TIMEPAC

Towards Innovative Methods
for Energy Performance Assessment and Certification of Buildings

Deliverable 2.1

Generating enhanced EPCs with BIM data

Transversal Deployment Scenario 1

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Executive Summary

This report summarizes the work of Task 2.1 “TDS 1- Generating enhanced EPCs with BIM data”, one of the five scenarios carried out in Work package 2 “Transversal Deployment Scenarios” (TDS). This work package is concerned with the creation of future scenarios with the aim of deploying and delivering new methods to implement enhanced EPCs schemas. The purpose of Task 2.1 is to develop comprehensive guidelines to evaluate the feasibility of generating EPCs from BIM models. Additionally, these guidelines aim to ensure the high quality and reliability of the resulting EPCs, thereby promoting the widespread adoption of BIM for EPC generation.

The main outcomes of Task 2.1 are BIM-to-EPC guidelines for BIM integration in the existing and enhanced EPC schemes considering the availability and quality of data. The guidelines consider two scenarios for a certifier to generate an EPC:

- A BIM model does not exist for the building to be certified; therefore, it has to be created.
- The BIM model has already been created; therefore, it has to be checked to ensure it can be used to generate an EPC.

To promote the adoption of BIM for EPC generation, we have developed guidelines with a particular emphasis on enhancing open interoperability using the available methods and tools. These guidelines aim to contribute to developing standardized and reliable protocols to use BIM data for calculating EPCs in the European Union.

The guidelines encompass the process for extracting relevant data from BIM models and translating them into the inputs required for EPC calculation using specific tools. This includes information about the geometry, materials, systems, and performance characteristics of the building. By using BIM as a source of accurate and consistent data, the guidelines aim to address the issues of outdated, inaccurate, or incomplete information that currently hinder the proper generation of EPCs. Moreover, the open interoperability procedures outlined in the guidelines promote the exchange of data between BIM models and EPC software, facilitating a seamless flow of information.

To showcase the applicability and value of these guidelines, a comprehensive validation process has been conducted in six partner countries: Austria, Croatia, Cyprus, Italy, Slovenia, and Spain. Thirty BIM models, five per country, were generated and assessed using the guidelines. The results of the validation exercise demonstrate the applicability of the guidelines in real-world scenarios and highlights their effectiveness in enabling certifiers to confidently generate accurate EPCs.

Following the discussion of the results of the application cases, a series of recommendations are provided for software developers. However, achieving a seamless integration of BIM and EPC tools is a collaborative effort which requires the collaboration of industry organizations, government and regulatory bodies, professionals in the AECO sector, and researchers.

The next steps for the work completed in Task 2.1 involve verifying the applicability of the guidelines with external stakeholders, which will be carried out as part of WP3 "Verification Scenarios” and using them as training materials in the courses to be delivered in WP4 "EPC Standardisation, Training, and Capacity Building."

1 Introduction

1.1 Purpose and target group

According to the European Commission, the building sector is currently the largest consumer of energy in the EU; it is responsible for 40 percent of energy consumption and 36 percent of greenhouse gas emissions, also, approximately 75 percent of the building stock is energy inefficient. Concerning the above-mentioned data, the European Union intervenes through political actions aimed at the realisation of deep renovation and energy requalification interventions. Proposed policy actions include the European Green Deal, the Renovation Wave, and the proposed revision of the Energy Performance of Buildings Directive (EPBD), all aimed at achieving the political and environmental targets set for 2050.

In this perspective, the Energy Performance Certificate (EPC) represents an essential document to identify the buildings that need to be upgraded, the interventions to be performed, and the best methodologies to be applied. The project “Towards Innovative Methods for Energy Performance Assessment and Certification of Buildings” (TIMEPAC) aims to identify flaws in the current energy performance certificates and to improve current energy certification processes from single, static certification to more holistic and dynamic approaches.

The aim of WP2 “Transversal Deployment Scenarios” (TDSs) is to deploy and deliver new methods to implement enhanced EPCs schemas, which will be then implemented in the Demonstration Scenarios to be carried out in WP3. Different partner profiles — certification bodies, software developers, research groups — have been involved in the deployment of these methods, which embrace the technical, scientific, operational, legislative, and standardization levels.

WP2 includes five TDSs:

- TDS1 – Generating enhanced EPCs with BIM data.
- TDS2 – Enhancing EPC schemas through operational data integration.
- TDS3 – Creating Building Renovation Passports from data repositories.
- TDS4 – Integration of Smart Readiness Indicators and sustainability indicators in EPC.
- TDS5 – Large scale statistical analysis of EPC databases.

This deliverable reports the work done in Task 2.1 “TDS 1- Generating enhanced EPCs with BIM data” whose objective is to generate guidelines to assess the feasibility of creating EPCs from BIM models and to determine the quality and reliability of the EPCs generated.

The main outcomes of Task 2.1 are BIM-to-EPC guidelines for BIM integration in the existing and enhanced EPC schemes considering availability and quality of data. The guidelines consider two scenarios for a certifier to generate an EPC:

- A BIM model does not exist for the building to be certified; therefore, it has to be created.
- The BIM model has already been created; therefore, it has to be checked to ensure it can be used to generate an EPC from it.

1.2 Deliverable structure

This deliverable is organized in seven sections. Section 1 serves as the introduction, covering the purpose of TDS1 (1.1), the deliverable structure (1.2), the contribution of TIMEPAC partners (1.3), and how it is related to other project activities (1.4). Section 2 outlines the TIMEPAC vision for using BIM in EPC generation. The current status of BIM usage for EPC generation, considering the EPBD recast, sister projects, and existing guidelines, are presented in Section 3. In Section 4, the methodology applied for TDS1 is described, including the guidelines for EPC generation from BIM models (4.1) and the evaluation form used to assess their usefulness (4.2). Section 5 focuses on the application of the guidelines in each partner country. Section 6 presents the main findings derived from the implementation of the TDS1 in each country. And, finally, Section 7 provides the conclusions drawn from the findings and outcomes of TDS1.

1.3 Contribution of partners

FUNITEC led Task 2.1 with contributions from TIMEPAC partners. The guidelines were developed by FUNITEC in collaboration with CYPE, EDILCLIMA, and JSI. The rest of the consortium members provided the necessary data including drawings, models, and EPCs for generating the BIM models. FUNITEC was responsible for modelling and validating the buildings in Austria, Croatia, and Spain. EDILCLIMA validated the buildings in Italy, while JSI modelled and validated the buildings in Slovenia.

1.4 Relations to other project activities

Task 2.1 began by selecting BIM and EPC generation tools, which had previously been analysed in WP1 "Context Analysis to Support EPC Workflow." Specifically, these tools were investigated in the "EPC generation" section of Task 1.1 for and in the "Exploitation of EPC data" carried out in Task 1.4.

WP3 and WP4 will continue the progress made in Task 2.1. The subsequent stages will focus on verifying the effectiveness of the guidelines with external stakeholders, which will be conducted as part of WP3's "Verification Scenarios." Additionally, the guidelines will be incorporated into training materials for the courses delivered in WP4, known as "EPC Standardization, Training, and Capacity Building."

2 TIMEPAC vision

The TIMEPAC project aims to improve the quality and reliability of energy performance certificates (EPCs) in the European Union. According to a stakeholder consultation conducted by the European Commission in 2021, EPCs are often outdated, inaccurate or incomplete, and do not reflect the actual energy performance of buildings (European Parliament and European Council, 2021). One of the main reasons for this is the lack of reliable and standardized input data for calculating the EPCs. The input data can vary depending on the method, tools and experts used to perform the assessment, and may not capture the actual characteristics and conditions of the building.

The TIMEPAC project proposes to use Building Information Modelling (BIM) as a solution to overcome this challenge. BIM is a digital representation of the physical and functional characteristics of a building, which can be used to support its design, construction, operation, and maintenance. BIM models can provide accurate and consistent data on the geometry, materials, systems, and performance of a building, which can be used as input for calculating EPCs. BIM reduces human errors in assessing building characteristics, selecting simulation parameters, and defining thermal bridges, thus improving the reliability and efficiency of energy needs assessment (Carvalho et al., 2021).

Creating a BIM solely for the purpose of an EPC may not always be considered worthwhile due to the additional time required to create the model. However, when BIM is part of a building renovation passport (BRP), the efforts made are justified. The reusability of BIM data for such purposes amplifies the significance of investing time and resources into creating and maintaining BIM models, eventually driving the adoption of BIM technology in the field of energy performance assessment.

To promote the adoption of BIM for EPC generation, we have developed guidelines with a particular emphasis on enhancing open interoperability among the available methods and tools. These guidelines aim to provide standardized and reliable protocols to use BIM data for calculating EPCs in the European Union. Open interoperability encompasses the use of open standards and protocols that enable different software applications and systems to exchange data seamlessly. By adopting open interoperability procedures, BIM data can be effectively integrated into the EPC generation process, regardless of the specific BIM software being used.

The guidelines encompass the process for extracting relevant data from BIM models and translating them into the inputs required for EPC calculation using specific tools. This includes information about the geometry, materials, systems, and performance characteristics of the building (e.g., schedules and setpoint temperature). By using BIM as a source of accurate and consistent data, the guidelines aim to address the issues of outdated, inaccurate, or incomplete information that currently hinder EPCs. Moreover, the open interoperability procedures outlined in the guidelines promote the exchange of data between BIM models and EPC software, facilitating a seamless flow of information. This ensures that the data extracted from the BIM model can be easily utilized in the EPC generation process without manual data entry thus reducing potential errors.

The guidelines consider two distinct scenarios that certifiers may encounter when generating an EPC. In the first scenario, where no existing BIM model is available for the building to be certified, the process of creating a new BIM model tailored to the requirements of the EPC tool is described. In the second scenario, where a BIM model already exists, the guidelines provide a framework for evaluating its suitability and ensuring that it can be effectively used to generate an EPC.

To showcase the applicability and value of these guidelines, a comprehensive validation process has been conducted in six partner countries: Austria, Croatia, Cyprus, Italy, Slovenia, and Spain. Thirty BIM models, five per country, were generated and assessed using the guidelines. The results of the validation exercise demonstrate the guidelines' applicability in real-world scenarios and highlights their effectiveness in enabling certifiers to confidently generate accurate EPCs.

3 Recent developments

3.1 Energy Performance Building Directive recast

One of objectives of the TIMEPAC project is to contribute to enhancing the quality and usefulness of EPCs using BIM. The TIMEPAC vision regarding the integration of BIM and EPC is aligned with the latest developments of the Energy Performance Building Directive (EPBD), which is expected to be officially approved by the European Commission in 2023. The EPBD recast, published in December 2021 (European Parliament and European Council, 2021) introduces several new aspects that are potentially related to BIM, such as:

- **Building renovation passports (BRPs)** are documents that provide a long-term roadmap for the improvement of the energy performance and comfortability of a building over time. BRPs are based on an energy audit and include tailored recommendations for renovation measures to be carried out over the time, along with information on their costs, benefits, and impacts. BRPs can help building owners and occupants to plan and implement energy-efficient renovations, and to monitor and verify their results. **BIM has the potential to support the implementation of BRPs by serving as a comprehensive data repository that facilitates the calculation of key building performance indicators at every stage of the roadmap.**
- The **digital building logbook**, which is a common repository for relevant building data, including data related to energy performance such as EPCs, BRPs and smart readiness indicator (SRI), as well as on the life-cycle greenhouse gas emissions (GWP) and indoor environmental quality (IEQ) of the building. The building logbook facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions, and public authorities. **By incorporating BIM models into the logbook, a comprehensive digital representation of the building can be logged, allowing for efficient retrieval of the data, and supporting various building management tasks.**
- The **Smart Readiness Indicator (SRI)** measures the ability of a building to adapt its operations to the needs of the occupants and the grid. It is also used to improve the energy efficiency and overall performance. The SRI can be calculated using BIM data and can be included in the EPCs and BRPs (Boje et al, 2022)**. By leveraging BIM data, the SRI can be accurately calculated, providing valuable insights into the building's smart capabilities.**
- The life-cycle **Global Warming Potential (GWP)** assessment is a calculation of the total greenhouse gas emissions associated with the construction, use and end-of-life of a building. The assessment can be performed using BIM data and can be used to set minimum requirements for new buildings and major renovations. **BIM, as facilitates collaboration among various stakeholders involved in a construction project, can play a key role in conducting life-cycle GWP assessments with a holistic approach, covering all aspects of the building's life cycle.**

3.2 Open interoperability

Building Information Modelling (BIM) allows stakeholders to create, manage, and exchange digital representations of a building‘s physical and functional characteristics throughout its lifecycle. However, despite the expansion of the use of BIM in the AECO (Architecture, Engineering, Construction & Operations) sector, the exchange of information between different tools and software systems remains a challenge. An example is the workflow of designing a building in Autodesk Revit and subsequently simulating its energy performance using EnergyPlus, which often results in information loss during the exchange process. In this context, there are two alternatives for transferring BIM data from one software to another: (1) using proprietary formats, or (2) using open standard (non-proprietary) formats.

