, chapter 2 is focused on how to build such a model considering the main important sources of information: point clouds, 2D drawings, images, PDF files, etc..

Planning renovation projects are different from new buildings because of the uncertainty, ambiguity of the information from a BIM models perspective since they require to include a lot of initial data as well as the result (building after renovation). Structuring the information, creating special parameters to show data in the BIM Model, presenting several ways of modelling by introducing "modelling phases", and having a different level of development in the same model are some specific items tackled in this document.

List of acronyms and abbreviations

AEC   Architecture Engineering Construction

AECO   Architecture Engineering Construction and Owner

BIM   Building Information Modelling

BEM   Building Energy Model

BEP   BIM Execution Plan

BREP   Boundary Representation

CDE   Common Data Environment

HVAC   Heating Ventilation Air Conditioning

IDM   Information Delivery Manual

IFC   Industry Foundation Classes

LOD   Level of development, Level of Detail

LOI   Level of information

MEP   Mechanical Electrical Plumbing

MVD   Model View Definition

O&M   Operate and Maintenance

RASCI   Responsible, Accountable, Supportive, Consulted, Informed

RIBA   Royal Institute of British Architects

R&D   Research and Development

Definitions

3D Mesh: Is a collection of vertices, edges, and faces that define the shape of a Polyhedral (three-dimensional shape with flat polygon faces, straight edges, and sharp corners).

BIM: Use of shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions[1].

CDE: Agreed source of information for any given project or asset for collecting, managing, and disseminating each information container through a managed process[2].

Closed BIM: Is a BIM environment where all the stakeholders use the same software and the same version of a BIM authority tool.

Design phase: A phase is a part of the services an AECO design company can offer for a building project.

Photogrammetry: The technology of acquiring reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena.

Modelling phases: Most used BIM Application, allow to include a modeling timeline that may be correspondent to the timeline of the project (but not necessary, since one may want to group more construction phases into one modeling phase). Modelling phases can highlight how the building will develop over time, including as is situation, what will be demolished and what will be new constructed.

Open BIM: Is a working approach where stakeholders can share their data with any compatible software using vendor-neutral data formats.

RIBA stage: Defines the broad outcomes and strategic aims for a stage in the building process. A RIBA stage does not contain detail tasks and it is addressed to both client and project team to better understand what the goals for each step in the process are. The stages are part of the RIBA Plan of Work.

Workset: This term is specific to REVIT software and refers to a collection of 3D objects in a workshare project[3].

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[1] Definition according to ISO 19650-1/2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)- Information management using building information modeling – Part 1. Concepts and principles

[2] Definition according to ISO 19650-1/2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)- Information management using building information modeling – Part 1. Concepts and principles

[3] https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Revit-Collaborate/files/GUID-86810293-6510-4F5A-8009-27B4767CA136-htm.html

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1. INTRODUCTION

The goal of the document is to describe the practical steps and requirements for BIM modelling in the context of the BIM SPEED project. Currently, the vast majority of BIM projects refer to newly designed buildings, and the guidelines available are related to this type of project. Renovation projects and the purpose of the BIM model must be approached differently than "new building" projects since the base of information is different. In contrast to the new-building sector, where information is generated progressively throughout the design process, working on existing buildings requires gathering information from various sources to depict as-built conditions. Stakeholders in the AEC industry that are designing new buildings in a BIM environment have already implemented workflows that are tested, reliable, and stable.

This guideline is aimed and targeted specifically at that part of the AEC industry responsible for creating a BIM model, namely BIM modellers, BIM coordinators, and BIM managers regardless of their experience with BIM. The BIM Speed consortium has defined several BIM Use cases that are relevant for residential renovation projects to assist stakeholders in defining the information required for their specific renovation project. In Deliverable 1.1, the BIM Speed Methodology Toolkit was established, and the BIM Use cases were presented along with the associated business process and methods to accomplish the BIM Use Case. In Appendix 1, a glance at the toolkit is shown.

This document is oriented towards demonstrating the best practices and proposing specific recommendations in creating a BIM model in direct correlation with the BIM Use cases proposed. For a better understanding of how to apply the proposed principles, the authors described and detailed the principles for the two most well-known BIM authoring tools available on the market for creating BIM models. The principles can then be transposed to other BIM modeling software applications, and so they are not restrictive in this sense. This document will address the various sources of as-built information as well as their utilization in reconstructing a BIM model. Most often it is needed to share the BIM model with other stakeholders working on different disciplines to perform various BIM Use cases even when they use different software applications (for example energy analysis that cannot be done with the modelling tool). The standardized file to exchange the models between different stakeholders is the .ifc type, but the parties involved in a project can exchange files using other formats. The two authoring tools are only used as a means to describe and exemplify but the document is not emphasizing that these are the only two software to use. Principles can be applied to other software, but the different settings in so many software in the market make it impossible to address all.

2. General rules for project setup and BIM model creation

Proper creation of a BIM model translates into time-saving for the whole project and cost savings for the design company and the other relevant parties. This chapter refers to general requirements to create a BIM model taking into consideration the demands and specifications of the renovation project.

This section is aimed at highlighting the main requirements in creating a project template and understanding the specifics related to MEP project templates. It will describe the main units to use in a project, the need to set up the model on the coordinates and the ways to acquire them, and the definition and specification of the grids. Additionally, the chapter offers a short description of the level of development, how to create proper 3D objects to be used in renovation projects, what are the modelling phases, and how to manage the BIM model when a breakdown into separate models is required. Key points on responsibility and data ownership and different versioning of the BIM tool are also highlighted.

In the end, the chapter will showcase the necessary steps to successfully export ifc files from the two mentioned authoring tools.

2.1 BIM Model Project template

Having a BIM model project template (hereafter referred to as a project template) helps to create a certain standard when modelling. The aim is to ensure consistency across all the designers on the project in terms of information flow during the project regardless of the number of users.

Additionally, a project template ensures that repetitive and tedious work is reduced to a minimum. Tasks such as creating title blocks, exporting settings, styling, adding company parameters used across all projects (name, address of the company, logo, etc), scheduling, and setting of the project units, should all be done once in the project template. All these activities performed in a project template, which is done only one time, will ensure that a significant amount of time is saved.

Project templates are different from one company to another. Commonly, the project template is created by the BIM coordinator or BIM lead in the company (for roles description see Appendix 3). Best templates are usually created by the BIM coordinator with the active involvement of the BIM designers team. There are the main actors in creating a BIM model, so their perspectives and feedback should be highly considered.

For projects where multiple companies are involved, each with their template, a common ground should be established, and the templates should be discussed in a BIM kick-off meeting so that information is shown consistently on all the models. Thus, the project templates should give a certain degree of flexibility. The project template should have all the settings expressed in the following subchapters. views and MVD (a set of IFC parameters setup to be exported based on the further usage of the IFC file) are created so that the exported file will be done fast, without any errors and the intervention of other designers. The MVDs are linked to the BIM Use cases for which the model will be created. Most used MVDs refer to coordination, analysis (e.g., for structural or energy analysis), or quantity take-off, however,

specific MVDs can be made depending on the specific needs of a project (e.g. to export only the facades for a specific contractor).

For each type of export, a view should be created and presented in the project template. Every template should have a detailed guideline prepared for the designers to read. This guide will make it easier for new people joining the project to get accustomed to the principles by which the BIM models are created within a company.

Project templates should be different for new projects and renovation projects. Each of these types has different workflows and different types of required information. For example, in a renovation project designers will need to show what elements will be demolished and which elements will be kept as in existing conditions (Figure 1).
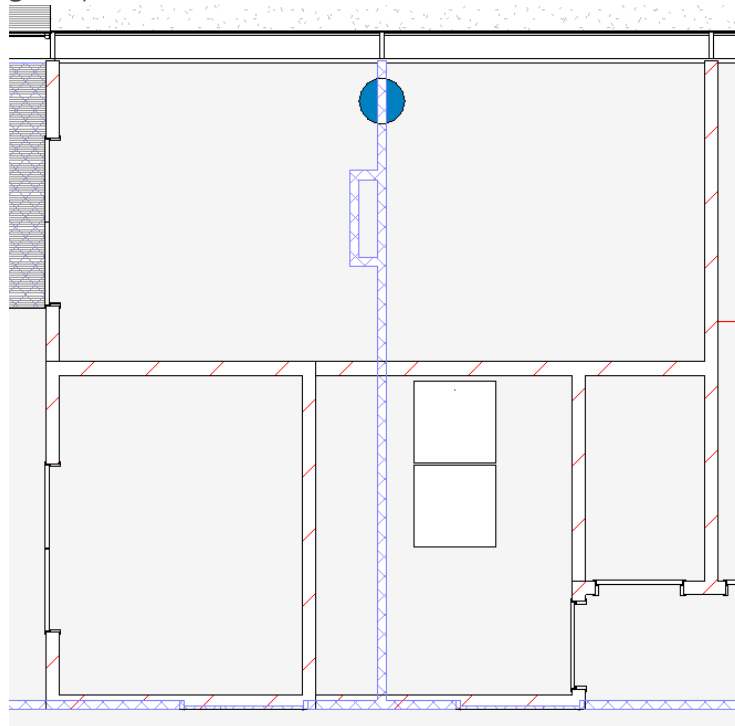
Figure 1. Blue wall is an existing wall that is marked for demolition. The walls with white are new.

The naming convention is one aspect that must be considered when creating a template. Since the template may contain some of the most used families, it is recommended to name them according to a BIM standard (e.g., NL-SfB standard) or the company standard. If the software allows, create a view of the described naming convention so modellers can refer to it during the naming phase, thus minimizing the risk of potential errors. Naming convention not only refers to 3D objects, but also the views created inside the model, schedules, rooms, levels and grids, and all other parts of the project documentation including the name of the BIM model file. The naming convention is described in the BEP.

2.1.1 MEP project template

MEP BIM project templates (Figure 2) have some particularities that differ from a project template for an Architectural BIM template or Structure BIM template. First of all, MEP has multiple

subdisciplines. Depending on the size of the project, the MEP model can be a single file or multiple files (see 2.6), i.e., one file for each subdiscipline (e.g., Electrical BIM model).

It is recommended to start with an MEP template that covers all the subdisciplines and then split the template into subdisciplines and remove what is not necessary for that specific subdisciplines. Acting in this manner will ensure consistency between the subdisciplines in terms of text styles, line styles, title blocks, to name only a few.
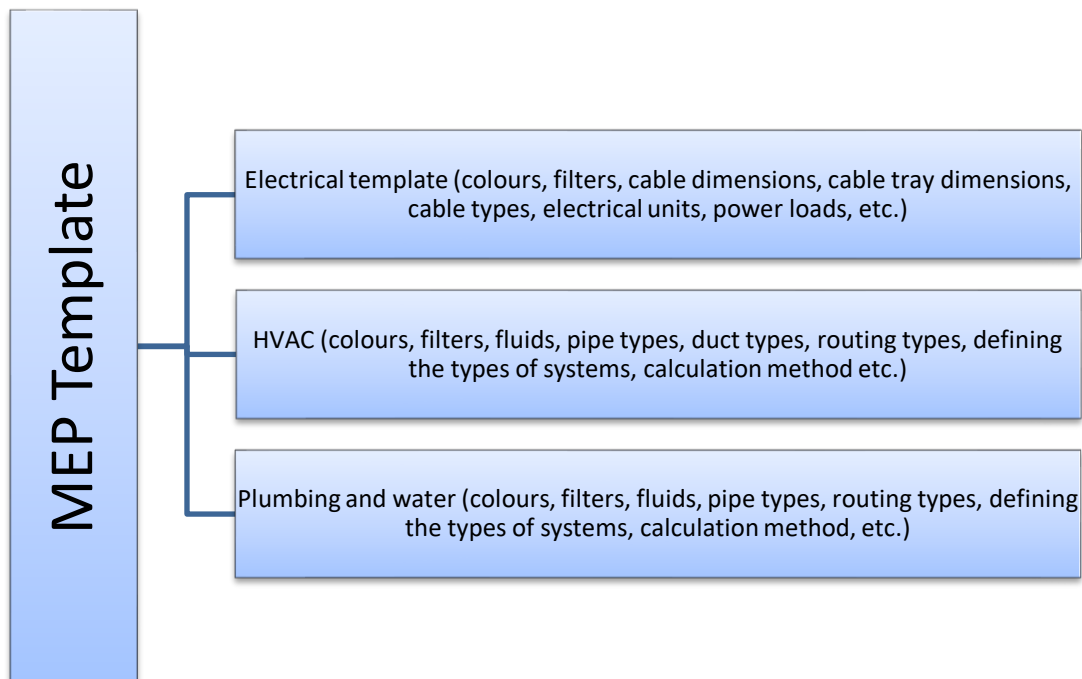
Figure 2. Example of items that an MEP template should contain, based on subdiscipline. Software Revit.

Residential buildings do not have so many types of installations as office buildings. Nevertheless, it is important to have all the MEP systems defined in the template, at the start of creation. Based on engineering requirements when the work starts, unused systems can be removed from the template if it is considered that this will increase the size of the model. Besides the name of the system used inside a building, the temperature of the fluid circulating through the system should be considered when creating a new MEP system in the template. A comprehensive list is as follows:

- heating radiators: supply and return.
- heating floor: supply and return.
- heating district: supply and return.
- cooling split system: supply and return.
- cooling network: supply and return.
- potable water system.
- Sewage system.
- Rainwater system.
- Greywater system.
- Ventilation – fresh air.

- Ventilation – supply air.
- Ventilation – return air.
- Ventilation – exhaust air.
- Natural gas.

It is recommended to set up all the types of piping used In an MEP template according to the material, diameter, fluid circulating inside the pipe, and proper fittings. As an example, a project template will contain copper, steel, polypropylene, polyethene, and PVC pipes. Polypropylene pipes can be for water distribution, heating systems, or cooling systems, each with a different colour and different specifications. The same setup must be done for ducts and electrical systems.