Proprietary formats are specifically developed and controlled by a particular software company or vendor, making them closely associated with their respective tools. These formats are commonly used when transferring BIM data between software tools within the same suite, ensuring compatibility and smooth integration. Additionally, proprietary formats may offer unique features or functionalities that are not available in other formats. This allows users to export information from one tool and import it seamlessly into another, minimizing issues related to BIM data conversions, especially for complex designs.

However, relying on proprietary formats comes with vendor dependency, which becomes a barrier when exchanging data with tools outside the vendor's suite. To address this challenge, some tools provide mechanisms, such as plugins, to import data when the corresponding Application Program Interface (API) is available. These APIs enable access to the BIM model data provided in the proprietary format, allowing users to read and import its elements, properties, and relationships.

Nevertheless, while ad hoc solutions can address data conversion from proprietary formats, in an industry that increasingly emphasizes cooperation, collaboration, and communication through digital technologies, restricted data accessibility may not be the most adequate option. As the industry strives for improved interoperability, open standard (non-proprietary) formats that promote data accessibility and seamless integration across different software tools are preferred.

As an alternative to proprietary formats, BIM open standard formats offer a more inclusive and comprehensive solution. These formats prioritize accessibility while ensuring compatibility, usability, transparency, management, and sustainability of BIM digital data. One of the primary advantages of open formats is that they establish a common language for diverse stakeholders, regardless of the BIM authoring tools they use. This fosters collaboration among different parties involved in the building process, thereby enhancing overall project efficiency.

In addition, open formats provide long-term standardization protection, ensuring the sustainability of BIM data. By adopting open standards like Green Building XML (gbXML) or Industry Foundation Classes (IFC), stakeholders can future-proof their data and guard against obsolescence. The use of open formats guarantees that data will remain accessible and usable, even as software and tools evolve over time.

The most widely adopted interoperability open standard in the AECO industry is IFC. This open, international standard (ISO 16739-1:2018) consists of data schemas represented in various schema languages (e.g., EXPRESS, XML, and OWL), along with reference data in the form of definitions of property and quantity names and formal and informative descriptions. The IFC schema allows for the definition of physical building components, manufactured products, mechanical/electrical systems, as well as more abstract models for structural analysis, energy analysis, cost breakdown, work planning, and other purposes. IFC is one of the open standards supported by buildingSMART[1], along with the Information Delivery Manual (IDM), BIM Collaboration Format (BCF), buildingSMART Data Dictionary (bSDD), Model View Definition (MVD), and Information Delivery Specification (IDS).

3.3 Sister projects

Currently, several research projects within the NextGenEPC cluster are focusing on BIM as a fundamental component element to enhance the existing EPC schemes.

D^2EPC project

The main goal of the D^2EPC project is to evaluate the asset and operational performance of a building (Klumbytė et al., 2021). The project aims to address the shortcomings of the existing certification system, such as the differences between calculated and measured energy consumptions, which have led to a lack of confidence in the results. By utilizing cutting-edge digital design and monitoring tools and services, the D^2EPC project aspires to deliver the next generation of dynamic Energy Performance Certificates for a regular assessment of buildings' energy performance.

[1] https://www.buildingsmart.org/

In D^2EPC project, IFC is utilized to define and transmit the physical geometry of a building, as well as its energy characteristics, construction products, and corresponding properties. However, interoperability problems can arise during the two-way data flow, especially when some software tools can only import or export IFC files, while others can import and export IFC files include in the official IFC certification table. The project has developed an IFC Parser to select and extract only the EPC related information from the IFC file.

EUB SuperHub

The goal of the EUB SuperHub project is to support the evolution of the certification process for buildings in the European Union (Gyuris et al., 2023). The project aims to develop a scalable methodology to view, assess, and monitor buildings throughout their lifecycle, considering factors such as embedded energy and costs. The ultimate objective is for energy performance assessments and certifications of buildings to reflect technological advancements, societal needs, and to be consistent across EU Member States.

The project has developed a digital building logbook structure considering existing data structures from EU projects, recommendations from the European Commission's reports, requirements from grant agreements and existing and upcoming EU legislation. The logbook's purpose is to bring together various data sources and serve as a common gateway to access data. One of the data sources are the BIM models that are categorized as building documentation.

Aldren

ALDREN is a project that supports deep renovation investments in buildings, aligning with the European Green Deal's "Renovation wave" initiative. It introduces a transparent assessment framework and building renovation passports to encourage ambitious renovation projects. These passports provide reliable assessments of current energy performance and indoor environmental quality, predict future performance, and allow benchmarking on a European scale.

In the ALDREN project, the Building Information Modelling is integrated in the ALDREN Building Passport and logbook (Salvalai et al., 2019). Specifically, BIM is one module of the ALDREN BuildLog.

The research projects D^2EPC, EUB SuperHub, and Aldren can benefit from the work conducted in TIMEPAC. The BIM-to-EPC guidelines devised in Task 2.1 for integrating Building Information Modelling into existing and enhanced EPC schemes provides a framework for using BIM in energy performance certification. By following TIMEPAC's guidelines, these projects can enhance data quality, promote consistency, and ensure standardized approaches in leveraging BIM data to accurately assess and certify buildings' energy performance.

3.4 Guidelines for generating BIM for EPC

There are some precedents for the proposed guidelines in utilizing BIM for energy performance certification. For example, Reeves et al. (2015) proposes guidelines for evaluating and selecting building energy modelling (BEM) tools for different phases of the building lifecycle. These guidelines can help potential BEM users identify the most appropriate BEM tool to apply in particular building lifecycle phases. The target users of those guidelines are architects, contractors, and facility managers.

Another example is the online course “Introduction of BIM enabled EPC assessments”[2], in particular lesson 4 “How to prepare BIM and how to extract data from BIM to EPC”. This lesson explores ways to leverage EPC data in BIM. It covers integrating EPC data into native BIM models, various BIM models used during a building's life cycle, and examples of energy data within native BIMs. It also examines how BIM can be applied to renovation projects and existing buildings when no BIM exists. Furthermore, it discusses utilizing Model Checkers for EPC assessment and provides examples of energy data analysis using these tools. Additionally, the training delves into exporting data directly

[2] https://eksergia.fi/en/introduction-of-bim-enabled-epc-assessments/

to energy simulations through IFC-files, highlighting the data transferred via IFC and addressing data exchange challenges with rules and requirements for improvement. It also briefly touches on validating IFC files. Overall, this course offers practical insights into harnessing EPC data in BIM for efficient energy analysis and decision-making.

4 Methodology

During the development of Task 2.1 “TDS 1- Generating enhanced EPCs with BIM data”, several subtasks have been performed in parallel in each of the six participating countries (Figure 1), specifically:

- **Analysis of tools**: Based on the WP1 reports, tools for BIM authoring and EPC generation have been identified and selected.
- **Data gathering**: Data and files required for generating BIM models have been collected and uploaded to the project SharePoint. They included drawings, CAD files, energy performance certificates in PDF, among others.
- **BIM modelling**: Based on the guidelines, BIM models (architectural and analytical) have been created for existing buildings through the guidelines’ recommendations and tips.
- **EPC generation**: Energy performance certificates have been generated from the BIM models generated in the previous task following the guidelines.
- **Quality check**: An evaluation form has been filled in to assess the effectiveness of the guidelines.
- **Cross country comparison**: After completing the guidelines and generating the BIM models, a comparative analysis of the findings from each country was conducted.

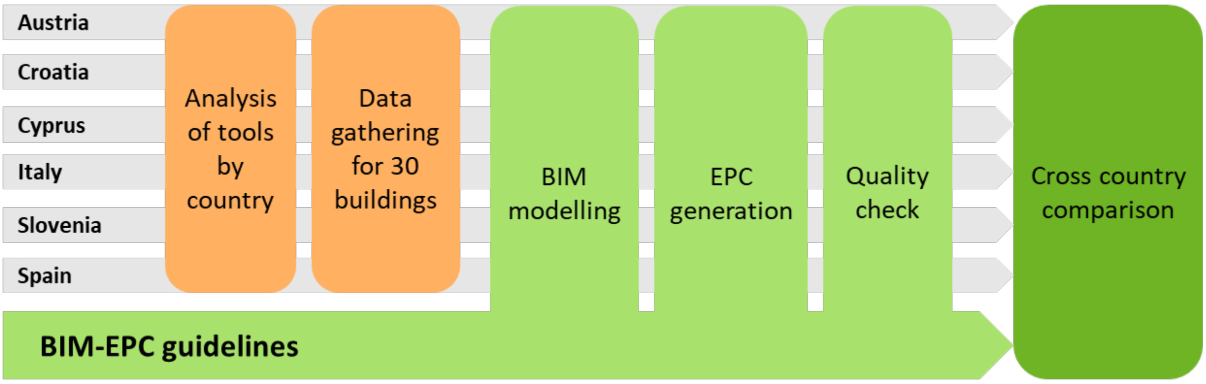


Figure 1. Tasks carried out for the TDS 1

The main output of this task has been the elaboration of guidelines for the generation of EPCs from the BIM models that are described in Section 4.1. To validate them, 30 models have been generated or validated following the recommendations of the guidelines and the whole process has been evaluated through a form that is described in Section 4.2.

4.1 Guidelines for the generation of EPCs from BIM models

The main output of Task 2.1 are the guidelines to facilitate the creation of BIM models and their subsequent export using the IFC format (Figure 2).

The guides emphasize the importance of entering all the necessary parameters in the BIM model to generate an EPC, ensuring its reusability across various disciplines (e.g., architecture and energy simulation) and throughout different stages (e.g., construction and renovation). However, it is essential to acknowledge that, currently, not all parameters introduced in the BIM can be automatically exchanged with other tools. Therefore, in some cases, these parameters may need to be manually introduced into the EPC tools.

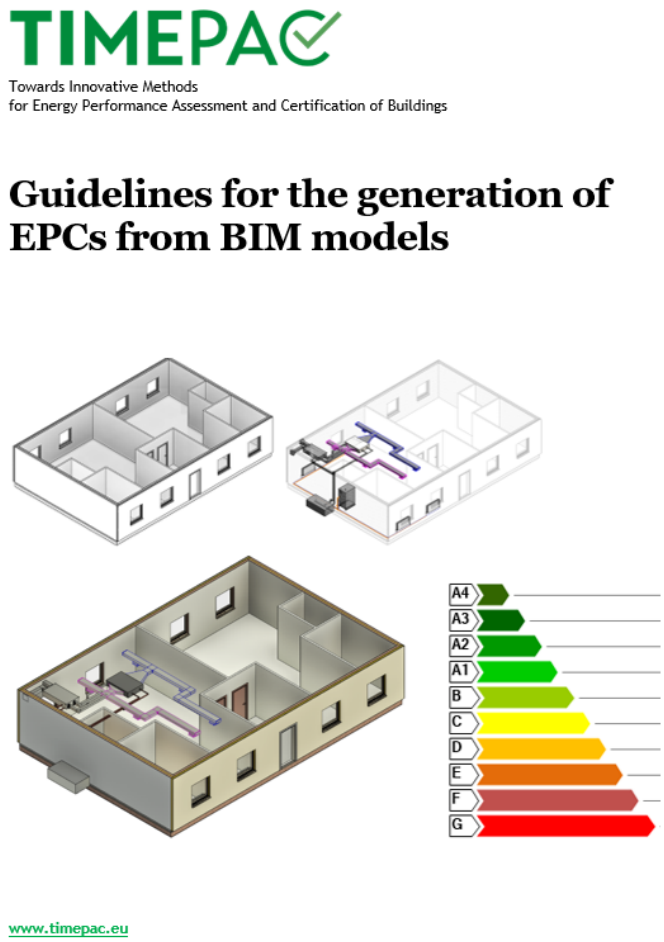


Figure 2. Cover of the guidelines

The following BIM and EPC tools have been considered:

1. BIM modelling: **Revit**, **Cype**
2. EPC generation: **Edilclima EC700**, **Cypetherm HE Plus**, **ETU**

When it comes to BIM modelling, the chosen software has a substantial user base and incorporates energy modelling modules. In the case of EPC generation tools, the selection criteria turn around the tools' ability to import IFC data, their certification as reliable tools for EPC in their respective countries, and the researchers' accessibility to these tools.

Given the collaborative nature of BIM processes, it is common for diverse stakeholders with diverse specializations and responsibilities in the building design, construction, and operation, to participate in a project. Consequently, the guidelines have been structured into chapters dedicated to specific domains, such as architecture, energy analysis, and building systems, as well as another chapter addressing importation into various EPC software for the technicians responsible for generating the certificates. This way, each user profile, whether it is a BIM modeller or energy consultant, can utilize the guidelines tailored to their specific area of expertise. In the case of a user encompassing both roles, the guidelines provide a comprehensive view of the entire process.

To facilitate the access to the guidelines content and its intelligibility, they have been organized using predetermined questions and concise answers. This enables users, regardless of their prior familiarity with the guidelines, to directly access specific chapters. Experienced users can also refer to detailed questions in the subchapters.

The guidelines are structured in the following chapters (Figure 3):

1. **Introduction**: It offers an overview of the guidelines and provides a general analysis of EPC and BIM concepts, information exchange, and Industry Foundation Class (IFC) format.
2. **BIM modelling for EPC assessment**: It addresses the specific requirements of different domains (architectural, analytical, MEP) to ensure the completeness of the models for Energy Performance Certificate generation.
3. **Information exchange for EPC assessment**: The process of exporting, validating, and importing the model from BIM software to EPC software, using the IFC format is described.
4. **In-depth study**: It contains an analysis of common issues that may arise during information exchanges between special elements and presents effective solutions.
5. **Annexes**: These provide detailed descriptions of the minimum requirements on how to generate models for EPC purposes, considering two specific BIM tools: Revit and Cype.

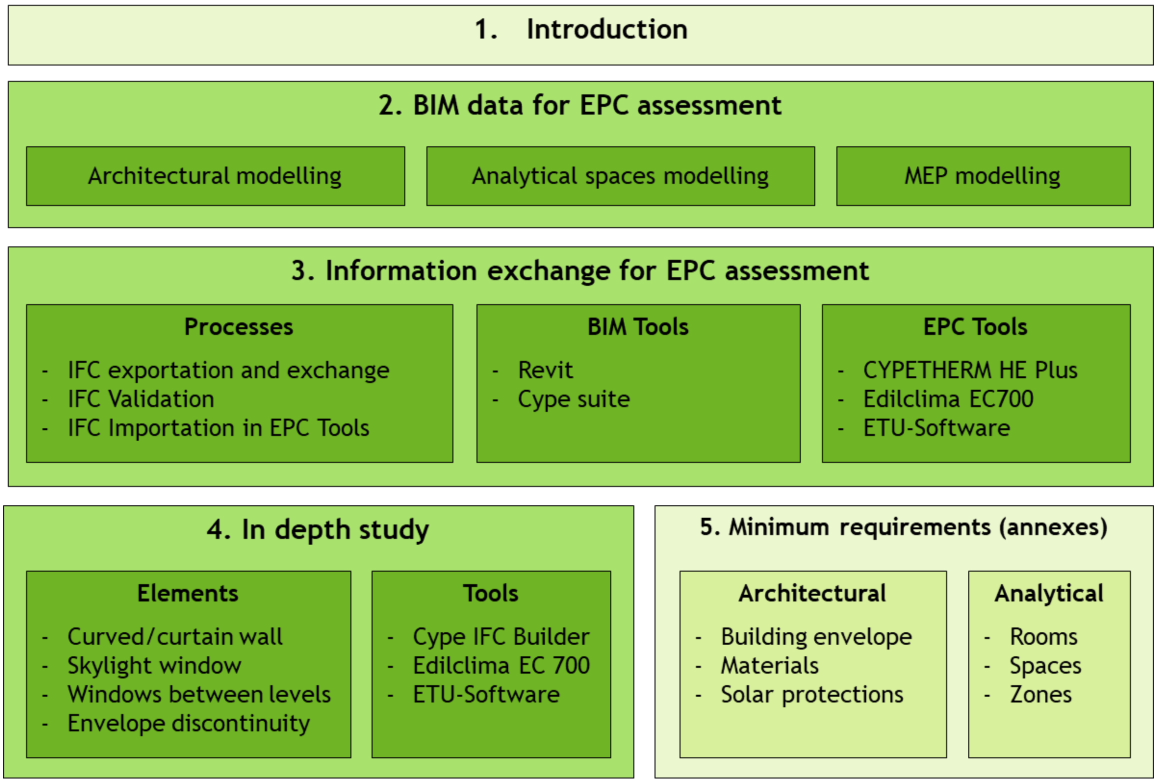


Figure 3. Structure of the guidelines for the generation of EPCs from BIM models

To exemplify the process outlined in the guidelines, a case study depicting a two-story residential multi-family building has been used. The process of model generation also serves as a means of verifying the instructions set forth in the guidelines.

4.1.1 Introduction

The introductory chapter provides comprehensive information on the rationale behind the guidelines and the target audience, consisting of professionals in the construction sector. Some of the key concepts that professionals should familiarize themselves with before delving into the subsequent chapters are introduced, including:

1. **Energy Performance Certificate (EPC):** This subchapter provides an in-depth exploration of EPC in accordance with European legislation. It covers the definition of the certificate, the parameters it involves, and the elements that require assessment for its generation. An overview of the EPC verification process is included.
2. **Building Information Modelling (BIM)**: This subchapter provides a comprehensive exploration of BIM. It distinguishes between BIM as a model and BIM as a methodology,

offering clear outlines of both concepts (Eastman, 2011). Moreover, a brief introduction to the benefits of implementing BIM in practice is provided.

3. **Information Exchange**: Continuing the focus on information exchange, this subchapter explores the inherent issues and highlights the significance of effective information exchanges within the BIM workflow. Additionally, it provides a brief overview of the advantages associated with efficient information exchange.
4. **Industry Foundation Classes (IFC)**: This subchapter provides a comprehensive focus on the use of Industry Foundation Classes (IFC) as an open exchange standard. It covers various aspects, including its definition, current market status, operational framework, released versions, compositional structure, and the subsets that constitute it, such as Model View Definitions (MVDs). This subchapter offers a detailed illustration of the key elements that define IFC and its role in facilitating interoperability.

4.1.2 BIM modelling for EPC assessment

The second chapter acts as a comprehensive guide, focusing on the generation and utilization of BIM models to exchange parameters related to elements that require evaluation for EPC generation. The goal is to integrate these parameters seamlessly into EPC software.

The subchapters dedicated to architectural, analytical spaces and MEP modelling, highlight the benefits of using BIM in EPC assessment, provide an overview of available BIM software solutions in the market, and offer guidance on selecting suitable software while providing answers to these questions.

- What are the benefits of an EPC assessment from BIM data?
- Which software solutions are on the market?
- Which software should I use?

The core the second chapter are the explanations about BIM model generation, ensuring the inclusion of all necessary information for EPC calculations. The information is organized into three disciplines: Architecture, Analysis, and Mechanical, Electrical, and Plumbing (MEP). Each discipline has a dedicated subchapter to help modelers understand and create models within their respective domains.

4.1.2.1 Architectural modelling

This subchapter highlights key concepts that technicians or designers, responsible for constructing and representing the building in BIM, need to know. These concepts ensure a smooth information exchange and the inclusion of necessary data for EPC software.

The subchapter is organized around the following questions:

- What is an architectural model?
- How is an architectural model for energy purposes created?
- What are the minimum requirements for the information exchange?

The subchapter offers a clear definition of the architectural model, guiding the modeller to identify construction elements falling under the architectural discipline of BIM. These elements possess distinct characteristics compared to other disciplines. For instance, the architectural model encompasses all components of the building envelope, necessitating accurate representation of their geometry and properties.

The elements within an architectural model are categorized based on their nature within the construction, the required information type, and the precision needed by the EPC software or the auditor generating the EPC. These categories include orientation, building envelope, materials, and solar protections (Figure 4).

Architectural model minimum categories, elements, and level of detail		
Minimum Required Categories	**Minimum Required Elements**	**Information Accuracy**
Orientation	Real North of the building	High - Accuracy in the direction of the orientation angle
Building envelope	• Floor in contact with the ground (ground slabs) • Interior floors • Roof • Ceilings • Exterior walls • Interior walls • Windows • Doors	High - Including detailed and accurate geometry, and detailed information about its physical and thermal characteristics
Materials	• Material layers of each part of the building envelope	High - Including detailed and accurate information of its physical and thermal characteristics
Solar protections	• Overhangs • Slats • Other exterior solar protection	Low - Including general geometry and some physical information

Figure 4. Minimum required categories, elements, and accuracy in architectural modelling

The guidelines offer valuable suggestions that cover different aspects of the BIM-to-EPC process and instructions to avoid generating incorrect or misleading information during modelling. This ensures smooth data communication with the IFC format and the EPC software. Emphasizing the model's accuracy in relation to reality, they highlight the importance of using levels, appropriate family selection, and proper utilization of modelling tools.

For each group of elements in the architectural model, an explanation of information requirements is provided, covering both geometric (i.e., shape and positioning) and non-geometric (i.e., characteristics) data. These specifications align with the general requirements of EPC software for energy simulations using dedicated calculation engines.

Moreover, specific recommendations are offered for each group of architectural elements. These recommendations serve as a guiding tool for the user throughout the modelling process, ensuring that relevant information is properly provided and consistent with reality during the export and import phases.

While the recommendations are presented in a generic manner to be applicable to any modelling software, detailed information is provided for Revit and Cype in corresponding annexes dedicated to each category considered in the architectural model. This supplementary information aims to offer a more precise and detailed guide for modelers utilizing these two tools.

4.1.2.2 Analytical modelling

To feed an energy simulation tool with data derived from a BIM model, it needs more than just the information about construction components. Equally necessary is the provision of spatial data in a format compatible with the energy software's requirements. To acquaint users with these concepts, the following matters are discussed:

- What is an analytical model?
- How is an analytical model for EPC purposes created?
- What are the minimum requirements for the information exchange?

A general definition of the analytical model is provided so that modellers understand the analytical model as an abstraction of the BIM model which needs to be comprehensible and usable by an energy simulation tool. Specifically, for EPC software, the analytical model is generated based on information and relationships that contribute to the building's heat exchange processes.

A space analysis model is typically generated automatically by EPC software from the modelling of analytical spaces. This model includes both geometric and non-geometric information of elements (spaces), which, together with architectural information, enable the creation of the analytical model (Figure 5).

Basic recommendations for developing a space model are included. These insights cover concept definition, space, and zone identification, as well as appropriate modelling tools for generating analytical spaces with Revit and Cype software. Although the examples provided may be specific to these programs, the basic recommendations are applicable regardless of the BIM software used.

Furthermore, geometric, and non-geometric information requirements are established and described for spaces and thermal zones. Recommendations are provided to support users to meet the requirements. While the recommendations are valid for any BIM software, explicit references are made to Revit and Cype, which are comprehensively detailed in the corresponding annexes of the guidelines.

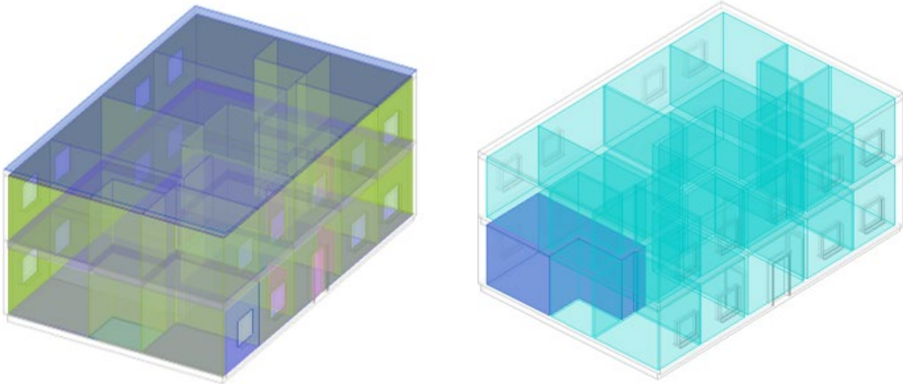


Figure 5. Revit analytical surfaces and analytical spaces views

Moreover, the process of creating the analytical model based on information derived from architectural elements and analytical spaces is referenced. This accounts for transforming the BIM model into an analytical model within BIM software (Revit) or externalizing it from the software (Cype). Finally, both programs and the practical utility of the created analytical models are discussed in a concluding section.

4.1.2.3 MEP modelling

MEP (Mechanical, Electrical, and Plumbing) modelling focuses on building services and installations. These basic concepts are addressed:

- What is a MEP model?
- What are the minimum requirements for the information exchange?

Typically, a MEP model is carried out by specialized technicians or engineers within a collaborative BIM environment. Due to the complexity of building services systems, it is essential to outline the basic elements that should be included in an MEP model to meet the information requirements of the EPC software. This ensures that the user can get from the BIM model all the necessary data to generate an energy certificate.

The recommendations to meet the information requirements could not be provided due to the inability of the EPC software to import MEP information.

4.1.3 Information exchange for EPC assessment

This section of the guidelines is dedicated to the generation of EPCs and the exchange of information during the modelling process to ensure its applicability. It covers two primary topics:

the exchange of data between BIM software and EPC software, and the benefits of using open formats, particularly IFC.

The content revolves around the following topics:

- Data exchange between BIM and EPC software
- IFC exportation and exchange
- IFC validation
- IFC importation in EPC tools

The exportation considers two specific BIM tools: Revit and Cype. Each one is addressed separately due to their unique export processes.