The colouring of any MEP system should be done in the template. MEP systems are coloured in 2D and 3D according to international standards or national standards. A few widely used colours are the following:

- Heating: supply – red
- Heating: return – blue
- Gas pipe - yellow
- Sewage – brown (usually)
- Potable water – blue
- Domestic hot water - red
- Ventilation – supply - green
- Ventilation – return - blue

Not all BIM modelling tools allow the possibility to model MEP elements. Since the number of settings and customizations needed for an MEP model are more than for a structure model, choosing an appropriate software application is important. Depending on the strategy of every company, one may choose only one single software application that can cover all three disciplines or different software applications for each discipline.

2.2   Coordinates and units

Project units and setting the coordinates of the model are very important for further project coordination and clash detection. When combining multiple models into one central model, all the models must be in the correct place with respect to each other (e.g., the structural slabs to be above the architectural floor). Arranging the models into the correct place can be done afterward, but it is not advised since it can lead to errors and time-consuming process of revising. For this reason, it is highly recommended to set the units in a project template. As such, setting the units should be part of the project template. If project specifications require to work in different units than the company's standard, then this activity should be done at the beginning of the project. The units for the model are specified in the BEP. The following units should be defined:

Common units:

- Length: m (2 decimal)
- Area: m2 (2 decimal)
- Volume: m3 (3 decimal)

- Angle: degree (3 decimal)

MEP units:

- Density: kg/m3
- Friction: Pa/m
- Power: kW
- Power density: W/m2
- Pressure: Pa
- Temperature: Celsius
- Velocity: m/s
- Air/ pipe flow: L/s

- Duct size: mm
- Cooling/ heating load: W
- Current: A
- Frequency: Hz
- Conduit size: mm
- Pipe density: kg/m3
- Pipe size: m

Working in a BIM environment requires having the model placed on the correct and real-world coordinates. The coordinates are dependable by the country's own reference coordinates system and must be provided by the BEP. When working with multiple models, the coordinates must be placed correctly in one model (either in a master model or in an architectural model). From that master 3D model, the coordinate will be transferred to the rest of the models.

Coordinates are obtained via the topographic surveys. Most commonly, coordinates are stored in an Excel file or a civil .dwg file. In Table 1, for the most commonly used software tools, general workflows on setting up the coordinates are given:

Table 1. Setting up coordinates

Software	Setting the coordinates inside a model
REVIT	Based on a .dwg file, .csv or .txt files, coordinates can be acquired in the model. Coordinates can be stored in a Master 3D model or, commonly in the Architectural 3D model. Other models will acquire their coordinates from the previously mentioned model.
ARCHICAD	Use the Coordinates Pallet and choose the appropriate type of coordinates according to country.

2.3   Level and grid definition

Defining the levels (or floors) and grids are an important activity and should be performed at the start of the BIM modelling. Considering this is a renovation project, the information comes from the existing 2D drawings or a point cloud if available. If one must add new levels needed during the design process, then it is advised to add them from the start as much as possible (e.g., adding a new ceiling level). Adding new levels while in an advanced stage of modeling can result in spending more hours than estimated.

The name of the level should be easily identifiable and as short as possible. The name and the graphic representation of the levels should be part of the template. The name of the levels is part

of the naming convention and should be found in the BEP. Depending on the size of the project (2.6) the levels and grids are created in a master model or directly in the Architecture model. The level should be defined above the structural part of the floor and below the finishing. (Figure 3).
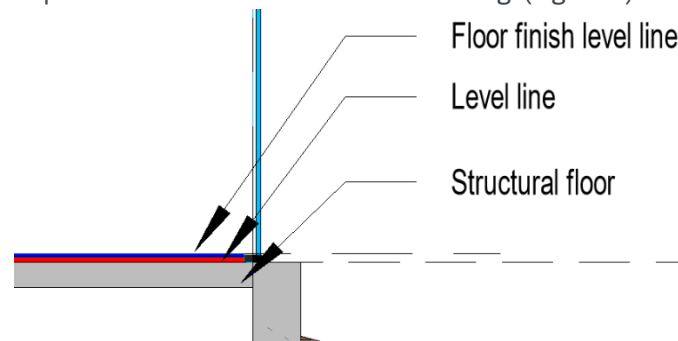
Figure 3. Defining the level of a building (picture from Revit software)

Levels can be found under different names, depending on the BIM tools used. For exemplification, we will refer to the BIM tools mentioned in the Introduction chapter.

- Since REVIT works with work-sets, the levels and grids must be assigned to a work-set. The most recommended approach is to use the default work-set "Shared levels and grids". Simply create a section view and start creating the levels using the "Level" command from the Architecture tab. Structure and MEP modellers can use the "copy/monitor" command to create the levels from the architectural model (see Figure 4). To remove the graphical duplication of the levels or grids, one must go to "Manage links" -> select a link -> Manage work-sets -> close the work-set -> Ok.

Figure 4. Doubling the levels after Copy/Monitor.

- In ArchiCAD, one should use go to Design -> Story settings. This will allow users to create, delete, or rename stories. (Figure 5)

Figure 5. ArchiCAD defining levels.[4]

2.4 Level of development

The release of ISO 19650-1 introduces the terms of "Level of Information" with the scope of introducing only one concept that all stakeholders need to adopt and understand, adding more clarity to the terminology used by each member when discuss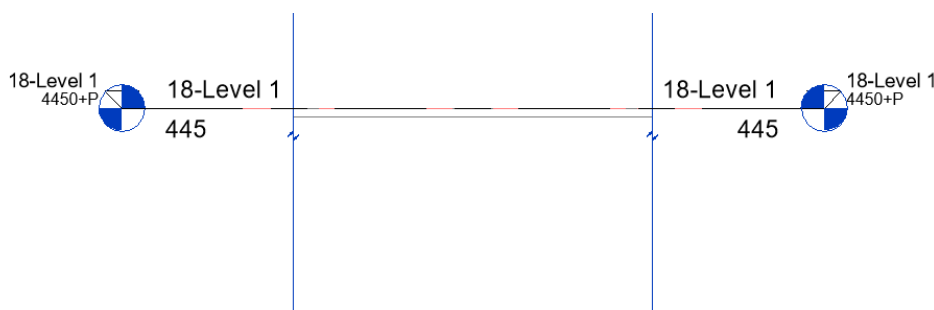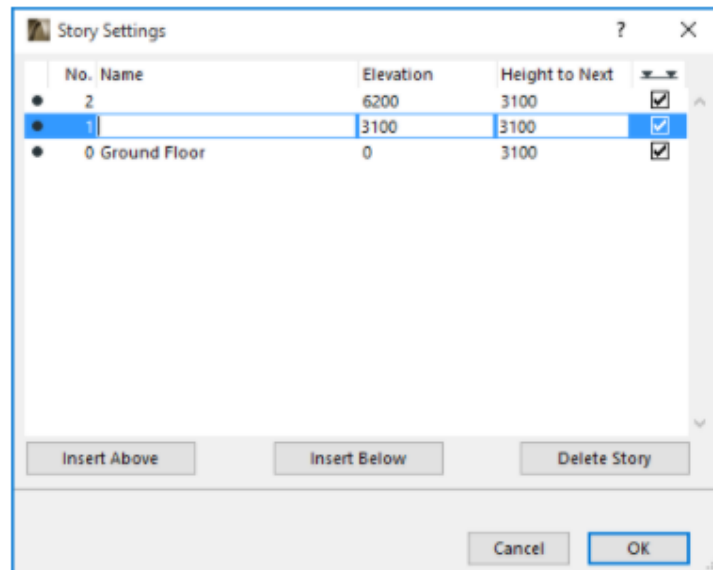ing BIM. As it is specified in ISO 19650-1, the level of information required is *"the quality of each piece of information to be provided in terms of granularity so that it serves the purpose for which this information is required and no more"*.

Unfortunately, one concept was not fully defined and explained and that is the Level of Information. The term Level of Development is still very used and most countries try to define it around ISO 19650.

Level of development (LOD) comprises of three levels, and it is about graphical and data aspects related to the 3D objects presented in a BIM model:

- Level of Geometry – from a geometrical and graphical perspective, it is the level of detail included in 3D elements
- Level of Information – of the 3D elements, referring to specifications, performances, and all the data that is contained in a 3D element. Also known as the level of detail (LOD).
- Level of documentation – the connection between external files and 3D elements.

The level of development should be defined or strictly associated with a project phase. This will prevent over-modelling for different stages throughout the project. Some recommendations can be followed to frame a BIM map, based on RIBA project phases and the graphical view of the 3D object:

- LOD 100 – RIBA stage: Preparation and brief – In the case of MEP, LOD 100 signifies schematic design. In a BIM model, large equipment or entire technical areas will be represented as a volume reservation. (See Figure 6)

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[4] https://helpcenter.graphisoft.com/user-guide/76759/

- LOD 200 – RIBA stage: Concept Design – for the MEP model, generic 3D objects are modelled. The characteristics are related to approximate size, shape, location, and orientation. Maintenance space is presented (see Figure 7)

- LOD 300 – RIBA stage: Developed Design – 3D objects for MEP at this LOD will mean that they will have the exact number of items to be used, exact shape and volume, and non-graphic information such as airflow, heat output (Figure 8).

- LOD 400 – RIBA stage: Technical design and construction – the 3D objects are accurate. Elements are defined as they will be built, containing all necessary parameters for procurement, assembly, and commissioning,

- LOD 500 – RIBA stage: Operate and Maintain, Construction Handout. – Model elements are field verified, functional representation of the asset in terms of size, shape, location, quantity, and orientation. The accuracy of the information attached to objects is more relevant.

MEP technical space
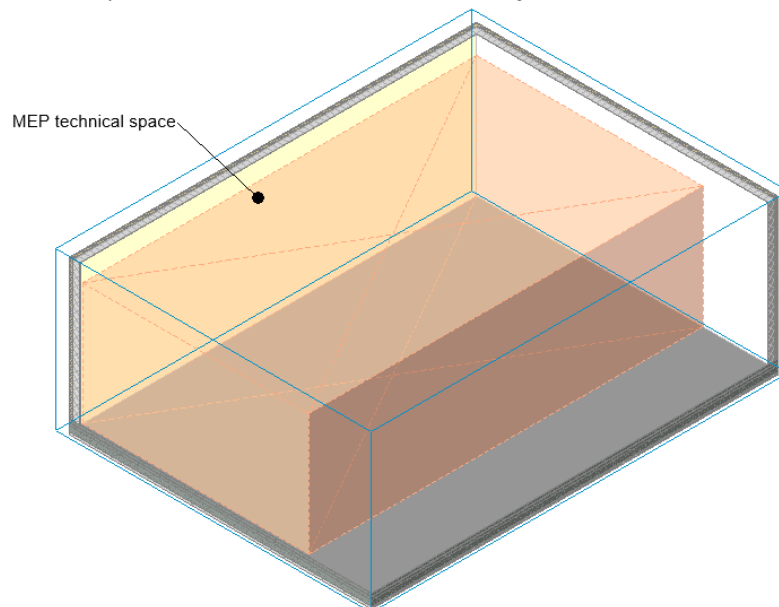
Figure 6. MEP represented at LOD 100
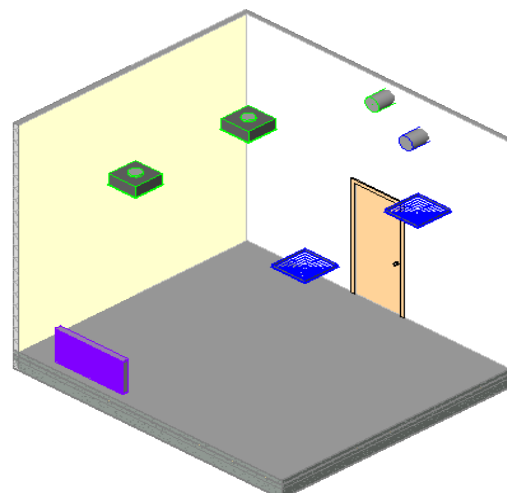
Figure 7. Ventilation and heating. LOD 200.
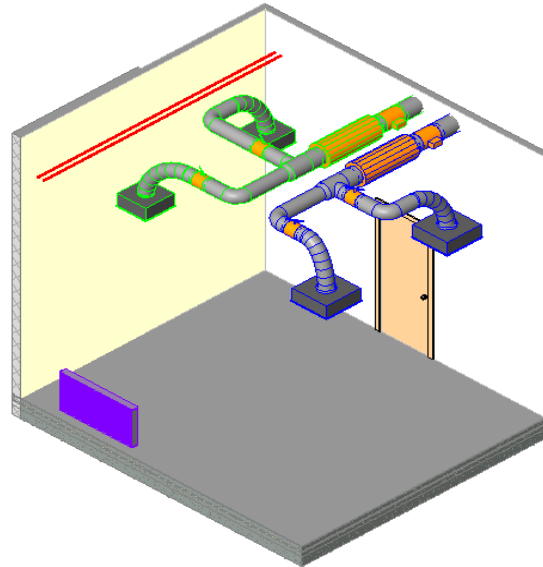
Figure 8. Ventilation and heating LOD 300
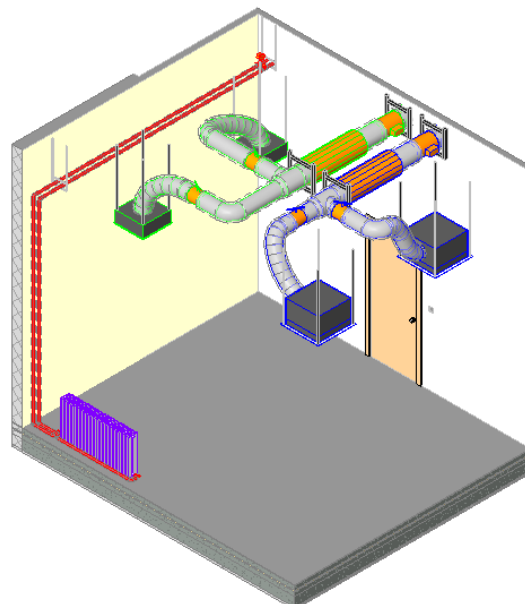
Figure 9. Ventilation and heating. LOD 400

2.4.1 Level of Geometry

The modeler or designer must take into account the connections between structural and architectural when modelling. The geometry itself must provide exact quantities for quantity take-off for a given design phase or BIM Use Case. The way of modelling should tightly correspond with the rules of measurement of specific building categories defined at the outset of the project. This will enable the quantity surveyor to perform accurate quantity take-off from the model.