In the case of Revit, a step-by-step description of the exportation process is provided, along with illustrations depicting each step. The goal is to ensure that the exchanged information meets the requirements for the proper interpretation by EPC software or the professional responsible for generating the energy certificate. During this procedure, specific parameters need to be selected for exportation.

Two common scenarios have been identified during the exportation process using Revit. The first one involves including parameters in the model that are not predefined in Revit. These parameters are either created by the modellers to address specific needs or exist as parameters in Revit but are not automatically associated with a required component. The guide provides various methods to successfully include and export those parameters, and particularly recommends using the "Exporting schedules as property sets" due to its simplicity.

In the second scenario, Revit is used across different domains. When the BIM software lacks the capability to handle certain aspects, such as material properties, the guidelines suggest using a naming convention for the material. This allows for easy identification in a material database later on.

The issues that arise using Cype are of a different nature. Cype utilizes its own internal workflow for data exchange between its software tools based on proprietary formats. However, the guide covers the exchange of information through the open IFC format in case there is a need to interact with external software. The workflow, used to exchange information using the open IFC format, is explored in greater detail, supplemented with visual explanations through images that illustrate the exportation processes (Figure 6). The workflow includes this software: IFC exchange using Cype Architecture, IFC Builder, and CYPECAD MEP.

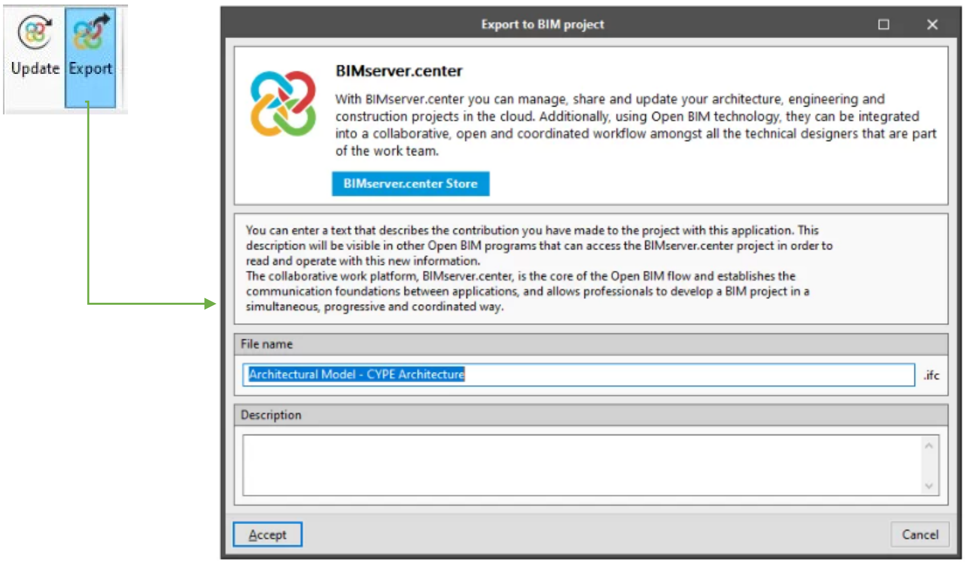


Figure 6. Exportation in CYPE Architecture

Ensuring the accuracy and integrity of the data introduced into the EPC software is crucial to achieve reliable results. This part of the guidelines aims to provide comprehensive information on validating an IFC model before importing it into the EPC software, including:

- Understanding IFC Viewer to visualize the contents of an IFC file and check its data structure.
- Explanation of the IFC structure exported from the BIM model.
- Searching for errors and verifying data integrity.
- Evaluating model accuracy, especially in cases where multiple fields are involved.
- Validating and saving the IFC model.

The final section of the guide is dedicated to the importation process of IFC models into three verified EPC software options: CYPETHERM (available in Spain, France, Italy, and Portugal), EDILCLIMA EC700 (utilized in Italy), and ETU (used in Austria). This process encompasses transforming an IFC file into an analytical model, which can then be utilized by the professional responsible for generating the energy certificate within the respective tool.

The guide does not cover the process of completing data that cannot be loaded from an IFC file. The reason for this omission is that the professional responsible for performing EPCs should ideally be a specialized technician proficient in handling the EPC software. The information required by the EPC software should ideally be present in the model itself, which can be verified through an IFC viewer if the modeller has followed the guidelines outlined in the previous chapters of the guide.

Additionally, it is worth noting that EPC software is specifically designed for energy analysis and does not have specific minimum information requirements. Instead, the technician must manually complete all the necessary information required by the software to conduct accurate simulations. This process involves supplementing any missing or incomplete data in the model, ensuring that the EPC analysis is based on comprehensive and reliable information.

4.1.4 In-depth study

During the process of generating an EPC from a BIM model, various issues arising from the complexity of real-world building representations have been identified. These problems stem from the intricate forms of buildings, which are difficult to translate into an IFC format, for example curved walls, windows between floors, and skylights, among others.

In the guide we enumerate these issues and evaluate the capabilities of the EPC software to import BIM models and transform them into suitable analytical models for energy simulation. Overall, it has been observed that the importation of BIM models into EPC software is correctly displayed on the IFC Viewer. However, these tools lack the ability to fully convert BIM models into functional models specifically tailored for EPC generation. Figure 7 is an example of a building with complex elements (skylight, curtain wall, and window between levels) that can be represented by BIM models and the IFC format.

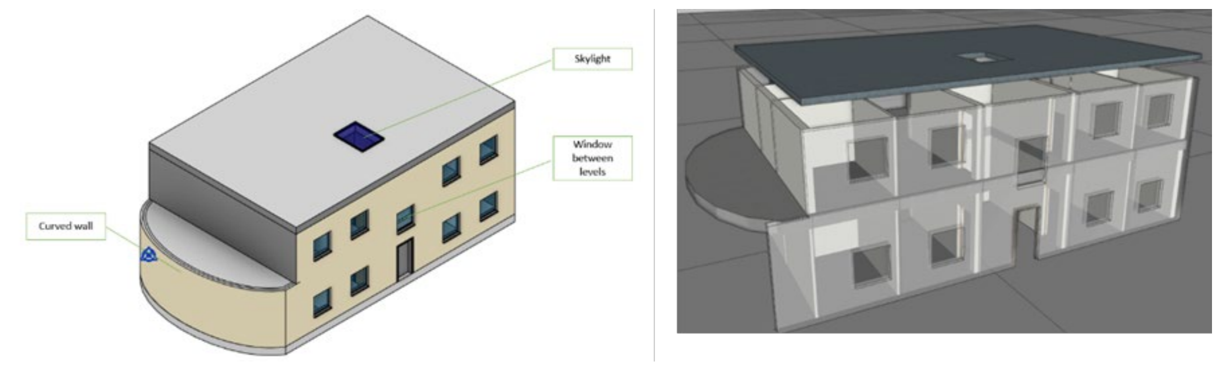


Figure 7. Using complex forms in BIM and how they are imported into EPC software

The guidelines provide specific suggestions for each software to deal with such complex elements, offering alternative ways to model them in BIM to ensure their proper conversion by the EPC software. These solutions serve as temporary workarounds to achieve successful EPC generation from BIM or IFC models with intricate characteristics.

However, it is crucial to acknowledge that these solutions are not definitive fixes, and the responsibility for adequately addressing these types of problems lies with the providers of BIM and EPC software, as well as the developers of the IFC schema. Further advancements and improvements in these software and schema are necessary to fully resolve the challenges associated with importing complex elements into EPC software for accurate energy performance assessments.

4.2 Evaluation form

Once the user has applied the guidelines to import a BIM model to the EPC tool, an evaluation form is completed. The purpose of this evaluation is to thoroughly assess whether the guidelines effectively assist modelers in the importation process. To ensure an accurate and insightful evaluation, each building is evaluated individually. While it is true that certain issues encountered during the process of generating an EPC may be common among multiple buildings, the complexity of buildings can vary, potentially leading to variations in the challenges faced. By evaluating each building separately, we can account for these potential variations and obtain a more comprehensive assessment of the guidelines' applicability and effectiveness.

The form starts with a table that aims to capture information about the users’ professional profile and their familiarity with BIM software, EPC tools, and IFC viewers. Then, the form focuses on the applicability of the guidelines to building to be certified. Finally, there are the questions to assess the effectiveness of their application.

The form is divided into sections with individual sheets that represent different stages of the guidelines (Figure 8):

- General information
- Architectural modelling
- Analytical spaces modelling
- MEP modelling
- Exportation
- Validation
- Importation
- Opinions

BUILDING MODEL IDENTIFICATION							
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HI
GENERAL DATA OF USERS							
USER PROFILE							
Is this the first time you have used a BIM software?	No	No	No	No	No	No	
How many times have you used a BIM software before?	A few times	A few times	A few times	A few times	Usually	A few times	
Is this the first time you have used an IFC viewer software?	Yes	No	No	No	No	No	
How many times have you used an IFC viewer software before?	Never	A few times	A few times	A few times	A few times	A few times	
Is this the first time you have used an EPC software?	Yes	No	No	No	No	No	
How many times have you used an EPC software before?	Never	A few times	A few times	A few times	Usually	A few times	
TYPE OF BUILDING							
Use	Other uses: Tertiary use (Office, commercial	Residential: Multifamily building	Residential: Multifamily building	Other uses: Tertiary use (Office, commercial	Other uses: Tertiary use (Office, commercial	Other uses: Tertiary use (Office, commercial	O T
Year of construction *(write a year)*	1978	1969	1987	1900	1978	1975	
Sq meters of the buiding or premise *(Writte a number)*	1110	3076,8	684,11	410,88	1110	2061	
Number of floors of the building *(Writte a number)*	3	7	5	2	3	6	
SOFTWARE USED							
BIM software used *(Mark below with an X all the software used)*							
Revit	X	X	X	X	X	X	
Cype Architecture							
OpenBIM Analytical							
OpenBIM construction systems							

General | Architecture | Analytical | MEP | Exportation | Validation | Importation | Opinion

Figure 8. Using complex forms in BIM and how they are imported into EPC software

Each section has a dedicated part to rate the guidelines' usefulness in the process. This allows us to understand how helpful the guidelines are to each modeler, as indicated by their assigned scores, and how well they address the challenges faced during the processes. Furthermore, there is a comments section at the end of each table where responsible individuals can provide more detailed opinions, clarify difficulties encountered, explain the reasoning behind the guideline ratings, and suggest potential improvements.

As an example, here are the questions for the architectural modelling section:

- *If you developed the model, were you able to include all the minimum required elements? (See architectural model chapter: What elements are part of the architectural model?) If the answer is no, please explain why. If some or most of them were included, please specify which elements you were not included and why.*
- *If the model was already developed, did it contain all the minimum required elements? (See architectural model chapter: What elements are part of the architectural model?) If some or most of them were missing, please specify which elements were absent.*
- *If the model was already developed and some minimum required elements were missing, did you encounter difficulties modelling those elements? If the answer is yes, please explain why. If some or most of them were problematic, specify which elements posed challenges and the reasons behind it.*
- *Were you able to understand and apply all the basic suggestions for the architectural model? (See architectural model chapter: What elements are part of the architectural model?) If no, please explain why. If some or most of them were not applied, specify which suggestions were challenging to follow and the reasons behind it.*
- *Were you able to understand and apply all the recommendations for the architectural model? (See architectural model chapter: Minimum required categories subchapters) If the answer is no, please write why. If not, please explain why. If some or most of them were not applied, specify which recommendations were challenging to implement and the reasons behind it.*

- *If you used a BIM software other than Revit or Cype, were you still able to apply the guidelines to develop the architectural model?*
- *If you used a BIM software that cannot export some minimum required elements, did you understand, find useful, and use any of the alternative solutions? (See architectural model chapter: Minimum required categories of the materials subchapter)*
- *Did you experience difficulties when importing complex design architectural models that needed adequate modelling for interpretation by EPC software? (See In-depth Study Chapter: IFC importation of the complex design model subchapter - Architectural model elements) If yes, please specify which elements posed difficulties.*
- *In relation with the previous question, were you able to solve them with the help of the guidelines? If not, please explain why. If some or most of them were not solvable, kindly specify which elements remained problematic and the reasons behind it.*
- *In relation with the previous question, could you solve these difficulties without the help of the guidelines?*
- *Did the guidelines help you to develop the architectural model? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Did you find the basic suggestions for the architectural model useful? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Did you find the recommendations for the architectural model useful? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Did you find the recommendations for the complex design models with the architectural model useful? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*

The final section of the questionnaire consists of general questions about the guidelines. Users are requested to rate the overall usefulness, productivity enhancement, as well as to provide suggestions to improve them. The questions are the following:

- *Did you find the guidelines useful? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Did the guidelines help you save time in the process from BIM to EPC? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Do you find the extension of the guidelines to other BIM or EPC software useful? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Would you recommend the guidelines? (Scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")*
- *Were you aware of any previous development of similar guidelines by other authors? If the answer to the previous question is positive, please write down the name and authors of the guidelines.*

The detailed evaluation form can be found in Annex A.

5 Application

The guidelines introduced in the previous section have been applied to case studies in six countries: Austria, Croatia, Cyprus, Italy, Slovenia, and Spain. A total of 30 buildings, with five buildings from each country, were modelled following the guidelines. These buildings varied significantly in terms of their design, type, and purpose providing a diverse set of models for examination.

The steps of the application are the following (Figure 9):

- **BIM modelling**: The initial phase involves creating a BIM model using available information, such as drawings. Additionally, this step encompasses modifying the BIM model after the validation process, which occurs when errors are identified. These errors may include missing parameters or significant changes in the model, such as wall divisions.
- **Export**: The BIM model is exported as an IFC file, with the aim of including as many elements and properties as possible.
- **Validation**: The exported IFC file is examined using an IFC viewer to verify the presence and accuracy of all elements and properties required for an EPC. If errors are identified during this validation process, the workflow loops back to the BIM modelling step, where these errors are addressed and resolved.
- **Import**: The validated IFC file is then imported into the EPC tool.
- **EPC generation**: Since not all the data necessary for EPC generation can be automatically imported through IFC, this step involves manually inputting the remaining data into the EPC generation tool.

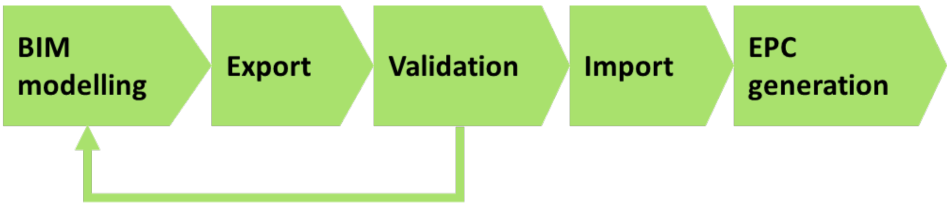


Figure 9. Steps of the guideline's application in the case studies

5.1 Scope of the application cases

Five buildings have been selected for each country, chosen based on the availability of corresponding building documentation. The selection includes buildings with different uses, sizes, and various spatial and constructive characteristics, aiming to encompass the diverse possibilities of the building stock.

<u>Building uses</u>

Out of the thirty proposed models, 21 of them have been identified as non-residential buildings, while the remaining have been classified as residential (Figure 10). Among the 30 proposed models, ten have been categorized as large buildings (Surface area ≥ 3000 m^2), another 9 as medium-sized buildings (1000 m^2 < surface area < 3000 m^2), and 11 as small buildings (Surface area ≤ 1000 m^2). Furthermore, it is worth noting that a diverse range of building sizes has been featured in each country, with Croatia and Cyprus leaning towards medium and small categories, respectively Figure 10.

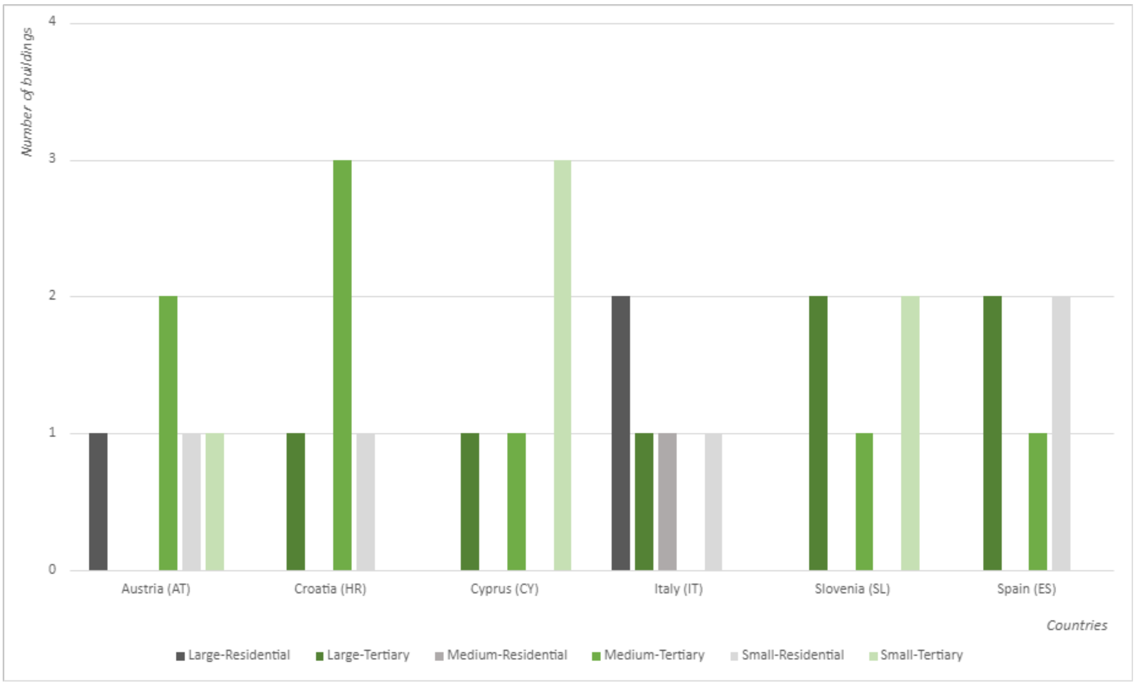


Figure 10. Relationship between the case studies and their functional and scale features

These data have provided an opportunity to evaluate the applicability of the guidelines without bias based on building typology in any of the countries. Simultaneously, they have allowed the assessment of the challenges associated with the particularities of each building typology.

<u>BIM and EPC software</u>

Despite the development of internationally applicable guidelines and the selection of comparable case studies, it is important to highlight that the processes for generating EPCs do not follow a unified approach across all countries. While a common framework has been established by Europe, the implementation can vary from one country to another. Thus, not all EPC generation tools have the capability to import BIM data. Consequently, the evaluation of the guidelines within the context of different countries has also reflected these variations.

For instance, Revit was used in Austria and Italy, while in Slovenia, ArchiCAD was used, enabling information exchange based on the open IFC format (Figure 11). Interoperability between these BIM software and the EPC software was achieved through the IFC exchange file. The process of generating EPCs from BIM using open standards was applied to all models of these two countries. In contrast, in the cases from Spain, Cype's software was used to develop the BIM models, while an EPC software developed by Cype was used for generating EPCs. In this case, interoperability between Cype's tools was facilitated by proprietary formats, although the software also supports information exchange using the open IFC format. Thus, for one of the five models we used open standards, and for the other four Cype’s.

In the cases of Croatia and Cyprus, the EPC software used in these countries could not read BIM models. Consequently, ad hoc models were created.

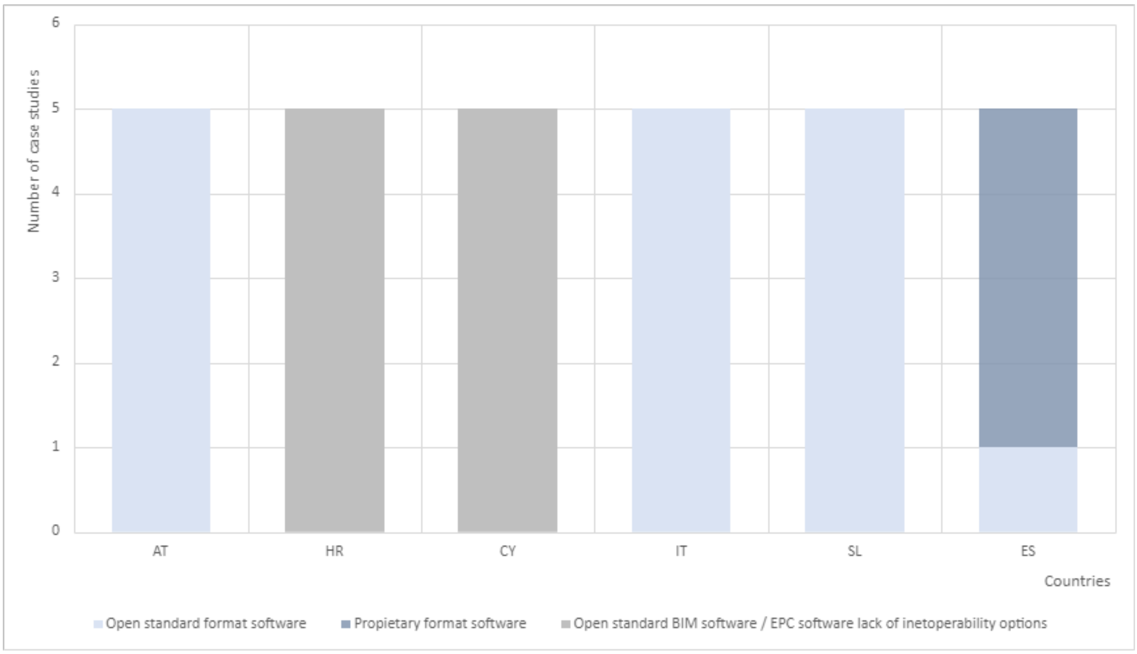


Figure 11. Relationship between the case studies and the software used by country

The diversity of software options and their impact on the processes provided an opportunity to assess the suitability of the guidelines for each country. Moreover, it enabled users to evaluate the advantages and disadvantages of using BIM for EPC in each country.

Input data

The collected information from participating users was divided into two categories based on the type of data, graphical and non-graphical:

- **Graphical information** encompasses the geometry and dimensions of the building, as well as any other representation defining construction characteristics which are deemed essential for project development. This information has typically been provided through construction plans. It represents the minimum requirements for conducting BIM-to-EPC processes, and all case studies have included this information in one format or another.
- **Non-graphical information** refers to technical data for building elements not found in the graphical documentation. This referred to any documents providing material and spatial characteristics, or other information necessary for generating EPCs.

In all the cases, the available information about the buildings, both graphical and non-graphical, had to meet the minimum requirements outlined in the guidelines. In the cases of Austria, Croatia, Cyprus, and Slovenia, there was graphical information in the form of scanned drawings or vector files (.dwg) (Figure 12). However, only two case studies in Austria and one in Croatia had a BIM model already created. Conversely, in Italy and Spain, there were BIM models available for all five buildings in each country.

Regarding non-graphical information, it is worth noting that in most models, a substantial portion of this data was derived from previously generated EPCs or simulation files used for EPC generation (Figure 13). This was particularly the case in Italy and Spain. However, in Croatia and Slovenia, energy audits played a more significant than EPCs, which existed in only three out of five buildings. Furthermore, Austria and Cyprus also provided technical reports on construction material characteristics.

Regarding the overall building description, Italy and Spain had a wealth of information about the buildings contained within BIM models and simulation files. In contrast, in the cases of Cyprus, the building information was limited to 2D plans and did not include EPCs.

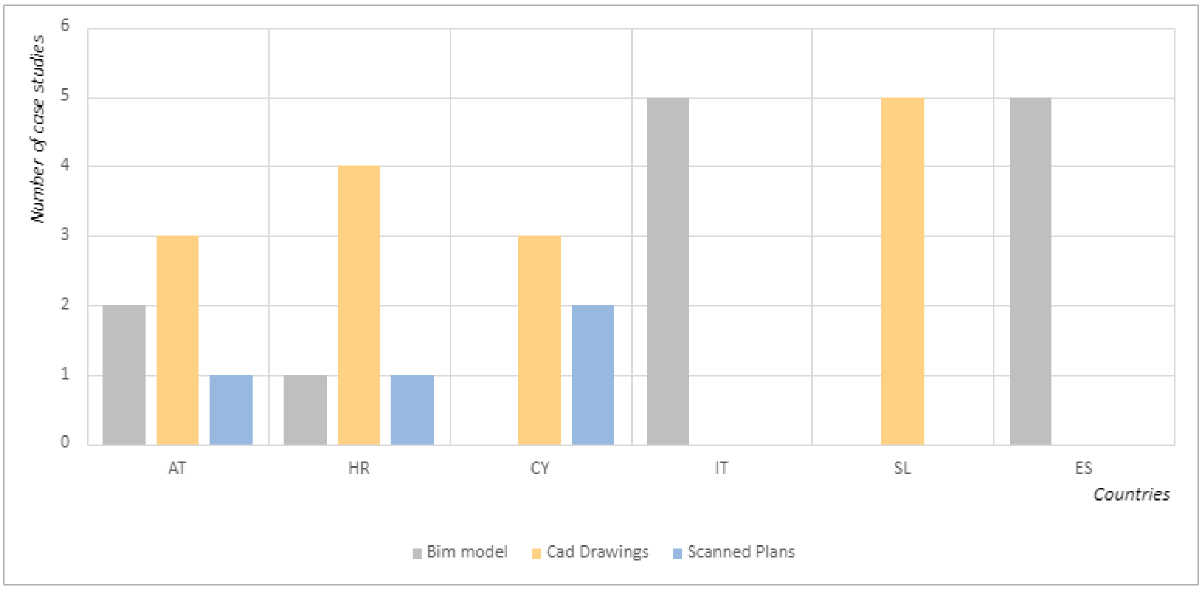


Figure 12. Relationship between the case studies and their initial graphical documentation