The typical rules of modelling might be:

- Modelling structure walls and columns from top slab to bottom slab (in-between two slabs).
- Beams, walls, and columns geometry should be cut out by slabs.
- There should be one solid geometry per structure element.

- Elements should be modelled on a specific level – elements should be divided by level. This is valid for MEP elements also.

Both rules of measurement and modelling guidelines should be described in the BIM Execution Plan.

Level of information

Every single model element needs to be given proper classification from the chosen classification system in the projects. If the official classification system is not chosen in the project, custom classification needs to be added to the element's parameters. The purpose of classifying model elements is to state what the elements are and what function they will perform in the building. As soon as elements have a classification, the designer can add matching properties to model elements. The properties and property sets need to be associated with classification items and can differ per project stage, as described in the BIM Execution Plan (Figure 10).

For instance, one can classify structural columns as Ss_20_30_75_15 - Concrete column systems according to Uniclass 2015. Three proprieties will be defined for Ss_20_30_75_15 - Concrete column systems item as stated in the BEP.
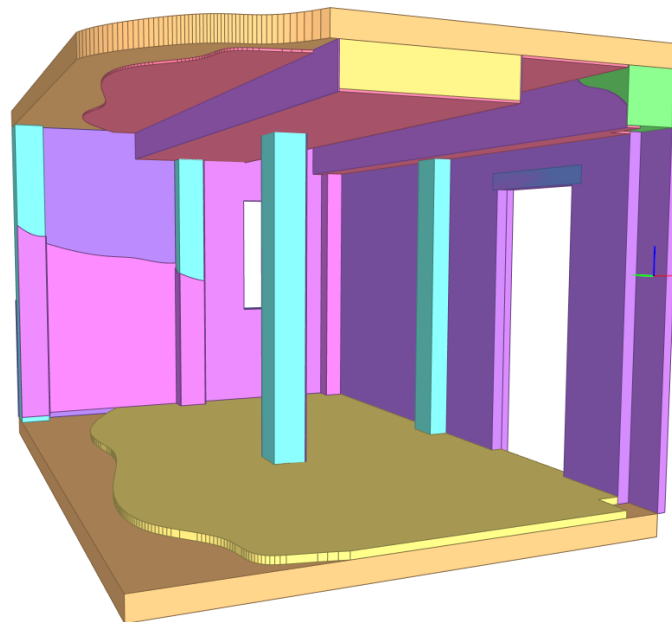
Figure 10. IFC Model - Elements modelled according to rules of measurement and coloured by a classification system

2.5   3D objects & libraries

As explained earlier, every 3D model is comprised of 3D elements, at different LOD levels, and 2D elements (grids, text, annotations, level line, etc.). The accuracy of a 3D model comprised also of correct classification of the objects. Software used for BIM modeling have certain categories to classify each object in a model such as columns, walls, floors, ducts, pipes, electrical equipment, mechanical equipment, etc. A key point in having clarity in the model is to always use the correct categories for the correct item intended to be modelled. As an example, a round duct should never be used to represent a pipe, or a cable tray to represent an existing duct.

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3D objects created by one specific BIM tool cannot be used directly by another BIM modelling tool. BIM objects created with a certain authoring tool have a certain extension (.rfa from Revit, .pln from ArchiCAD, etc.) that cannot be read by other software applications. Using an open BIM environment will reduce the risk of interoperability issues.

BIM authority tools have predefined libraries that come together with the software. These libraries have all the basic elements to start modelling, e.g., walls, columns, pipes, ducts, valves, floors, etc. Every company can develop its specific library for renovation or new building projects (e.g., Family editor in REVIT or Library Part Maker for ArchiCAD) starting from those default libraries. Free-form objects can be made using either embedded tools in the BIM modelling software or using add-ins (e.g., Dynamo for REVIT, Grasshopper for ARCHICAD)[5].

There are also online libraries such as bimobject.com, mepcontent.eu, nationalbimlibrary.com, bimstore.co from where BIM modellers can use 3D objects. However, these objects should be inserted directly in a model in compliance with the internal guidelines of the company but not without a BIM coordinator to revise them. Below there are some criteria that a BIM object should fulfil.

Important 3D objects that most users frequently forget to define in their libraries are represented by openings in building elements and placeholders. Openings in 3D objects are important for solving crossing issues between MEP elements and structural building elements. Placeholders are generic elements that are used to illustrate the space that will be occupied by one or more objects. Placeholders are directly connected with the LOD level used. As seen in the previous subchapter, for LOD 100 only a volume is needed to represent MEP technical areas. That volume constitutes a placeholder. In Figure 6, the box constitutes a placeholder for that technical space.

Until LOD 300, the same library can be used for new and existing buildings. For LOD 300 and 400, libraries should be different between these two types of projects, because the items they represent can even be from different periods. For architectural elements such as walls, floors, doors, and windows, objects can be created as information on different types of elements can be found in books or guides (e.g., brick walls with the most common thickness used).

For MEP, this item becomes more complicated since equipment and valves can be completely different (e.g. manufacturers are off the market) or pipes can have materials that in the present are not used (e.g., lead for sewage). Pipe types and systems can be easily created since the information may be easier to find, but for the rest of the elements that are part of an MEP system, the library will be developed in time. BIM object libraries should be kept, either on a local server or on a shared platform. It is recommended to be kept on an online platform, such as SharePoint or BIM-SPEED Platform.

Before using any 3D object inside a project that is not included in a verified library, it should be tested. Below, is a fast checklist to be considered when checking a 3D object:

- compliance with the naming convention.

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[5] Grasshopper can be used also for REVIT by using a package for Dynamo. Please visit https://primer.dynamobim.org/ for more information about Dynamo.

- correct assignment of parameters (especially for MEP elements).
- depending on LOD, the 3D object has the correct dimensions and information.
- presence of a thumbnail. This is important so that picking a family from a library is much easier. It allows one to visualize the family before loading it.
- if materials are shown correctly.
- the size of the file of the 3D object.
- if the family is parametric, test to see if it is working as it was planned (change several dimensions, with up and down values)
- REVIT specific: if the family is hosted, check to see if it's adjusting to thickness

In the following subchapters, users will be able to distinguish between how two BIM authoring tools tackle 3D object creation.

2.5.1 REVIT 3D objects

For REVIT, 3D objects are named "families" and can be saved separately in a native file format (.rfa). There are 3 kinds of families in REVIT.

1. System families: walls, roofs, floors, ducts, pipes, cable trays. These are elements that a contractor will assemble on site. System families are preloaded into REVIT, they cannot be loaded for somewhere else, nor can they be saved to a library. More information can be found here.

2. Loadable families: these objects can be created, saved, and loaded from and to a library. For better performance, the files should not exceed 1 Mb per file. The number of parameters does not influence the size of the family. Loadable families are used to creating the following: More information can be found here.

    o Building elements that can be purchased, delivered and installed such as windows, doors, furniture, etc.
    o MEP elements that can be purchased, delivered and installed such as boilers, plumbing fixtures, air handling units, sprinklers, etc.
    o Annotation elements as 2D symbols, title blocks.

3. In-place families are unique elements that are created for a specific project.

    They can be transferred from one project to another, however, consequently, the size of the file will increase rapidly, and thus there will be consequences on the performance. Therefore, it is recommended to limit the use of such elements. More information can be found here.

In REVIT, all families are referenced to the level where they were created. Some families can be hosted or not. A hosted family is a 3D object that needs a building element (host) so that it can be placed in the model. The most common hosts are walls, ceilings, floors, etc. Once a family is created as hosted, there is no process to make it non-hosted. The only solution is to create it from scratch.

For MEP designers hosted families are not preferred as they do not work across linked models (the MEP planner rarely works in the same model as the architect), and a wall-hosted family cannot be placed in the MEP model since the host is not in that model. Another big disadvantage is that if

the host is deleted the corresponding hosted element(s) are also deleted. This situation can lead to coordination issues.

A compromise is to use face-based families. These families look for a "face" of an element (not necessarily need to be a wall or a ceiling). The advantage here is that these families detect and orient to the faces of an element and work across linked models. Face-based families have two important parameters: "default elevation" (definition of the height the element is placed at) and "maintain annotation orientation" (force nested annotation symbols to display correctly). Furthermore, the hosting information of a face-based family is tied to the element ID of the host. To move the family with the hosting element, the hosting element must be moved—it cannot be deleted and recreated. These types of families are recommended for modelling existing elements since the position is fixed.

Another option is non-hosted families, which only refer to the level on which they are placed. They will not adjust to the orientation of the host element but can be placed anywhere and their rotation can be adjusted manually. To facilitate this process, rotation parameters can be introduced to make this process slightly easier. Non-hosted families can be copied very easily and can also be grouped. Non-hosted families are recommended for modelling the new installations since their position can be changed in the design process.

The most common practice, which is highly recommended, is to distinguish between face-based families and non-hosted families by naming them accordingly. For face-based families, the abbreviation "FB" can be used in the naming of the 3D object file. For non-hosted, the "UN" abbreviation is commonly used.

REVIT families, besides their geometry, have data attached to them. For data to be stored in a family, REVIT created parameters where a user can fill them in to define the objects' proprieties (a few examples: length, width, height, airflow, power, material, etc.). In REVIT, there are multiple types of parameters that are handled differently and shown differently:

- Family Parameter: this is a parameter that exists only in the Family and cannot be scheduled (place into a REVIT table). Users can see it and fill the data inside it and can be variable, for example, height, material, width.

- Shared Parameter: this is a parameter that can be used in multiple families and multiple projects. They are stored in a separate file (a .txt file). These kinds of parameters can be put in a table or create tags (a label used in REVIT for showing some information about that object in a 2D view) for them.

- Project Parameters are parameters that are used in one project. One can add project parameters to multiple families (or categories) at once. These parameters appear in schedules but not in tags.

- Global Parameters are similar to project parameters with one difference, mainly that these parameters cannot be assigned to family categories.

Regarding the parameters inside the families:

- Take advantage of default parameters (such as description, manufacturer, cost, etc). One must be careful of family parameters. This kind of parameter in Revit cannot be scheduled.

- One should create a new parameter only if no default REVIT parameter can be used to express correctly the information intended to be placed. For example, for a socket, BIM

designers may need to display its "use". This will imply creating a new parameter called "function" because this parameter is not included by default in REVIT.

- All parameters used by a company should be stored in the "Shared Parameters" file.
- Parameters must be created based on their use for fulfilling a certain BIM USE CASE. It is recommended to either have them in different "Shared Parameters" files or the same file but divided into groups.

2.5.2 ArchiCAD 3D objects

ArchiCAD comes with a standard object library that covers most of the building elements. The native file for 3D objects of the tool is .pln. The 3D objects are parametric by default. The parameters from one object can be transferred also to another object from the same subtype (for example from one object that represents a window to another one that represents another type of window).

When a new project is created, the software will load the library contained in the project template. Further libraries can be added as well. ArchiCAD works with multiple types of libraries, the embedded library, or linked libraries.

An embedded library is a project-specific library containing the objects that users have created or saved for a specific project. It is worth mentioning that embedded objects are available only in a particular project and once an object is deleted they will be gone.

Linked Libraries include the standard ARCHICAD library loaded by default, as well as any other libraries added by users. In contrast to the objects of the Embedded Library, these libraries are linked folders that are saved as .lcf or .pla files. Libraries can be stored in a traditional server or in the cloud.

The following approaches are recommended as best practices for setting up Object libraries:

- Upload all company's libraries to a dedicated BIMcloud/BIM Server. This enables one-step updates which are then available to all users, including one-user and teamwork project users.
- The Embedded Library should serve as a project library, containing project-specific objects that are always available and editable, and saved with the project.
- Any project-specific object that is modified frequently should be placed in the Embedded Library.
- Only those objects that are project-specific should be embedded. For better performance, it is recommended to keep the size of the Embedded library low.
- If users want to use a custom object in several projects, it is recommended to place it into a company Library stored on a BIMcloud/BIM Server that is accessible to all users, rather than save it to an Embedded Library.
- When one must archive a project, it must be saved in the PLA file format.
- It is NOT recommended to save all objects in the Embedded Library.

The characteristics above also apply to the MEP library, which is divided into logical folders such as ductwork, pipework, electrical, etc. Most common MEP systems are available by default, but users are able to create new ones or rename the existing ones.

The data for 3D objects in ArchiCAD are also inserted using parameters similar to REVIT. The software provides default parameters. ArchiCAD allows the creation of user-defined parameters, the only difference from REVIT is that they are called "proprieties". Users can create as many as they want according to the needs of the project. The proprieties can also be scheduled similarly to ArchiCAD parameters.

2.5.3 3D Object Classification

Regardless of the BIM software used, 3D objects in a BIM 3D model need to be classified according to certain rules that are known to stakeholders. This makes the comprehension of the BIM model much easier. The file exchange format for Open BIM is IFC. By exporting to IFC, each 3D object will be classified according to the principles issues by BuildingSmart. However, besides the IFC classification, other standards? are largely used in conjunction with IFC classification in the model. The BIM authoring software allows users to import classification codes such as Omniclass (for the U.S.) or Uniclass 2015 (for the U.K. and in Europe) and add the classification complementary to the IFC one.

2.6   Modelling phases and model management

BIM modelling in a renovation project will most likely involve the modelling of phases. Modelling phases can be defined as the state of the BIM model of a building at a certain milestone in the project. The easiest setup of a BIM model includes 3 modelling phases:

- Existing phase – the existing building is modelled as it is, and all its elements are assigned to this phase.
- Demolition phase – the existing elements proposed to be demolished will be assigned to this phase. The elements are the same ones modelled in the existing phase.
- New phase – new elements added to the building will be included in this phase.