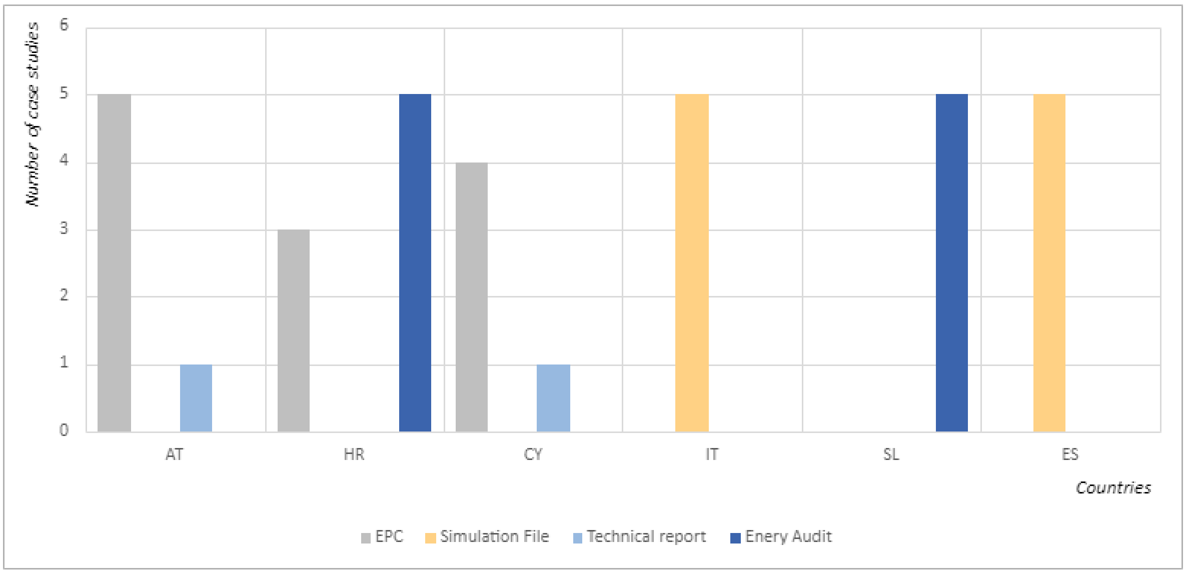


Figure 13. Relationship between the case studies and their initial non-graphical documentation

The fact that EPC generation processes can be initiated by users based on existing or non-existing BIM models has been taken into consideration. If an existing BIM model is available, the processes start with the validation phase. In the absence of a BIM model, the guidelines can be used to define a BIM model that fulfils the validation phase requirements.

For the evaluation of the guidelines, both scenarios have been considered in Austria and Croatia. The verification phase of existing BIM models has been undertaken in two Austrian case studies and one Croatian case study. However, for the remaining case studies in each country, the development of BIM models from scratch has been deemed necessary. In the case of Italy and Spain, all case studies have been based on existing BIM models. Lastly, none of the case studies in Cyprus and Slovenia have a BIM model.

The diverse characteristics of the buildings and the software typology; the quantity, quality, and format of the building descriptions have brought about a variety of BIM-to-EPC processes in each country. As shown in Figure 14, all the stages from BIM to EPC (modelling, exporting, validating, and importing) were completed only in Austria, Italy, and Slovenia. The import phase could not be performed for the case studies in Croatia and Cyprus due to the software's inability to read BIM models. Consequently, the validation stage assesses how the data input process would unfold from a BIM, contrasting with the current processes based on plans, documentation, and measurements.

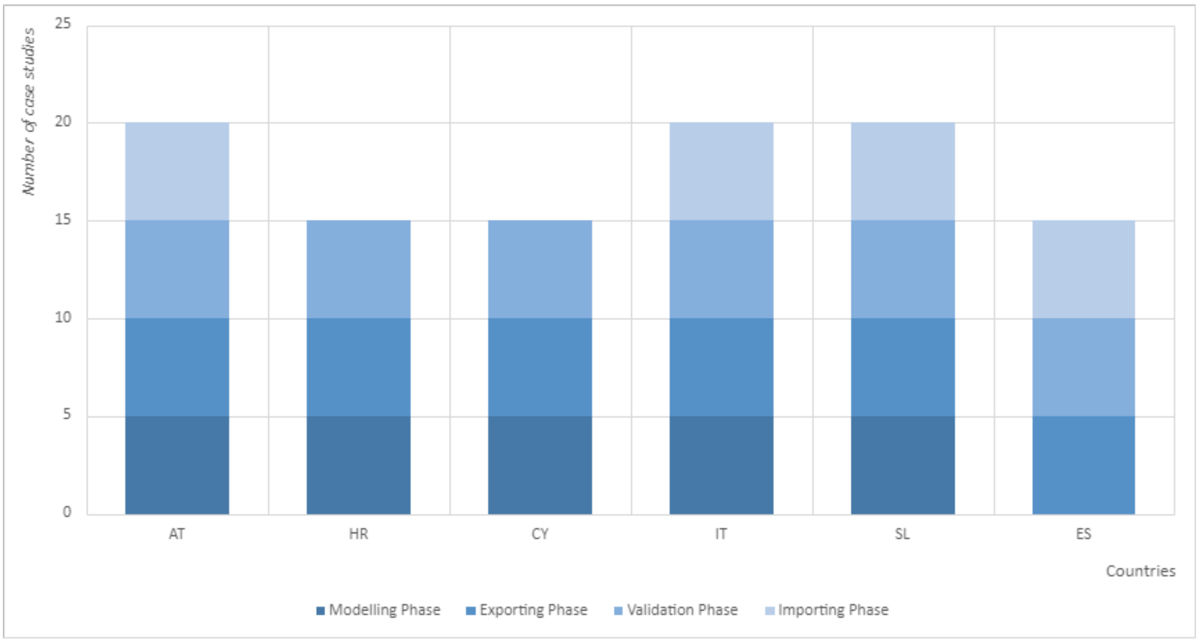


Figure 14. BIM to EPC processes developed for the case studies by country

An evaluation of the applicability, usability, usefulness, and potential improvements of the guidelines in each BIM-to-EPC generation process carried out in each country is provided in subsequent chapters.

5.2 Austria

In Austria, the following buildings have been used as case studies to replicate the BIM to EPC processes outlined in the guidelines: AT_04, AT_06a, AT_06b, AT_08, and AT_09. The Table 1 and 2 contain the characteristics, photographs, and models of the Austrian buildings.

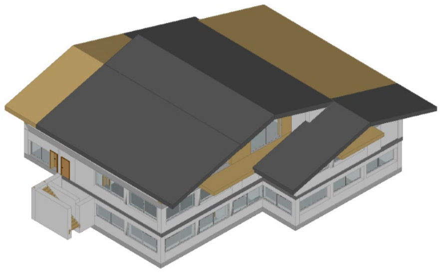
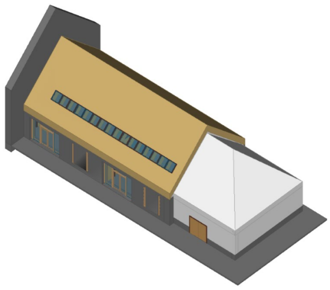
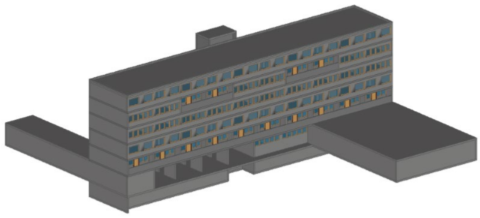
Table 1. Characteristics of the Austrian buildings

Building	Use	Year of construction / period	Square meters	Number of floors
AT_04	Residential: Multifamily building	1987	685	5
AT_06a	Other uses: Tertiary use	1978	1,110	3
AT_06b	Other uses: Tertiary use	2016 (1978)[3]	1,110	3
AT_08	Other uses: Tertiary use	1900	411	2
AT_09	Residential: Multifamily building	1969	3,077	7

Table 2. Photographs and models of the Austrian buildings

Building	Photograph	Model
AT_04		
AT_06a		

[3] The building was built on 1978 and rehabilitated on 2016

AT_06b		
AT_08		
AT_09		

The selected cases consist of existing buildings that have been constructed between 1900 and 1978, with the exception of the AT_06b model, which represents the renovated version of the AT_06a building and dates back to 2016. Their primary use varies, encompassing both tertiary buildings (AT_06a, AT_06b, and AT_08) and multi-family residential buildings (AT_09 and AT_04). Each building has had different heights, ranging from two stories for AT_08 to seven stories for AT_09. The sizes have also varied, with the oldest building (AT_08) having a total area of 411 m^2, while the AT_09 building spans 3,077 m^2. These variations have been critical in assessing the suitability of the guidelines for diverse architectural models.

5.2.1 Input data

The initial documentation for the selected buildings comprised a collection of files that facilitated the replication of the BIM to EPC processes in accordance with the prescribed guidelines, thus enabling their evaluation (Table 3). All buildings contained graphic files that allowed for architectural modelling, along with their EPCs. However, building AT_08 included additional documents specifying the technical characteristics of certain materials. The initial data associated with the EPCs provided a means to input authentic and reliable information that may not have been readily available in the graphical documentation.

Table 3. Documentation of the Austrian buildings

Building	Initial graphic documentation	Initial data documentation
AT_04	CAD plans (.pdf)	EPC (.pdf)
AT_06a	BIM model (.rvt) + CAD plans (.pdf)	EPC (.pdf)
AT_06b	BIM model (.rvt) + CAD plans (.pdf)	EPC (.pdf)
AT_08	Scanned plans (.pdf)	EPC (.pdf)
AT_09	Scanned plans (.pdf)	EPC (.pdf)

5.2.2 Application of the BIM guidelines

The application of the guidelines was carried out by an architect with experience in using BIM software Revit and EPC software.

The software used in Austria was:

- BIM modelling: Revit
- IFC validation: usBIMviewer
- EPC generation: ETU

In the case of the Austrian buildings, three of them have required the creation of BIM models due to the absence of initial BIM information. As a result, the modelling process for the AT_09, AT_04, and AT_08 buildings started from scratch, adhering to the recommendations outlined in the guidelines. However, the AT_06a and AT_06b buildings already had pre-existing Revit files, so the modelling process for those buildings started with the validation stage and has required remodelling the BIM to fix the issues detected during validation.

The time spent in each stage of the process was monitored and is shown in Figure 15.

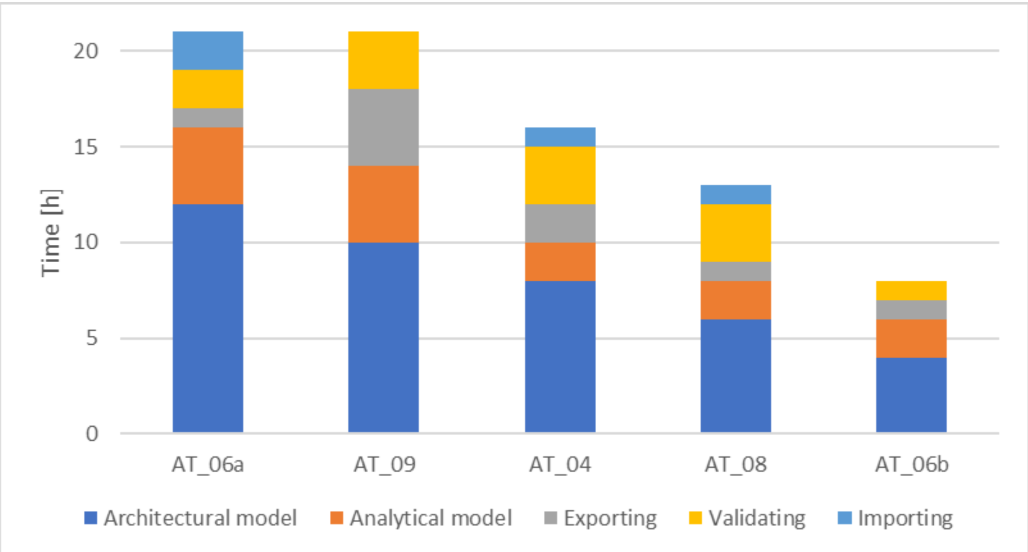


Figure 15. Time spent in hours using the guidelines for Austrian buildings

Architectural models

The duration of a model development is influenced by several factors. Firstly, there is a direct correlation between the time required for modelling, the dimensions of the building, and the availability of documentation. Building AT_09, which has the largest surface area but limited initial graphic documentation, required more time for modelling compared to AT_08, which has a smaller surface area but more detailed documentation. It is worth noting the case of AT_06a, which despite starting from an existing BIM model and having a smaller surface area than AT_08, required the highest amount of time for modelling.