Specifying the modelling phase of an element requires setting visible graphics overrides or filters in the model. These graphic overrides will be necessary for a 3D view but also 2D if the project requires exporting 2D drawings. Changing line weights and/or colour will help with the identification of the phases assigned to the 3D objects. All the graphic overrides can be stored in view templates.

Depending on the BIM authoring tool, a certain graphic hierarchy can be in place. As an example, REVIT has a visual graphic hierarchy, and modelling phase overrides are least powerful than filter overrides (Figure 11Additionally, REVIT does not allow filtering based on the modelling phase. The most common workflow to filter elements is by using REVIT work-sets. Every discipline model will have an "Existing" work-set where all the elements assigned to the "existing" phase will be placed. A similar workflow can be applied to other disciplines.

Another workflow for filtering elements can be achieved by creating a shared parameter called "Installation date". A shared parameter can help the BIM designer to find a certain element based on its parameters.
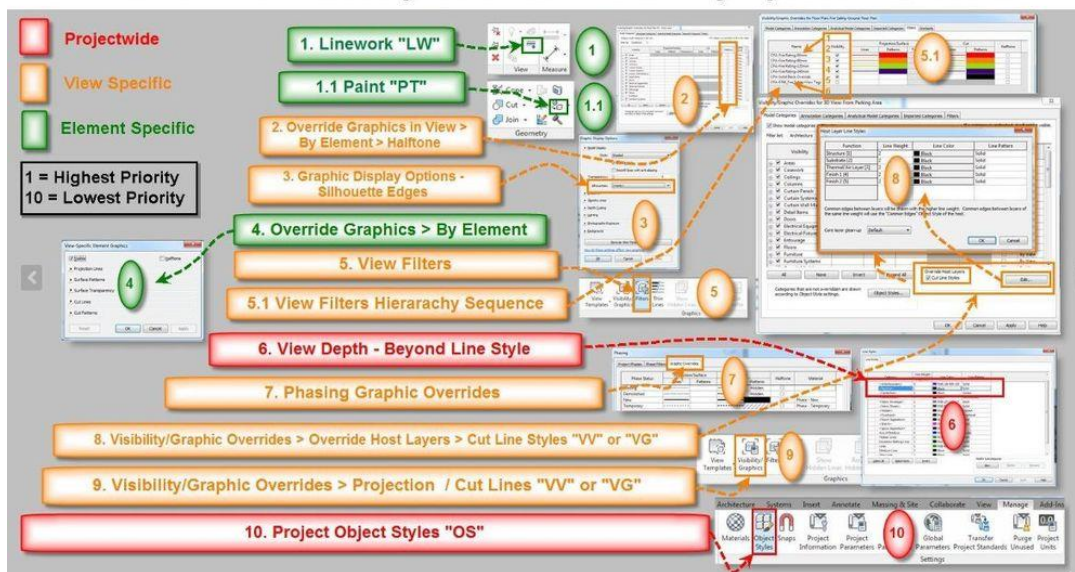
Figure 11. REVIT Visibility Override hierarchy Pyramid[6]

2.7 Model breakdown strategy and work-sharing (CIVIL, INFRA, MEP)

Having a working station that fulfills the minimum requirements of the BIM modelling tools is very important. Even though the workstation fulfils the recommended requirements of the BIM tools used, sometimes the BIM model may still be lagging. To name a few characteristics that describe a BIM model as lagging is the slow graphic performances (e.g. rotating a 3D view takes a couple of seconds or even a minute) or freezing when saving. The reasons can be that several disciplines are represented in one BIM model, the large sizes of the 3D objects in the model as well as the LOD of the 3D objects. These can influence greatly the handling of a 3D model making it hard for the BIM modeller to perform tasks. Deleting unnecessary items in the model is usually the simplest way to reduce file size. One can use the "Purge" command only to see what 3D objects can be removed but "purge all unused elements" should not be used at once. Purging all elements should be done before the BIM model is delivered to the client in the final version.

If deleting unnecessary items in the model does not improve the performance then splitting the model into subdisciplines is a commonly used solution. Tests made by various companies and BIM designers showed that it is recommended to keep the project file size under 200 Mb.

One way to split a model is by disciplines such as Architecture, Structural, Electrical, and HVAC. If the building is very large, one can split even more by placing the facades and furniture in different models and/or HVAC divided into Plumbing and Water, Heating and Cooling, Ventilation. If exterior networks need to be modelled, those can also be part of a separate 3D model.

When working with REVIT, it is recommended that each discipline or subdiscipline be modelled on its work-sets. Working with work-sets allows a much easier split of the BIM model if this is operation is becoming

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[6] https://forums.autodesk.com/t5/revit-architecture-forum/phasing-issue-graphic-overrides-not-changing-all-existing-phases/td-p/9238015

necessary during the project. For ArchiCAD, a separate file where all layouts are stored can reduce the file size.

2.8   Data ownership and responsibility

The ownership of the data in the BIM model depends on the project specifics and cannot be generalized. 3D models shall be generated in a manner that allows for other project team members to collaborate and/or assist, without recourse to complicated instructions.

In every project, a BIM RASCI matrix should be available to ensure every company and BIM role involved in the project know what they are responsible for. This matrix can be part of or referenced in the BEP. An example of a BIM RASCI matrix can be seen in Table 2.

Table 2. Example of a BIM RASCI matrix.

Role	Project BIM Manager	BIM Coordinator	BIM Modeller
Task			
Project BIM management	**R**	**C**	**I**
Manage the BIM process.			
Has responsibility and power to issue necessary instructions on BIM related issues.			
Ensure the creation of suitable project templates as and when required. Update, amend and issue the BIM Execution Plan (BEP) throughout the lifetime of the project.			
Monitor implementation of BIM for consistency and adherence to the BEP and the BIM Protocol, including regular spot checks and policing of standards adherence.			
Assist in the preparation of project outputs, such as data drops.			
Ensure that the agreed BIM standards and protocols are continuously communicated to all BIM Coordinators and are maintained throughout the project and applied to all the models.			
Monitor communication and file sharing to ensure that it is occurring as agreed.			
Hosting and attending project design reviews and 3D coordination meetings.			
Guide the project team through the BIM process.			
Liaise with the project team, client and consultants to review all the models for the project and initiate any necessary amendments.			
(Discipline) BIM Coordination	**C**	**R**	**S**
Combining the federated model, made up of the merger of the different aspect models of the various disciplines involved in the construction process, using certain protocols, programs and structures.			
Guide a project team through the BIM process.			
Hosting and attending project or discipline design reviews and 3D coordination meetings.			
Ensure compliance with the BIM Execution Plan.			
Guide a project team through the BIM process.			
Regular spot-checking and policing of files to ensure standards are being maintained.			

Assisting the Project BIM Manager in coordinating and delivering multi-disciplined data issues.			
Clash detection for discipline and interdisciplinary issues.			
Administration of clash resolution.			
Enforce the best modelling practices.			
Production of digital engineering information.			
(Discipline) BIM Modelling	I	C	R
Design/construct the project within the BIM environment.			
Adding data to the model and generating graphical and (alpha) numeric output.			
Making 3D visualizations, derived 2D drafts.			
Making drafts, calculations and analyses that are based and/or will be transferred to the BIM environment.			
Ensure compliance with the BIM Execution Plan.			
Alert the (Discipline) BIM Coordinator of any issues.			

2.9   Consequences of software updates

BIM models are created using modelling tools. Most tools have different versions, which are usually released each year. The reason for this is to fix bugs reported by users and the release of new features. This can be an issue that has to be considered as a renovation design project can last for a long period. While for large companies, this is not a problem in terms of software costs, for SMEs may pose an issue because they can usually not afford to have multiple versions of the same software at the same time and therefore are forced to upgrade the models to the newer versions. It is important to know that the version of the software to be used in a project is to be determined in the BEP. Switching to another version is a decision that has to be communicated by the BIM Manager to all stakeholders involved, documenting the new requirements and associated consequences

Upgrading a BIM model is a fairly easy process regardless of the modelling software. However, this process can entail errors in the new model. The cause of the errors either lies in changes regarding the program's script or changes of functionalities in the newer versions of the software.

The first step, independent of the tool used, is to create a backup version of the current model before upgrading it. Depending on the tool used, one can just open the file with the newer version and the model will be upgraded automatically. Alternatively, special tools for example the migration tool for ArchiCAD can be used.

The workflow for translating a BIM project created in REVIT, from one version to another, is as follows:

1.   Create a backup of the model to be upgraded.

2.   When working within the collaborative mode, before upgrading, all users must synchronize their models and close the software. In other cases, the model must be saved and closed. While the model is upgraded by one user, the rest of the team cannot work on it.

3.   Before upgrading open the model again, using the "Audit" command selected.

4.   After auditing the model, save the file in a new location (if it is in a work shared environment, the models must be detached, before saving them to a new location).

5. Open the file in the new version of the software, with the Audit option checked. This is the final step of the model upgrade

6. If there are other REVIT files linked to the current project, every single file needs to be upgraded.

Special attention is to be given to the REVIT families throughout the process. Depending on how they were created, their type, and their complexity, some may get corrupted during the process. If this is the case, one must delete the corrupted families from the model, upgrade the families separately, and insert them into the project.

For ArchiCAD, the process is slightly different as there is a specific command:

1. Create a backup of the model.

2. Start the older version of the software and open the model. If it is a Teamwork project, all users must save their project and close the file.

3. One user needs to start the command "Prepare for migration" and follow the steps indicated in the dialogue box that appears.

4. After that, the user needs to close the old version of the software and open the new one. In the newer version, the user needs to start the command "Migrate prepared projects". There is an option to replace the project library with the one from the newer version. A dialogue box appears, and the users must follow the steps indicated there.

5. If the migrated projects contain links to other models in older versions, all models must be migrated.

2.10 Export settings

2.10.1 Exporting to IFC 2X3, IFC 4

IFC (Industry Foundation Classes) is an open, neutral data exchange format. It is optimized for Open BIM and model-based design among disciplines in the AEC industry. It allows the data to be exchanged between different tools and even operating systems, throughout the stages of the building design process. As a neutral file format with an open standard that supports different systems, the IFC schema enables stakeholders to coordinate building models between the disciplines much easier than in the conventional approach for design and coordination.

The IFC format can be used for the import and export of 3D elements as well as related non-geometric data, regardless of the modelling application used, while a preference should be given to certified software tools. As an ISO-certified schema, it can be integrated into the existing quality assurance policies of a company. It is developed by buildingSMART and its member organizations.

Even though there are many BIM authoring tools on the market that support IFC export, there are big differences regarding their approach and scope of the export functionalities which pose a significant challenge to the user. For additional help, for some of the major tools, some add-ons can be installed to ease the export as well as additional freeware that imports the 3D geometry that is already created. One example is the IFC Builder developed by CYPE, which allows the creation of IFC files based on 3D or 2D files or to create an IFC model manually. This kind of tool is suitable if there is

a need for creating an IFC file for energy analysis because it will take only the necessary attributes, allowing the user to define spaces inside buildings, and eventually exporting an IFC file fulfilling the specific requirements. For more information visit http://ifc-builder.en.cype.com/.

The process and the information required for an IFC that is used with a certain scope should be detailed in an Interaction Delivery Manual. This document exemplifies what is the scope of to exchange the models using IFC format, the roles and their purpose, relevant characteristics of the process that are linked with the desired BIM Speed use case, and what are the requirements so that the exchange of information is performed as optimum as possible. The creation of an IDM is standardized, and the guidelines are issued in ISO 29481-1:2016, ISO 29481-2:2012.

The IDM describes the process and the characteristics but the actual settings of what an authoring tool must export are done via MVD's. An MVD, as it is described by BuildingSmart is "is a selection of entities of the overall IFC schema to describe facilitate a specific use or workflow. MVDs can be as broad as nearly the entire schema (e.g., for archiving a project) or as specific as a couple of object types and associated data (e.g., for pricing a curtain wall system)"7. As one will see below, MVD's are already available in the BIM modelling tools but further additional settings are still required. These settings are exemplified using the two software applications chosen for this scope. The export of IFC files from two widely used BIM modelling software tools will be described in the following subchapter.

2.10.2 ARCHICAD

In ARCHICAD, there are three export functions for IFC files according to the software guide:

- Save as (File menu): exports the entire current ARCHICAD project or just its filtered content to an entirely new IFC file.
- Merge to IFC Model (File > Interoperability > IFC): merges only certain elements or the entire content of the current ARCHICAD project into an existing (unopened) IFC file. Users may use this command to want to add selected content from an ARCHICAD model to an IFC file from another discipline.
- Publisher (Document menu): publishes views to any of the IFC file formats. For each Publisher item, you can vary the Translator, so that the view content can be customized to the needs of the recipient, creating the desired output with a single click.[8]

No matter the choice, the settings are controlled by an IFC Translator for Export, which defines how ARCHICAD elements are interpreted and displayed in IFC. When exporting IFC users must choose the translator.

The main steps that a BIM designer needs to follow to export a model to IFC are:

- Choose the IFC export command desired (Figure 12): File > Save as… or File > Interoperability > IFC > Merge to IFC Model
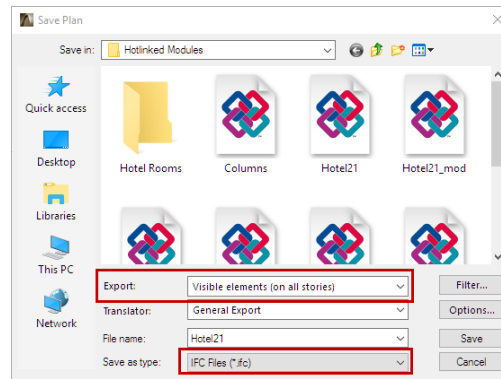
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[7] https://technical.buildingsmart.org/standards/ifc/mvd/
[8] https://helpcenter.graphisoft.com/user-guide/128889/

Figure 12 ArchiCAD – Step 1 in saving IFC[9]

1. Select the type the intended file type. When using the "Save as" command multiple types of files may appear but when the command "Merge to IFC Model" is used, only the available IFC file types are displayed. (Figure 13)

2. Define the name of the file. One should use the "Filename" field to define a file name (Save as) or browse for an existing IFC model (Merge to IFC Model).