Furthermore, the relationship between AT_06a and AT_06b, where the latter represents the rehabilitated version of the former, facilitated the efficient adaptation of the modified AT_06a BIM model according to the guidelines' specifications, focusing exclusively on the areas affected by the rehabilitation to become the AT_06b model. This explains why the development time for the AT_06b model is shorter.

Additionally, a connection can be observed between the number of models previously developed following the guidelines and the duration of modelling. The more models that were produced, the shorter the modelling times (as seen with AT_08 and AT_06b). Conversely, the AT_06a building, which did not have any previously developed models following the guidelines, experienced longer modelling periods.

Development of analytical spaces models

The trends observed during architectural modelling also extend to analytical modelling. AT_06a and AT_08 have each taken four hours for modelling, while the remaining models have required two hours each.

Model export, verification, and import

The time allocated to the export phase of the buildings appears to be correlated with their complexity, with larger models requiring longer export periods. However, there is an exception observed with the AT_06a and AT_06b models, which have a combined export time of two hours. Along with AT_08, which has the smallest surface area, these models exhibit the shortest export times. This could be attributed to the possibility of replicating steps between the two models through file duplication or due to the existing BIM models already being prepared to incorporate certain export requirements.

On the other hand, the verification phase remained relatively consistent across all models, with each model requiring three hours, except for the AT_06a and AT_06b models, which required a total of three hours between them. No noticeable patterns related to model complexity, the number of previously developed models, or other phases such as the importation phase can be observed from this data. This circumstance may be attributed to the presence of existing BIM models for both AT_06a and AT_06b.

However, it is important to emphasize that the verifier encountered some difficulties during this process. These challenges stemmed from the complexity of the architectural models. While some of these challenges were addressed by the guidelines, others were unexpected and necessitated a careful analysis to solve them. As a result, the timing of the importation phase was extended to include additional hours, which were required for the reimporting processes after the remodelling and revalidating phases.

Conclusions

Based on the analysis of the temporal aspects of EPC generation processes using BIM models, several conclusions can be drawn. Firstly, the complexity of the buildings has a direct impact on modelling times. Additionally, consistent utilization of the guideline recommendations for each model significantly reduces modelling times. This can be attributed to the knowledge acquired by the modeler with each model, which facilitates the replication of requirements outlined in the guidelines.

It is worth noting that the presence of BIM in the initial information does not necessarily result in decreased modelling times unless the pre-existing BIM is optimally prepared for integration into EPC software.

Furthermore, the use of BIM allows for time savings by transferring and modifying previously developed models for the generation of new models. This time-saving can be extended to other processes leading up to EPC generation.

Overall, the guidelines have demonstrated their utility in defining model requirements and establishing comprehensible and replicable exportation, verification, and importation processes for users in their daily operations.

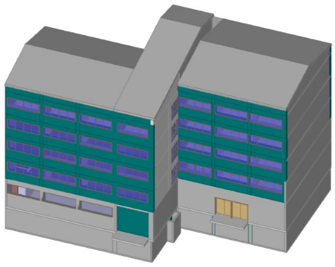
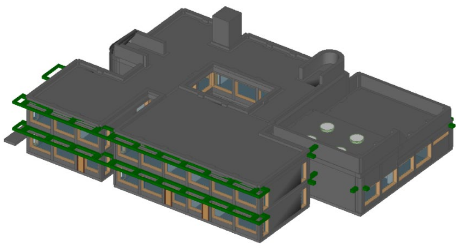
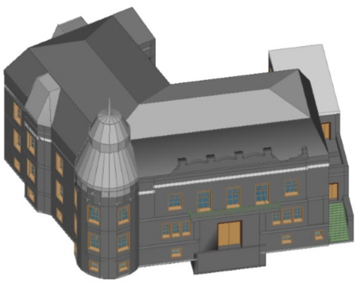
5.3 Croatia

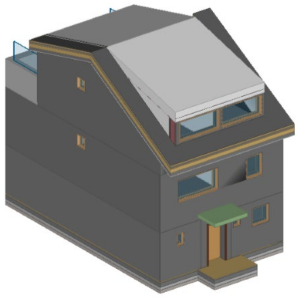
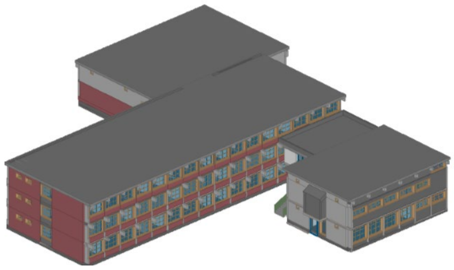
In Croatia, the following buildings have been used to replicate the BIM to EPC processes outlined in the guidelines: HR_01, HR_02, HR_03, HR_04, and HR_05. Tables 4 and 5 contain the characteristics, photographs, and models of the Croatian buildings.

Table 4. Characteristics of the Croatian buildings

Building	Use	Year of construction / period	Square meters	Number of floors
HR_01	Other uses: Tertiary use	1975	2,061	6
HR_02	Other uses: Tertiary use	1972	1,048	2
HR_03	Other uses: Tertiary use	1906	2,028	4
HR_04	Residential: Multifamily building	2012	150	3
HR_05	Other uses: Tertiary use	1976	3,446	3

Table 5. Photographs and models of the Croatian buildings

Building	Photo	Model
HR_01		
HR_02		
HR_03		

HR_04		
HR_05		

The selected buildings were mostly constructed in the 1970s, with the exception of HR_03 and HR_04, which were built in 1906 and 2014 respectively. These buildings primarily serve tertiary purposes, except for HR_04, which is a single-family residential building. Each structure varies in terms of surface area and height, ranging from two floors for the tertiary building (HR_02) to six floors for HR_01. Additionally, the surface area varies from 150 m^2 for the most recent building (HR_04) to nearly 3,500 m^2 for HR_05. The selection of buildings with different levels of complexity allows for an evaluation of the guidelines to ensure alignment with the diverse range of models.

5.3.1 Input data

The documentation for the selected buildings consisted of a collection of files that facilitated the replication of the BIM to EPC processes in accordance with the prescribed guidelines. In general, all buildings included graphic files that enabled architectural modelling (Table 6). Additionally, the documentation included relevant documents such as EPCs and energy audit reports. Notably, the HR-01 building also included Revit files from a pre-existing BIM model. In all cases, the initial data, including EPCs and energy audit reports, served to verify the graphical files and incorporate accurate and reliable data that may be missing from the files.

Table 6. Documentation of the Croatian buildings

Building	Initial graphic documentation	Initial data documentation
HR_01	Revit BIM model (.rvt) + CAD plans (.dwg)	Energy Audit Report (.pdf)
HR _02	CAD plans (.dwg)	EPC (.pdf) + Energy Audit Report (.pdf)
HR _03	CAD plans (.dwg)	Energy Audit Report (.pdf)
HR _04	Scanned plans (.pdf)	EPC (.pdf) + Energy Audit Report (.pdf)
HR _05	CAD plans (.dwg)	EPC (.pdf) + Energy Audit Report (.pdf)

5.3.2 Application of the BIM guidelines

The application of the guidelines was carried out by an architect with experience in using Revit and EPC software.

The software used in Croatia was:

- BIM modelling: Revit
- IFC validation: usBIMviewer
- EPC generation: N/A[4]

The buildings in Croatia were approached with different assumptions. HR_01 had BIM models, whereas HR_02, HR_03, HR_04, and HR_05 required the development of new models. As a result, the verification process for HR_01 involved correcting and adapting the existing models, while the other models were created from scratch in accordance with the guidelines.

The time spent in each stage of the process was monitored and is shown in Figure 16.

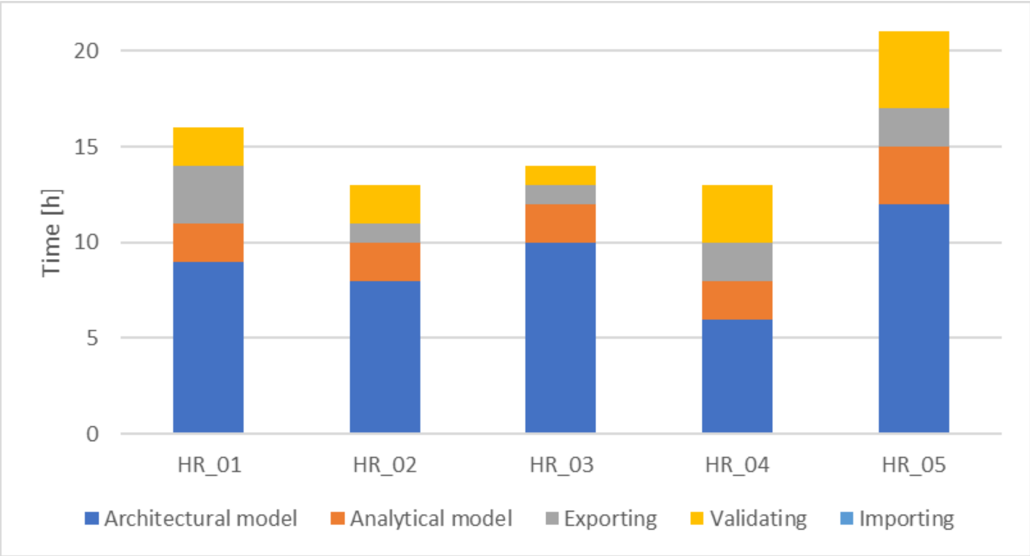


Figure 16. Time spent in hours using the guidelines for Croatian buildings

<u>Architectural models</u>

The duration of the models' development does not exhibit a correlation with the number of models previously developed using the guidelines. This finding suggests that the variations in the design of tertiary buildings have made it difficult to replicate the same steps followed in earlier models. Instead, more specific solutions are required for each individual case within the guidelines. However, a direct relationship between modelling time and building dimensions was observed. The building with the largest surface area, HR_05, has required the most substantial amount of time for modelling (twelve hours), while the smallest building, HR_04, has only required six hours. The remaining buildings, HR_01, HR_02, and HR_03, demonstrate variations in modelling time that align with their increasing surface areas, with HR_01 and HR_03 displaying similar patterns.

It should be highlighted that despite HR_01 having an existing BIM file, the architectural modelling times do not differ significantly from models without an existing BIM but with the same surface area and usage, such as HR_03. This implies that even with an initial BIM model, the time required to validate and fix models that are not optimized for information exchange with EPC software is comparable to starting from scratch with all the necessary initial information.

[4] For Croatian buildings, EPCs have not been generated because the software used in Croatia does not support the import of an IFC file. In such cases, the person seeking to certify a building would manually enter the values by reading them from the IFC viewer or from the BIM modelling tool.

Development of analytical models

Every model has taken approximately two hours to analyse and represent the spaces, except for HR_05, the largest building, which took three hours. The allocated time for the space modelling is relatively short, possibly due to limited initial information regarding the conditions of the spaces. It is important to note that despite HR_01 having an existing BIM file, the time spent on analytical modelling remains unchanged compared to the other models.

Model exportation and verification

The time dedicated to the exportation and review phases of the models does not exhibit a clear pattern related to the dimensions of the buildings. However, there seems to be a relationship between these two phases.

Regarding exportation, both the building with the largest surface area and the building with the smallest surface area required two hours. In contrast, the HR_02 and HR_03 models required one hour each.

In terms of the review phase, it can be observed that models requiring more hours for review (HR_04 and HR_05) also necessitated more time for export. Conversely, models with shorter review times (HR_02 and HR_03) required less time.

It is worth noting that HR_01, despite having an existing BIM file, required the most time for the exportation process. However, it did not require the longest review time. The shorter review time for this model may be attributed to the presence of much of the required data for generating EPCs in the initial model. However, this does not explain the export times.

Although the export process hours may not follow a consistent pattern with all models, it is notable that export times can be related to the number of models previously developed using the guidelines. A smaller number of developed models leads to longer export times, while an increase in the number of models reduces export time. This justifies the HR_01 model requiring the longest export time, as three models were previously developed with the guidelines for this case, compared to HR_03 with a similar surface area, no existing BIM, and a shorter export time after ten models had already been developed.

Conclusions

Based on this analysis of the timing in the EPC generation process from BIM models, several conclusions can be drawn. Firstly, if an EPC software requires a BIM model for certificate generation, the existence of a BIM model does not save time unless it has been optimized for the EPC software. Additionally, the complexity of the buildings has a significant impact on modelling time. Lastly, the time spent on common processes for all models (exportation and validation) decreases as the responsible person repeats these processes.

In all these cases, the guidelines have demonstrated their usefulness in defining the model requirements for verifying existing models and establishing minimum requirements when developing models from scratch. They also provided understandable and replicable procedures for export, validation, and import.