3. Choose a Translator for Export (Figure 14)

4. Filter Model at Export. As needed, users can further filter the set of elements to be exported, using the Elements to Export dropdown and/or the Model Filter dialogue box; both available from IFC Save Options.

5. Export - Click "Save" (Save as) or "Open" (Merge to IFC Model) so that the export process will start.
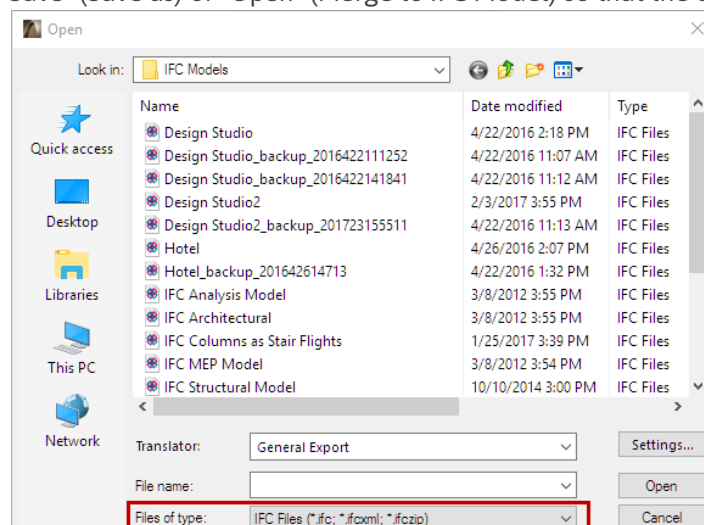
Figure 13. ArchiCAD – Step 2 in saving IFC[10]

BIM-SPEED D2.4 Guidelines for as-built BIM modelling of existing buildings
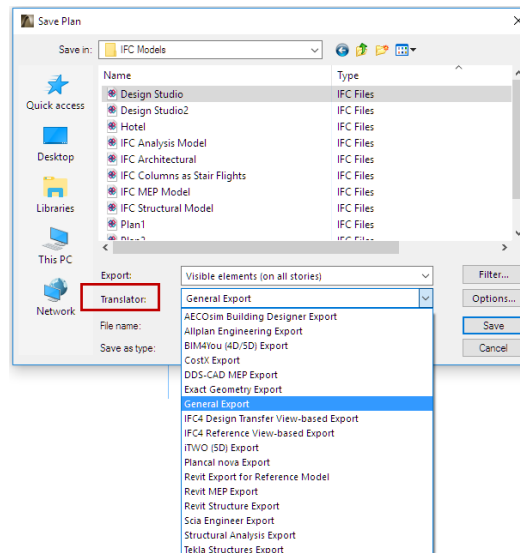
Figure 14. ArchiCAD – Selecting IFC translator[11]

The "Merge to IFC Model" command is not suitable if the goal is to merge changes from one version of a file to another because this command only adds new elements but does not override the existing ones.

An IFC Translator (Figure 15), defines the rules for how the elements should be converted and how they should be interpreted by any software - whether in ARCHICAD or another application reading the IFC file. Translators are listed by name on the left side. The Translator name exemplifies its use, e.g., "Import from Modelling Applications" or "Export to Tekla Structures". They are divided into Translators for Import and Translators for Export.
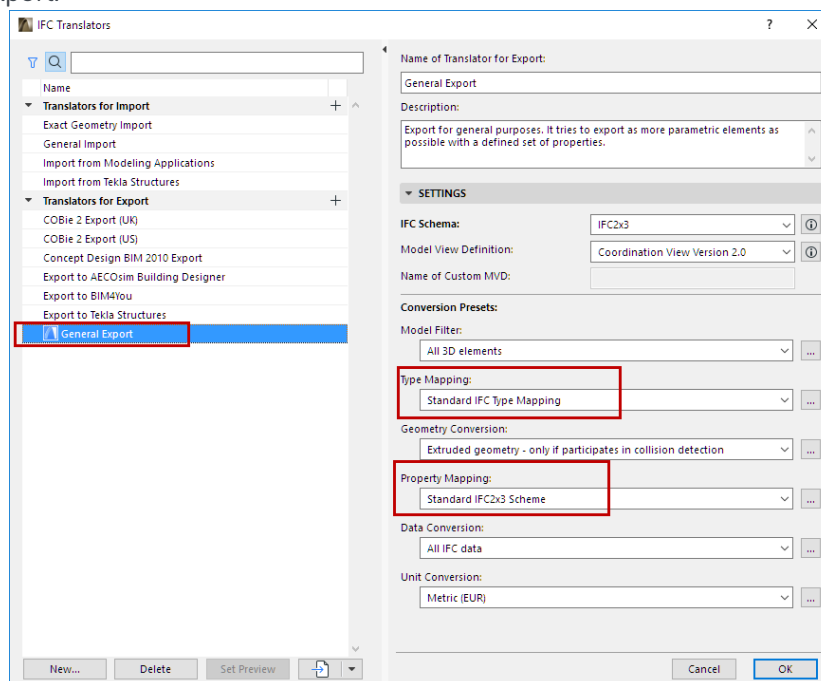
Figure 15. ARCHICAD – types of IFC exports[12]

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[11] https://helpcenter.graphisoft.com/user-guide/65781/
[12] https://helpcenter.graphisoft.com/user-guide/65791

Users can create new translators for exporting. The different settings that can be chosen are in the right part of the dialogue box. Detailing the settings includes:

- Name – users set the name of their translator
- Description –short description is necessary to be included so that other users will know the scope of the export settings.
- IFC schema - allows the selection between exporting to IFC 2x3 or IFC 4.
- Model View Definition – the proposed MVD that can be selected are according to buildingSMART International13 or other organizations. They are predefined by the software according to the regulations, making sure that the IFC is compliant with them. Depending on the IFC schema selected, MVDs are available. As an example, for IFC 2x3 there is a Coordination View. If IFC 4 is selected, the Coordination View is divided into two and the user will have to choose between IFC4 Reference view and IFC 4 Design Transfer view depending on the intended use of the IFC file
- Model filters – allow the user to select which elements should be exported.
- Type mapping – is detailed below.
- Geometry conversion lets the user select how the geometry of the elements is exported. To mention only a few: Extruded geometry – elements that are relevant for collision detection, export geometry of IFC Types, Use BREP geometry in current colour for all elements.
- Property mapping – shows the IFC properties assigned to elements when exported. The user can also create and assign custom IFC properties (Figure 16).
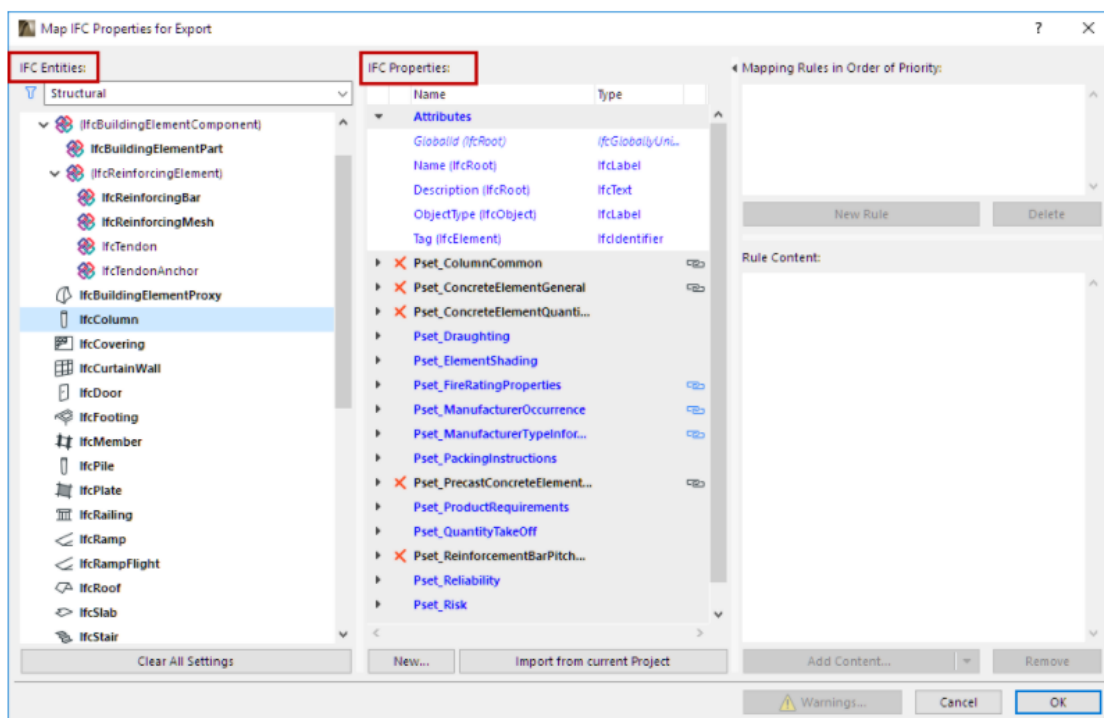
Figure 16. MAP IFC properties for exporting elements in ARCHICAD.

- Data conversion allows the user to choose, which data, besides the geometry, should be exported. There are a few pre-sets like "all BIM data", "all IFC properties", etc. From here, one can also select if data for quantification or space boundaries are required (Figure 17).
- Unit conversion allows the user to select the units for the conversion.
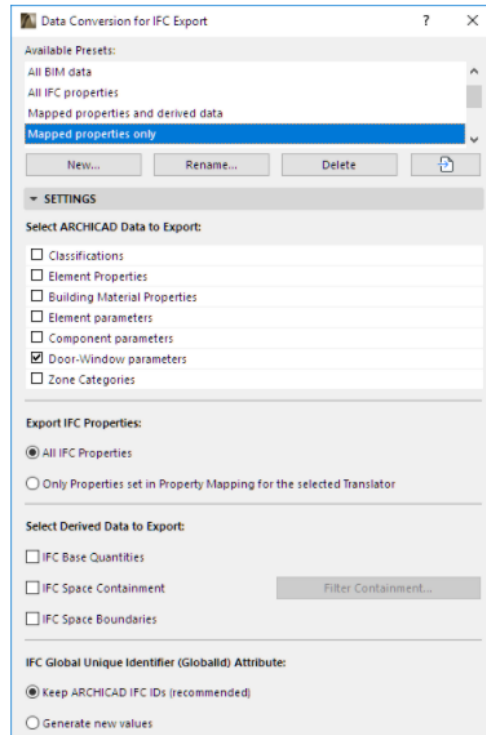

Figure 17. Data conversion for IFC Export in ArchiCAD.

An important step before exporting is to Type Map. This refers to what IFC proprieties users want to be displayed after export. Therefore, one needs to assign, for every element, an IFC Type, which can be done either by element or by classification (Figure 18).
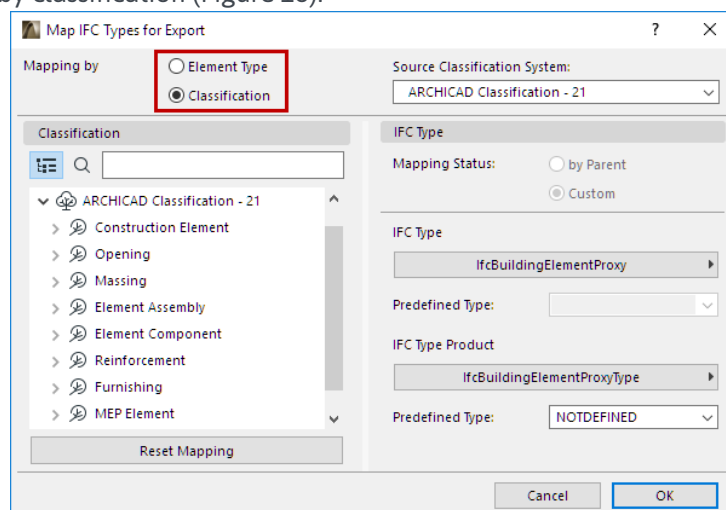
Figure 18. ARCHICAD – IFC Type Mapping[14]

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[14] https://helpcenter.graphisoft.com/user-guide/89323/

Mapping "by Element" type assigns each 3D object type automatically to a default, basic IFC Type, corresponding to its ARCHICAD tool or (for GDL objects) to its Object Subtype. If this method is chosen, no further manual mapping is needed.

If one decides to map the objects "by classification" to an IFC Type, Type Product, and/or Predefined Type, the method allows for flexible and detailed IFC Type classification, according to specific IFC standards. Users must choose a Classification System to display its classification structure in the tree and then map IFC types to the classified 3D objects when exporting.

Depending on the BIM Use case that IFC file is supposed to support, a few settings can be made in terms of how the data is exported:

- Property-type element parameters as IFC Properties: Export the parameters only if the Use Case requires this since it will significantly increase IFC file size

- Property-type element parameters as IFC Quantities: If the BIM Use cases require quantity take-off this box should be ticked to export parameters that convert to IFC Quantities (e.g., Weight, Length, Area, Volume, Time).

- Zone Categories as IFC Space Classification Reference: export the Zone Categories data (Code and Name) of ARCHICAD Zones as IFC Classification Reference data.

- IFC Base Quantities: check this to export Quantity Take-off parameters (size, area, and volume) to IFC. Useful in cost estimation applications.

- IFC Space Containment: export data defining the relationship between ARCHICAD Zones and objects they contain. This feature is useful in facility management applications.

- IFC Space Boundaries: Export geometry data of ARCHICAD Zones. (Useful in thermal calculation applications.)

2.10.3 REVIT

Exporting IFC from REVIT can be performed from File -> Export -> IFC (Figure 19). A new window will appear on the screen where various actions can be performed, namely choosing the location of the IFC file, naming the IFC file, and set up the export.
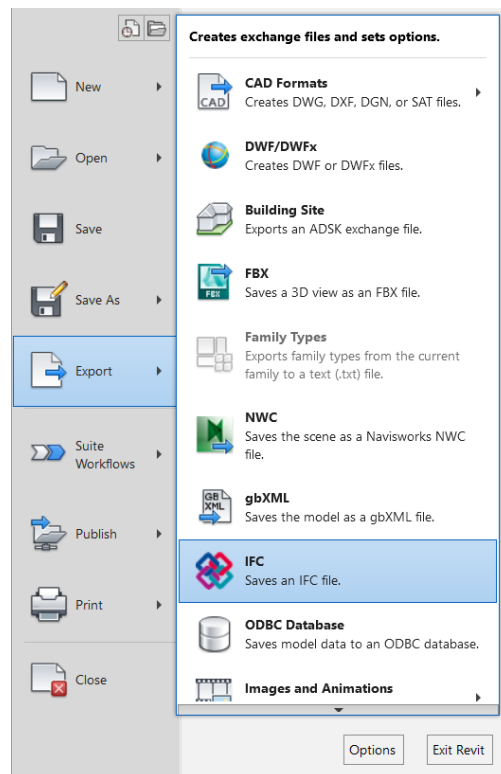
Figure 19. REVIT – Export IFC.

There are 3 different versions for the IFC file that REVIT can export to IFC 2x3, IFC 2x2, IFC 4 (Figure 20). The main ones are IFC 2x3 and IFC 4. Although IFC 4 is the newer version, IFC 2x3 is still the most used version on the market and a large variety of software use this version.
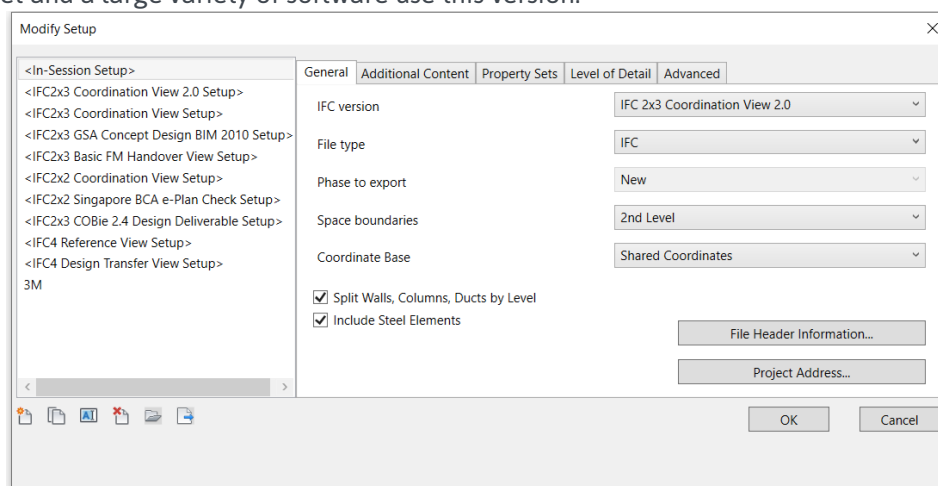

Figure 20. REVIT – Setup when exporting IFC.

Set up categories to consider based on types of settings (note that the number of options can be different from REVIT 2016 to REVIT 2020):

- General tab
  - *IFC Version: IFC 2x3*
  - *File Type: IFC*

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- *Phase to export: If the option "Export only elements visible in view" is selected and no modelling phase setup is needed. If not, a modelling phase must be set up. REVIT only can export one modelling phase at a time and not all the phases in the model.*
- *Space boundaries: users can choose from "None" (room/spaces not exported), "1ˢᵗ level" (the room/space boundaries are included but are not optimized to split elements concerning spaces on the opposite side of the boundary) or "2ⁿᵈ level" (the room/space boundaries are included and are split concerning spaces on the opposite side of the boundary. A second level space boundary considers the material of the building element and the adjacent spaces behind it, providing thermal properties, for example).*
- *Split Walls, Columns, Ducts by Level: This allows the model to be divided into multi-level walls, columns, and ducts by level. When this option is set, REVIT cuts the walls, columns, and ducts by each level that is defined as a building level.*
- *Coordinate Base: options are "share coordinates", "survey point", "project base point", "internal origin". It is recommended to use "share coordinates" since most models are set on coordinates.*

- Additional content
  - *Export 2D plan view elements: One must select this option to include 2D elements supported by IFC export.*
  - *Export linked files as separate IFCs: The user will select this option to export REVIT links in the model as separate IFCs. It is strongly recommended to export each model to IFC from its original Revit file.*
  - *Export only elements visible in view: One will select this option to export only the visible elements of the current view. This is highly recommended since the BIM model contains MVD specific to each BIM Use Case.*
  - *Export rooms in 3D views: If the "Export only elements visible in view" option is selected, selecting this option exports all rooms contained inside the section box of the selected 3D view. Usually left unticked.*

- Property sets:
  - *Export REVIT property sets: This option allows users to include the REVIT-specific property sets based on parameter groups. If selected, then the export will contain all the parameters of the REVIT family, filling the IFC files with unneeded information. There is the option to only export data defined by property sets, which enables a user to define based on a .txt file. (Figure 21).*
  - *In the file, parameters can be grouped in certain sets, according to companies' shared parameters files or BIM Use Cases for a clearer view. For example, one might create a parameter called LOD to specify the LOD of each element in case there is a need to work with different LOD on a project (depending on the BIM Use Case). This LOD parameter will be included as a BIM parameter. For this, a new propriety set will be created in the .txt*

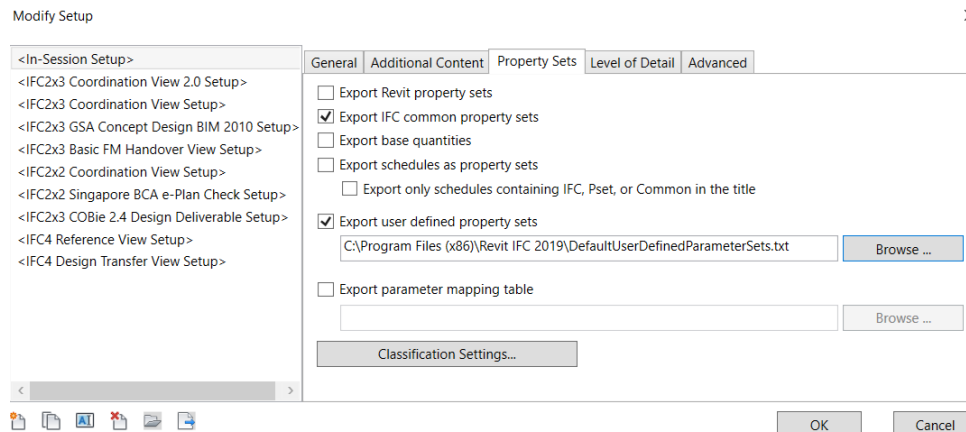*file and when the export is done this LOD parameter will be grouped under BIM parameter set.*

Figure 21 Exporting property sets from REVIT

– *Export IFC common property sets: One must select this option to include the IFC common property sets.*

– *Export base quantities: If the exported IFC is to be used for Quantity take-off BIM Use case, this option should be checked.*

– *The rest of the properties in this tab should be unticked. If you own a parameter mapping table or special property sets then tick the appropriate boxes.*

- Level of detail – set to extra low. This will decrease the file size and will not affect the parameters exported.

- Advanced:

  – *Export parts as building elements: Users can select this option to export parts as standard IFC elements. Clear the option to export them as IfcBuildingElementPart.*

  – *Allow the use of mixed "Solid Model" representation: Select this option to allow for mixing BRep and extrusion geometries for an entity. This can result in smaller IFC files, but the files are not strictly within the standard IFC MVDs.*

  – *Use an active view when creating geometry: one must select this option to use the active view to generate the exported geometry.*

  – *Use family and type name for reference.*

  – *Use 2D room boundaries for room volume: For IFC 2x3 this option should be unchecked.*

  – *The rest of the choices should be unticked.*

Recommendations:

- For Phase export: it is advisable to create a 3D view specially made for IFC export. This view should be without any view templates, or any graphics overrides made and should only be with the elements from that model (e.g., if an MEP model needs to be exported to IFC, the 3D view will contain only MEP families).

- Space boundaries depend on which BIM Use case you use the IFC file. For example, for energy analysis, it is best to choose "2nd level".
- If "Export only elements visible in view" is selected, one must consider that elements that are temporarily hidden are not exported. Categories marked as "Not Exported" in the IFC Export Classes dialogue are also not exported.

Before exporting an IFC from REVIT, one should check the IFC Mapping (Figure 22). The option can be found in the "File" tab -> Export Options 🔷 (IFC Options). BIM designers have two possibilities: either load the mapping from an external file or change the very setting manually (and save them). If the "Standard" option is selected, one will be able to create a new mapping, having the default mapping as a base. It is recommended that a first setup is done manually to ensure that every item is mapped according to its category. Certain software, when using the IFC file, requires specific settings to be made. CYPETHERM, for example, requires that curtain walls be defined as IfcWindow and not as IfcCurtainWall. Because of these particularities best is to have multiple IFC mapping file.
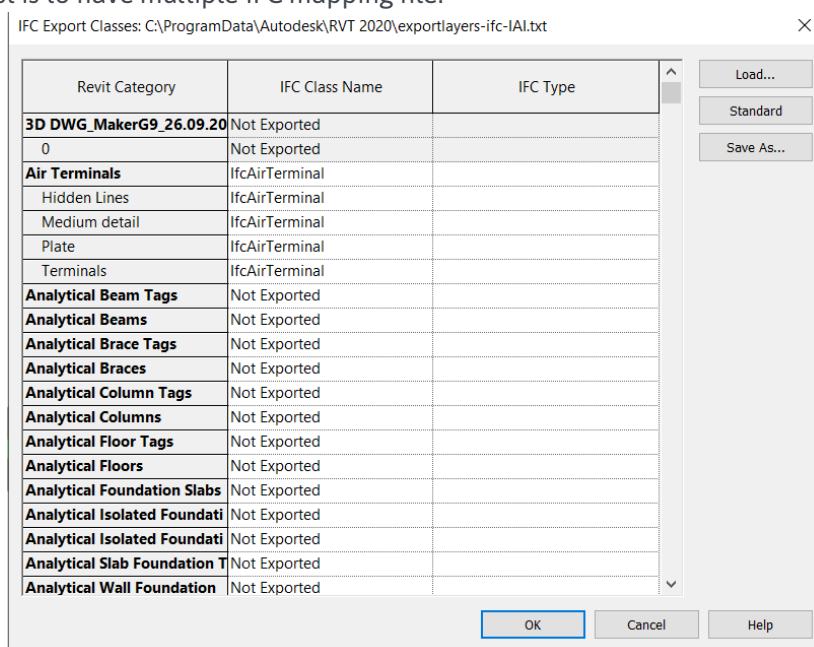
Figure 22. REVIT – IFC Mapping

REVIT allows users to create generic 3D objects that can be used for multiple categories. This is not a recommended way of working but a situation like this occurs. For these objects, an IFC class still needs to be chosen. Because of this, two shared parameters should be created and named "IFCExportAs" and "IFCExportType". Every generic family should have these two parameters included, grouped under the "IFC Parameter" category, and filled in.

2.10.4 Export to other formats

A list of different file formats which some software applications can export is listed in APPENDIX 1 – BIM SPEED METHODOLOGY TOOLKIT.

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2D CAD drawings may be still required to be exported. REVIT and ArchiCAD have different approaches to this. REVIT can export dwg, dwf, dxf, dgn. If the requirements are to have elements on specific layers (with defined colors and names), a layer mapping will be needed, since Revit assigns each element from the model (either 2D or 3D) to a predefined layer. These settings must be part of the template.

ArchiCAD needs a translator (similar to exporting to IFC) to be able to export to dwg, which is embedded in the software. In the translator, one must define layer mapping (layers in ArchiCAD do not have a color or a line type), file format, model space, attributes, hatches, etc.

Another file format allowed by both software that is largely used is .nwc. From REVIT, this is done while exporting any other files, but for ArchiCAD, an add-on called "Navisworks Connection" is needed.

To perform energy analysis other types of files can be used besides IFC. A file that can be exported directly is a .gbXML file. It can be used directly or to create a .idf file (a type of file used by EnergyPlus to perform energy simulation). Before exporting to a gbXML file, all the settings regarding location, weather, and space specification must be made. The file should be checked since there can be geometrical errors as in the way the file understands some connections between elements.

With REVIT 2020 energy analysis can be formed directly using the 3D model. The engine behind the simulations is from EnergyPlus and DOE2. After the analysis is done, from Autodesk INSIGHT it is possible to export a .idf file. Other formats that require special attention are .dwg.

3. AS-BUILT Model creation

Creating an as-built model compared to making a new building model may seem a lot easier since the first assumption is that the building is already constructed, and all the data is there and thus no need for iteration, as it often is the case when designing new buildings. However, in reality, data is not always available and has to be gathered (See Deliverable 1.1 and 1.2. for the proposed data collection methods). But even if the data is available, there are occasions where the data is incomplete (e.g., not all floor plans are available, schematics can be missing).

In the following subchapters, we describe the steps needed to work with various types of files to create as-built BIM models. To achieve an accurate model representing the reality of the existing building, Different workflows for different data types are proposed.

3.1   Model creation

3.1.1 Based on point clouds

Scan to BIM or the process of creating a 3D model of a building using 3D scans is used more and more in the last years. Point cloud data set can be generated in different formats, such as .xyz, .pls, .fls, however, most 3D modelling software applications allow to import of only a few of them. For example, ArchiCAD allows the import of point cloud data sets as .e57 and .xyz while REVIT does not allow a direct import of points cloud. REVIT allows only .rcp or .rcs files to be imported, types that are created using Autodesk RECAP. RECAP allows a great number of formats of point clouds (Figure 23) to be imported. After they are processed, the point cloud datasets can be exported in one of the two formats supported. Similar to RECAP, there are Bentley Pointools and other software applications provided by manufacturers of 3D-Laser scanners (for example Riegl RiSCAN Pro, Trimble RealWorks, FARO Scene, and Leica Cyclone.)
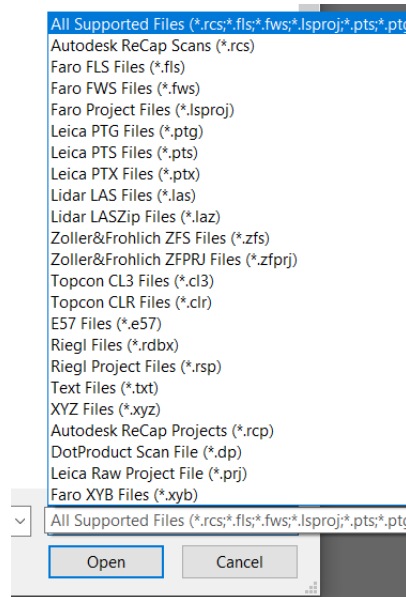
Figure 23. Point Cloud formats supported by Autodesk Recap

Point clouds can only contain information regarding the position of elements, the signal intensity of the surface reflection, and its color depending on the system used. Every point has a x, y, z coordinate, and a multitude of points represent the captured elements. Information regarding the material and other physical characteristics describing the condition of the captured building elements are not covered by the point cloud and need to be included during the modelling process.

Creating a 3D model based on a point cloud can be done using two procedures:

- Manual modelling
- Automated modelling

Manual modelling refers to importing the point cloud and modelling using the file as a reference. Before starting the activity, a few steps must be considered:

- Point cloud datasets should have enough point density to be able to make the elements visible and distinguishable
- Before inserting them into the model, the point cloud must be cleared of any unnecessary elements. For example, if the surrounding environment is not relevant for the activity, the points representing the surrounding environment can be deleted. This will reduce the file size of the point cloud and thus making it easier to use.
- Another method to improve the handling of the point cloud inside the model is to split the point cloud into floors and insert and model floor by floor. This way it is ensured that the model is not lagging.

Below we propose a number of recommended actions that one must take when a point cloud dataset is linked or imported:

- In the case of REVIT, the point cloud dataset should be placed on its work-set. If the point cloud has been split, for every part a work-set should be created. When opening the model, those work-sets can be closed, thus the model will open faster.
- For REVIT, create specific view templates to display point clouds in view. In the rest of the view templates, point clouds should be disabled. In this way, when a user wants to display a point cloud on a view, the view template can be used and the work-set will be activated.
- Link the point cloud from the local drive. Although all the files are on cloud platforms, it is best to download and use the dataset from the local drive. When the work is finished it can be relinked from the platform. This has shown an improvement in the performance of the BIM model.
- For ArchiCAD, do not import files that are bigger than 4 Gb. If the file is bigger, it should be split.

Automated modelling requires the use of specific techniques such as object detection, semantic classification, or model fragmentation. These techniques are described in D1.2 Methods for surveying and diagnostics of HVAC systems in the existing buildings.

There are already a few software applications available in the market that have implemented these techniques and can be used within a certain degree of performance (EdgeWise and FARO As-built are two examples). These two software applications allow the identification of walls, floors,

piping, ducts, cable trays. During an internal test with EdgeWise on a point cloud dataset for different types of buildings, the software showed reasonable results but also some mismatches (mainly rectangular ducts and complex architectural fixtures were not recognized). In deliverable 1.1, Methods for Data Acquisition, an add-in for Revit has been developed. The plugin is called 3D Dash Tool and its aim is to automatically detect architectonic features from a point cloud.

In the case of renovation projects, depending on the type of renovation, only some parts might be needed to model. In this situation, BIM modellers will focus more on the important parts of the renovation while detailing less the other parts of the building. As an example, in terms of façade renovation work, the elements of the façade will be modelled with a higher LOD than the rest of the building, which is needed just to highlight the volumetry of the building. In this case, a parameter/property should be created to differentiate between different types of elements.

Another situation can be that from a point cloud dataset, some elements are clearly visible and there is enough information to identify the elements properly while other parts are not easily distinguishable. In this case, a new set of parameters/properties should be defined that indicates the status of the element:

- defined – where the dimension and location of the element are verified on-site.
- undefined geometry - if there is not enough information regarded to geometry
- undefined position - if the position is not checked on-site, for example, a pipe placed inside a wall or in a shaft that is not accessible.
- Undefined – both position and location are not known.

These are only a couple of proprieties/parameters that can be considered when modelling existing buildings but not this list should not be considered restrictive. Depending on the number of parameters/proprieties inserted in a model, as mentioned in chapter 2.10, one must consider how these parameters to IFC and how it wants them to be visualized.

3.1.2 Based on CAD drawings

CAD drawings along with PDF files represent the most common information sources to create as-built BIM models. Most of the 3D modelling software tools allow the import of CAD files, under different formats. The most common format used is the .dwg but also .dxf, .dwf or .dgn can be used.

REVIT works with CAD files in two ways (Figure 24): either creating a link to that specific file or to import directly into the model.
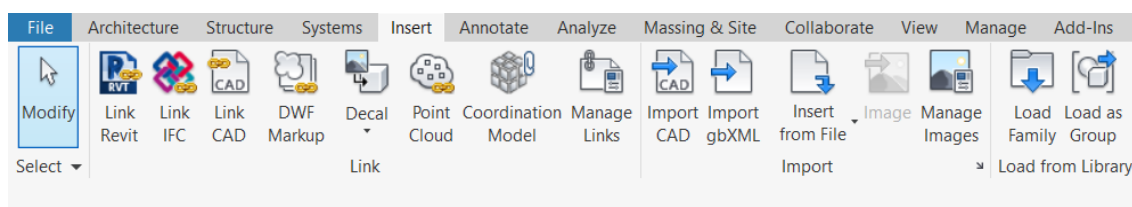
Figure 24. REVIT – Insert tab for linking or importing

The two methods have some particularities that differentiate their use that is highlighted in Table 3.

Table 3. Importing CAD files versus Linking CAD files in REVIT

	Importing CAD files	*Linking CAD files*
Connection to the source file	Loses all connections.	Keeps connection
Updating file	The files must be imported again	Files will be updated automatically when opening REVIT
Editing elements inside CAD files	Elements can be edited, exploded	Elements cannot be edited

Recommendations before using any of the techniques:

- Unwanted data from the CAD file should be deleted. This will reduce the file that will be imported into the BIM modelling tool.
- Either using a link or import functionality, every CAD file should be audited and purged for unused elements.
- Freeze or close the unnecessary layers.
- Make sure that all elements are assigned to the correct layer. This will result in better manoeuvring of the CAD file inside the BIM tool.

When using REVIT, one must also consider the following:

- Never explode the CAD file inside the REVIT model. If data is needed from the CAD file into REVIT, use a sandbox file where the CAD file is exploded and only the desired elements are copied.
- Linked CAD files should be placed on a work-set designated for this operation.
- Linked CAD files should be placed only on the required views.

For ArchiCAD, the recommended solution is to use the DWG as an external reference. To do this, one must go to "File-> External Content -> Attached XREF" (this option is similar to Linking a CAD file in REVIT as well as attaching an XREF in AutoCAD). In this way, the linkage can be deactivated after the modelling is done. The CAD file will be imported as a non-editable block. Another option offered by ArchiCAD is to place it as an "external drawing". This allows the user to pick the parameters from the drawings without importing all the attributes from the file. The last option offered by ArchiCAD is to merge the DWG file into a project, but this means that all items in the drawings will be part of the project, which is not recommended because one may end up with a lot of attributes that are not useful, making the handling of the model harder.

A technology developed rather recently that helps speed up automating modelling using CAD drawing is Flexijet 3D (www.flexijet.info). With this technology, measuring points are directly

linked with CAD drawing commands to produce finished 3D CAD drawings that can be inserted afterward in a BIM Model. It reduces time because the measurements of the elements are accurate (to the millimeter). It is already a 3D representation of elements and there is no more need for point cloud or CAD post-processing.[15]

3.1.3 Based on pictures

Most software allows the insertion of pictures in a BIM project, but the files will act as underlays, such as a .dwg or a PDF. However, photogrammetry can be used to create a 3D object based on pictures, more automatically. This technology offers a few types of outputs that can be used in BIM projects as starting points in preliminary design. They can also be combined with lasers or LIDAR scans to receive an accurate representation of existing objects or sites, close as possible to real objects.

The use of photogrammetry in the AEC industry has a lot of potentials and can be implemented when gathering on-site data and generating the surrounding environment, complex facades, recreating 3D positioning of MEP components, alignment of MEP components with proper proportions, material representation, detailed fixtures in a 3D format. Photogrammetry software can offer the following useful outputs: point clouds and 3D Meshes.

Previously, it was presented how point clouds, from laser scans, are used in a BIM model. Point clouds generated with photogrammetry are not that different but have two characteristics that one should be taken into account:

- The dimensions are less accurate.
- Have more details, colours, and faster data collection.

The point clouds are inserted in the same manner as the ones coming from laser scans, so all recommendations, from 3.1.1, should be followed.

Photogrammetry allows the creation of 3D Meshes based on a series of photographs of existing buildings or other objects with a high level of detail and textures. They can be incorporated in a BIM project as a reference. The advantages of a 3D Mesh in contrast to point clouds are that it is very easy to identify and interpret the captured elements. Depending on the resolution they can be used in technical designs with a high degree of reliability. 3D Meshes can be imported in most 3D software. Generating good results depend on the photogrammetry software used and the outcome desired. An example of open-source software worth mentioning is MeshLab), but also commercial products such as Agisoft, Bentley ContextCapture, and Autodesk Recap.

In Deliverable 1.2 there are recommendations on how to collect proper images to use in photogrammetry.

3.1.4 Based on PDF files

PDFs are one of the most common sources of design drawings. As-built BIM models can be developed starting from PDF files. As is the case with CAD drawings mostly all BIM modelling tools allow the import of PDF files (with REVIT it is possible only from 2020 version). Also, like in CAD drawings, information

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[15] www.flexijet.info

needs to be placed manually inside the 3D elements, because there is no way to extract and insert the information automatically.

Before inserting PDF and starting the modelling, one needs to be aware that the file is at the correct scale and size. Depending on the software used scaling a pdf might be possible with similar methods used to scale a PDF in a 2D drawing.

3.2   Working with phases

BIM modelling for renovation projects, as mentioned in subchapter 2.6, can include a minimum of 3 modelling phases: existing phase, demolition phase, and new phase. Depending on the software used the phases can have different names but the main idea is the same: when creating elements in an as-built BIM model attention should be given to phases.

There is no limit to the number of modelling phases that can be created but the recommendation will be to not create too many since it will burden the modelling tasks. When creating a new modelling phase, the name assigned should be clear and concise and should also include a timestamp (year, quarter, month). In the following subchapters, a few recommendations on how to work with phases for the 2 different software applications are presented.

3.2.1 REVIT Phases

In REVIT there are two default modelling phases; "existing" and "new". When the Master Model is set up, all the modelling phases should be created there. Each model should have the same phases defined as in the to the master model. To perform "phase map" command, one must select a link, and in the properties should go to "Phase Mapping". To create phases in REVIT, go to Manage-> Phases (Figure 25).
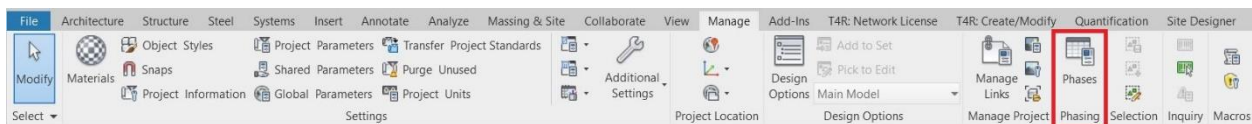
Figure 25. Phase tab in REVIT.

After clicking on "Phases", a dialogue box will appear (Figure 26) where they can be defined or filtered. Graphical overrides can also be defined, but one must consider how the project template is setup as well as the hierarchy for graphic overrides. Modelling phases should define the most important milestones inside the project. Activities may be combined and placed in a single-phase if possible.
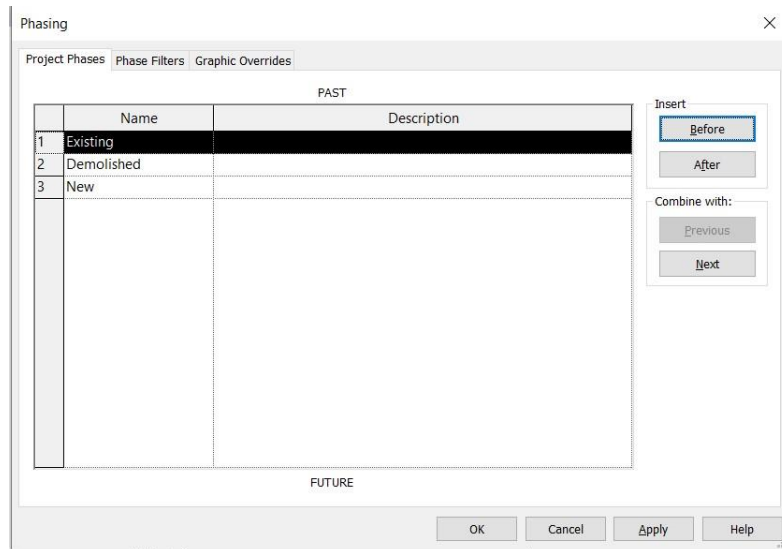
Figure 26. Defining project phases in REVIT

The phase filter (Figure 27) works similarly to the view filter. The difference is that they relate to the modelling phases. Users can choose a display mode using these filters. Phase filters can be controlled either by view or from a view template and the recommendation is to control it from the view. The reason behind this is because a view template contains a lot of settings and most probably it is applied to a great number of views that may not display the same phase, thus requiring to place different phase filters.
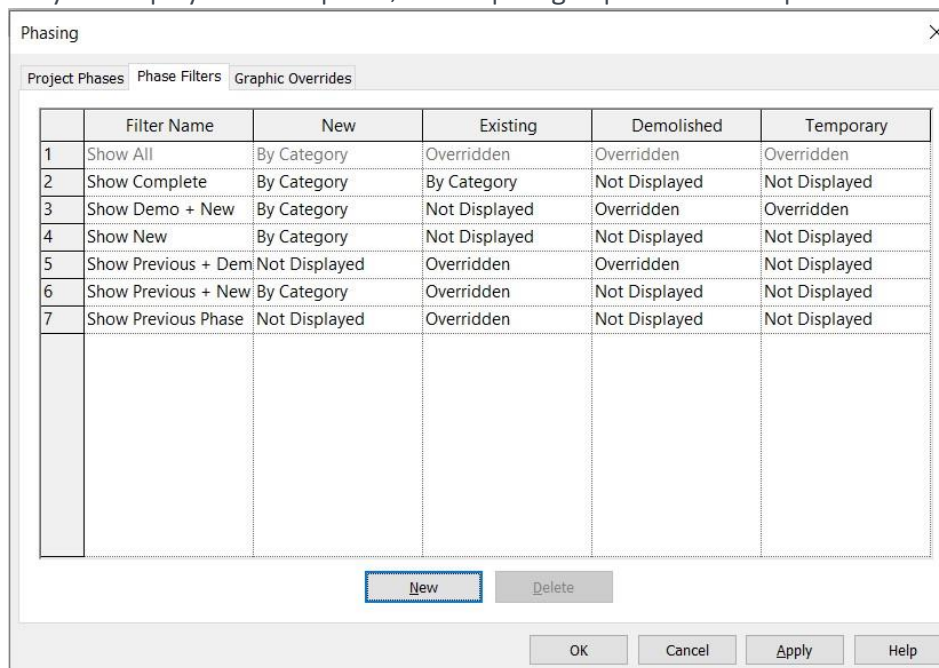
Figure 27. Phase filters in REVIT

The Graphic overrides (Figure 28) allow modelers to control how elements are viewed based on phases. These settings will affect every element in that modelling phase status. Unfortunately, the modelling phase is not a parameter based on which a user can create a filter.
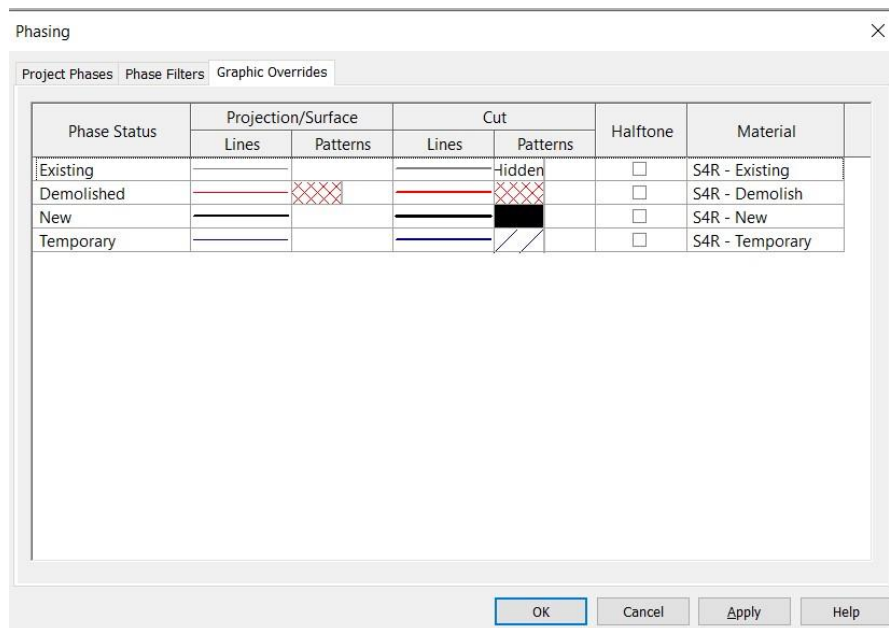
Figure 28. Graphic Overrides for phases in REVIT

3.2.2 ARCHICAD phases

In ArchiCAD, modeling phases are easier to work it. The software has embedded a Renovation Palette, where three modeling phases are already defined: "Existing", "New" and "To be demolished". One may also select the relevant phase when creating elements. By default, all elements will have the status "Existing" (Figure 29 a and b).
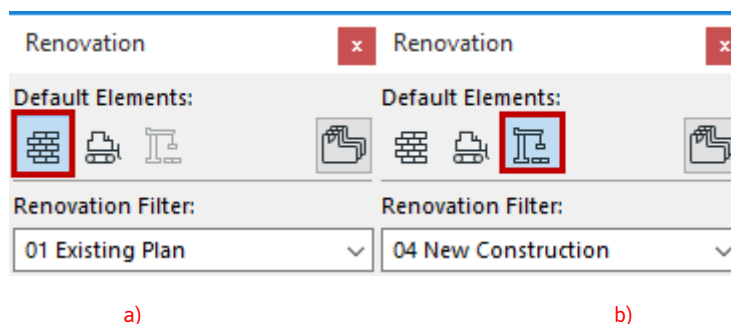
Figure 29. Phases in ArchiCAD[16]

Renovation Filters can be used to display the project to reflect different stages of renovation (such as "Demolition Plan" or "New Construction"). ARCHICAD comes with several predefined Renovation Filters, but users can change the options at Document > Renovation > Renovation Filter Options.

ARCHICAD, like REVIT, has its predefined Override Styles for each of the three Renovation Statuses. To change these default styles, the Graphic Override Rules dialogue box should be used (Document > Graphic Overrides > Graphic Override Rules).

ARCHICAD's Renovation feature depends on assigning the proper Renovation Style to individual elements and then displaying them in the different filters corresponding to the different stages of the renovation process. In most cases, once modelers have assigned element styles and defined filter options,

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[16] https://helpcenter.graphisoft.com/user-guide/89347/

graphical feedback can be viewed just by clicking from view to view - from Existing Plan to New Construction to Planned Status. The display of elements changes automatically.

4. Conclusions

The scope of Deliverable 2.4 was to establish a set of practical steps to be taken by any company to perform renovation projects in a BIM environment. The document has highlighted and identified the differences that one may encounter in modelling new buildings and renovation projects. All the proposed steps were contextualized for two BIM tools available in the market: REVIT and ArchiCAD. Specific examples were given to better demonstrate the proposed steps. Moreover, the document has illustrated the need and the required parameters for a "BIM Model project template" for renovation projects as well as specific items to be taken into consideration when creating an MEP template for this kind of projects. 3D objects for residential projects were a topic tackled in this document highlighting the differences between new and renovation projects, as well as guidelines for including MEP 3D elements in a BIM model for renovation projects.

It was highlighted that part of the modelling process is about exporting to other file formats. Exporting the information from the BIM model in other file formats is of great importance with special consideration to .ifc format for OPEN BIM workflows. Exporting from .ifc from REVIT and ArchiCAD was detailed and explained illustrating the importance and the use of .ifc files.

Building a BIM 3D model of an existing residential building relies on the information given by the building owner (e.g., existing 2D plans) and collected from the site (e.g., point clouds, pictures). Methods to collect data are shown in Deliverable 1.1 and 1.2. Based on the type of data collected, this report has 1) detailed ways to build a 3D model, 2)highlighted particularities of the process (uncertainty of some items and how to model them), 3) presented ways to make modeling more automatically (using existing software on the market that speed up the process of 3D modelling based on point clouds), and 4) illustrated how to depict them in a 3D model by using phases.

The report is addressed to all stakeholders and it offers guidance and assistance to the companies in creating their own workflows while being aware of some of the challenges (since renovation projects have always a degree of unknown) that they might face when modelling for a renovation project for residential projects. The experienced companies in renovation projects can also use this document to refine their ongoing process.

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APPENDIX 1 – BIM SPEED METHODOLOGY TOOLKIT

**BIM Speed
Methodology Toolkit**
Rev. 2.3
HOCHTIEF ViCon
25.08.2020

The BIM Speed Methodology Toolkit supports you to identify the main renovation goal for your renovation project.
You can differentiate relevant Renovation Phase and RIBA Stage and identify possibilities of corresponding
Business Process and/or BIM Use case, including range of potential methods.
Result is a list of data to be collected and a link to corresponding task of WP1.
This list will be specified more detailed during project runtime of BIM Speed project and
in accordance to demo site requirements, elaborated in WP8.
First impression of WP8 integration can be reviewd in Tab "2. DemoSite".

Please Note:
If new data is available, please update corresponding tab (marked with ###) and update PowerPivot data model.
Please do not change formatting of this tab.

Figure 1. Starting page of the BIM SPEED Methodology Toolkit

BIM-SPEED D2.4 Guidelines for as-built BIM modelling of existing buildings

APPENDIX 2 – LIST OF TOOLS FOR 3D MODELING

| Software Name	Developer	Discipline	Native output file	Other types of files	Type of License
REVIT	Autodesk	Architecture, Structure, M.E.P.	.rvt	IFC, .nwc, .dwg, .dxf, .dgn, .sat, .dwf, .dwfx, .fbx, .gbxml,	Paid license
ARCHICAD	Graphisoft	Architecture *	.pln	IFC, IFCxml, IFCzip, .3dm, .dwf, .dxf, .dwg, .dgn,	Paid license
VECTORWORKS	Nemetschek	Architecture	.vwx	.dwg, .dxf, .dwf, .dwfx, .sat, .stp, .step, IFC, IFCXML, .3ds,	Paid license
MICROSTATION	Bentley	Architecture, Structure, M.E.P.	.dgn	.dwg, .dxf, .fbx, .skp, .step,.3mx	Paid license
BRICSCAD BIM	Bricsys	Architecture, Structure, M.E.P.	.dwg	.ste, .stp, .step, .igs, .iges,	Paid license
ALLPLAN	Nemetschek	Architecture	.ndw	.dxf, .dwg, .dwt, .dxb, .dgn, IFC, IFCXML, .skp, .3dm, .stl, .wrl,	Paid license
FreeCAD		Architecture, Structure, M.E.P.	.fcstd	IFC, .dwg, .dxf, .step, .ply, **	Free license
B-processor	Aarhus University	Architecture, Structure, M.E.P.			Free license

Notes:

* An Add-in from the software company needs to be installed.

** A lot more files can be exported, but only the most common ones where mentioned

APPENDIX 3 – BIM Roles inside a company

There are 4 different BIM Roles involved inside a project and in an organization (See figure below). The number of resources depends on the size of the company or project involved. The organigram for each BIM project is presented in the BEP.
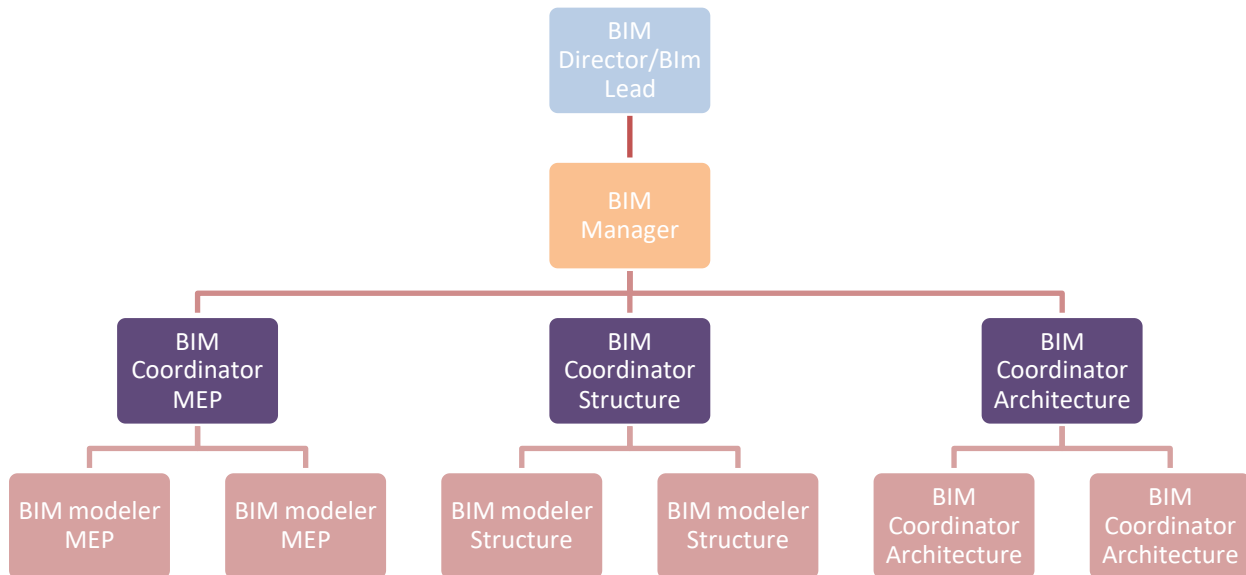
A brief description of the role description, competency, and role inside an organization for each position are presented in the following table.

BIM Role	Role description	Role inside the organization	Competency and BIM experience
BIM Director/Lead	Leads the entire BIM department	- develop BIM policies; - implement and ensure compliance with the company's BIM policies; - create the framework for internal collaboration;	- leadership and coaching; - planning and ability to persuade; - the ability to define BIM outcome; - capability in 2 or 3 BIM modelling software packages;
BIM Manager	Responsible for the implementation, management, and	- Manage the BIM process by the necessary tools;	- leadership and coaching; - planning and organization;

		- setting up BIM protocol and BEP; - Guide a project team and offer assistance to the wider practice - meet and present to the client BIM related issues - Continuously review optimal BIM related software - Provide BIM training internally.	- creativity, problem-solving, collaboration. - experience in viewing and coordinating BIM. - setting up a BEP and a BIM protocol.
	delivery of BIM on projects.		
BIM Coordinator	Responsible for model delivery, coordinating, and reviewing. Ensures the standards are met.	- checking the models with objectives and condition; - ensures compliances with BEP. - checking and monitoring the implementation of changes in the model; - promote the use of BIM and best practices.	- problem analysis, - planning and organization; - quality orientation; - collaboration and creativity. - the ability to use 2-3 BIM software; - experience in BIM outcomes; - experience in setting up and coordinating a BIM project.
BIM Modeler	Responsible for model delivery and ensures the model complies with project and company standards.	- add data to the model in a BIM Environment; - ensure compliance with BEP; - Optimally use of the software and make suggestions for developing or improving software tools	- collaboration; - creativity; - quality orientated; - knowledge of the BIM process. - knowledge of BIM modelling software;