However, it is important to note that the responsible person carried out these BIM-to-EPC processes in multiple work sessions for each model, which may introduce bias in the indicated times due to the need to resume work on different days, requiring additional time for organization. Therefore, these times should be interpreted considering this limitation.

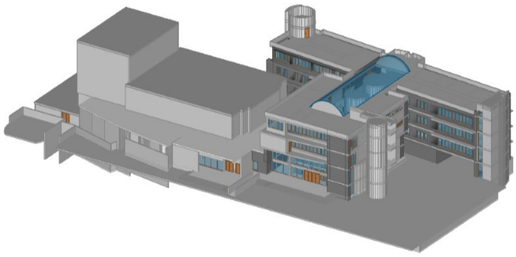
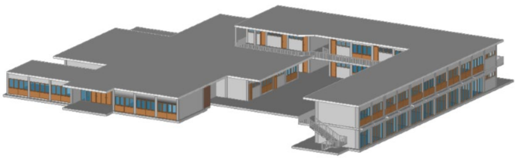
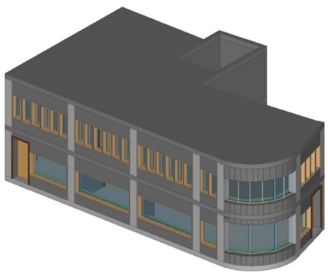
5.4 Cyprus

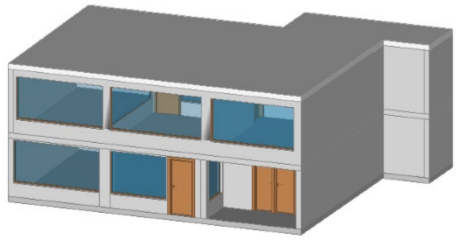
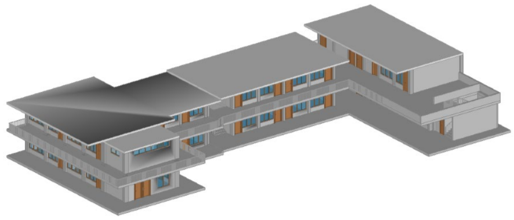
In Cyprus, the following buildings were used to replicate the BIM to EPC processes outlined in the guidelines: CY_01, CY_02, CY_03, CY_04, and CY_05. Table 7 and 8 contain the characteristics, photographs, and models of the Cypriot buildings.

Table 7. Characteristics of the Cypriot buildings

Building	Use	Year of construction / period	Square meters	Number of floors
CY_01	Other uses: Tertiary use	1986	4,650	5
CY_02	Other uses: Tertiary use			2
CY_03	Other uses: Premises	1953	170	2
CY_04	Other uses: Premises	1953	202	2
CY_05	Other uses: Tertiary use	1993	2,000	2

Table 8. Photographs and models of the Cypriot buildings

Building	Photo	Model
CY_01		
CY_02		
CY_03		

CY_04		
CY_05		

All the buildings are existing structures constructed between the 1950s and 2000s. These buildings are exclusively used for tertiary purposes, with the exception of case studies CY_03 and CY_04, which correspond to individual premises rather than complete buildings but are also used for tertiary purposes. The dimensions and heights of each case study exhibit certain variations, allowing for an evaluation of the guidelines based on their adaptability to the specific circumstances of each building.

In terms of heights, all buildings, including premises CY_03, have two floors, except for building CY_01, which is five levels high. The dimensions of the buildings differ significantly among the models, ranging from 170 m^2 for case study CY_03 to 4,650 m^2 for the largest building, CY_01.

5.4.1 Input data

The initial documentation for the selected buildings consisted of a set of files that have enabled the evaluation of the guidelines and have ensured the replicability of processes from BIM to EPC (Table 9). Each building includes initial graphic files that facilitated their architectural modelling. However, it is important to highlight the lack of graphical information regarding the construction systems of the buildings, which posed challenges in the modelling tasks. Additionally, the majority of the buildings have energy performance certificates (EPCs) or related files that provide information on energy ratings as part of their initial data. Notably, CY_01 has supplementary technical data specifically related to window glazing.

Table 9. Documentation of the Cypriot buildings

Building	Initial graphic documentation	Initial data documentation
CY_01	Scanned plans (.pdf)	EPC (.pdf) + Glazing technical report (.pdf)
CY_02	CAD plans (.dwg)	EPC (.pdf)
CY_03	CAD plans (.dwg) + CAD plans (.pdf)	EPC (.pdf)
CY_04	CAD plans (.dwg) + CAD plans (.pdf)	No Data
CY_05	Scanned plans (.pdf)	EPC (.pdf)

5.4.2 Application of the BIM guidelines

The application of the guidelines was carried out by an architect with experience in using BIM software Revit and EPC software.

The software used in Croatia has been:

- BIM modelling: Revit
- IFC validation: usBIMviewer
- EPC generation: N/A[5]

The buildings selected in Cyprus necessitated the creation of new BIM models. The process of generating these models and their subsequent importation into the EPC software provided an opportunity to verify both the structure of the guidelines and the effectiveness of their recommendations.

The time spent in each stage of the process has been monitored and can be shown in Figure 17.

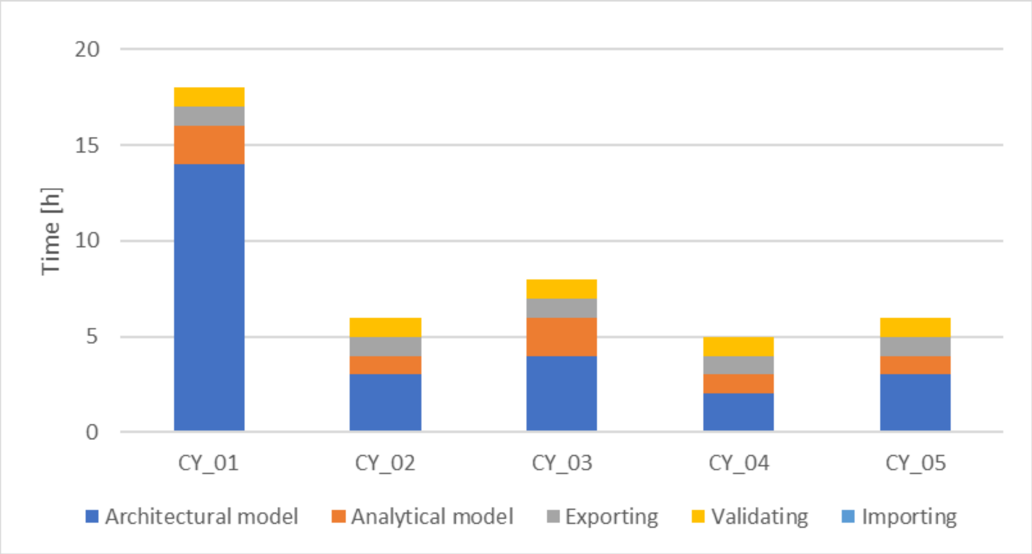


Figure 17. Time spent in hours using the guidelines for Cypriot buildings

<u>Architectural models</u>

The recorded times for architectural modelling exhibit variability and might have been influenced by various factors.

On one hand, there appears to be a correlation between the dimensions of the building and the modelling times. For example, the CY_01 model with a surface area of 4,650 m^2 required fourteen hours of development, while the CY_04 model with a surface area of 202 m^2 required two hours. However, when considering the dimension-time relationship alone, certain inconsistencies arise. For instance, both the CY_02 model with a surface area of 860 m^2 and the CY_05 model with a surface area of 2,000 m^2 have required the same modelling time (three hours).

Furthermore, there seems to be a correlation between the time invested in the models' development and the number of previous models created following the guidelines. This would explain why the CY_03 model, despite having the smallest surface area (170 m^2), took a total of four hours to develop instead of two hours like the CY_04 model, which has a similar surface area

[5] For Cypriot buildings, EPCs have not been generated because the software used in Cyprus does not support the importation of an IFC file. In such cases, the person who would like to certify a building would manually enter the values by reading them from the IFC viewer or from the BIM modelling tool.

(202 m^2). The CY_03 model, however, was the fifteenth model developed by the person who has modelled the buildings, whereas the CY_04 model was only the third one.

Lastly, the complexity of the models, in terms of geometry or lack of information, played an important role in the Cypriot case. Many models were influenced by one or both of these factors, resulting in increased modelling hours as more time was required to find suitable geometric modelling solutions or gather initial information.

Development of analytical spaces models

Some trends observed during architectural modelling are transferable to the development of the space model. Specifically, a relationship can be observed between the building with the largest surface area, CY_01, and the longest time dedicated to the space modelling. Similarly, a correlation exists between a smaller number of previously developed models and the modelling times for the CY_03 case. Despite their differences, the modelling times for space models was the same (two hours), whereas only one hour was necessary for the remaining models.

Model export and verification

In contrast, the times for model exportation and verification in the Cypriot buildings were not directly linked to the complexity of the models. The total time spent on the export phase was five hours, with each model requiring one hour, which also applies to the verification phase.

Nevertheless, it is still evident that the time spent on these phases were influenced by the previously developed models. This explains why the review of the model with the largest surface area (CY_01) has taken the same amount of time (one hour) as the review of the model with the smallest surface area (CY_03). A more detailed observation reveals that the CY_01, CY_02, CY_04, and CY_05 models were developed consecutively by the same person using the guidelines. All of them have taken the same number of hours for the export and verification phases. However, despite its lower complexity compared to the others, the CY_03 model required an equivalent amount of time, as it was the third model developed by the same person following the guidelines.

Conclusions

Based on this analysis of the time spent in the EPC generation processes from BIM models, it can be concluded that the replicability of the guidelines, while not the sole determining factor, significantly influences the EPC generation processes from BIM models. This is likely to be due to the consistent use of specifications within the guidelines for each model, resulting in a significant reduction in the time required for each phase.

However, it is important to emphasize that the complexity of the models can impact this replicability and even the applicability of the recommendations provided by the guidelines.

Nevertheless, a more detailed evaluation is needed to understand the role played by the amount of initial information in these developments. For a model to be optimally developed, exported, verified, and imported, it should avoid any lack of information, particularly when different individuals are responsible for each of the processes.

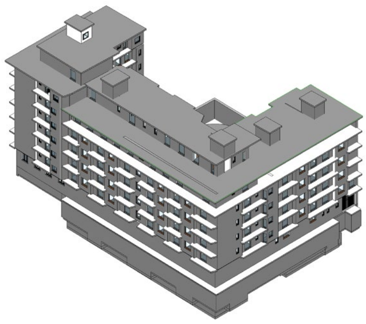
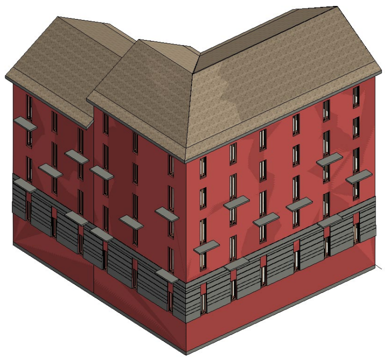
5.5 Italy

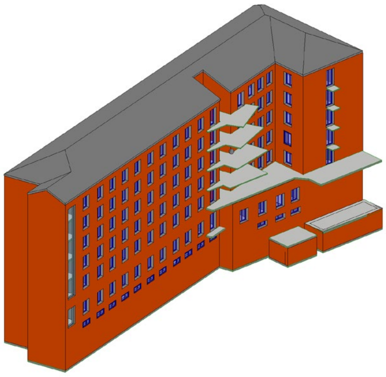
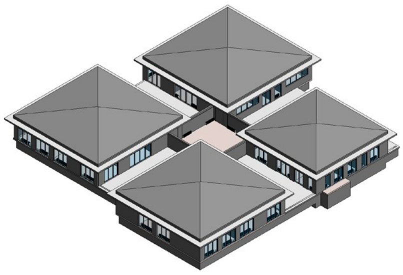
In Italy, the following buildings were used as case studies to replicate the BIM to EPC processes outlined in the guidelines: IT_01, IT_02, IT_03, IT_05, and IT_09. Table 10 and 11 contain the characteristics, photographs, and models of the Italian buildings.

Table 10. Characteristics of the Italian buildings

Building	Use	Year of construction / period	Square meters	Number of floors
IT_01	Residential: Multifamily building	1961-1975	5,974	9
IT_02	Residential: Multifamily building	1901-1920	2,018	6
IT_03	Residential: Multifamily building	1961-1975	6,449	8
IT_05	Other uses: Tertiary use	1961-1975	4,449	1
IT_09	Residential: Multifamily building	2006-2015	820	5

Table 11. Photographs and models of the Italian buildings

Building	Photo	Model
IT_01		
IT_02		

IT_03		
IT_05		
IT_09		

All the buildings were constructed in the 1990s, except for IT_09, which was built in 2015. These buildings primarily serve as residential multi-family buildings, with the exception of IT_05, which is a school. The buildings exhibit variations in surface areas and heights, ranging from a two-story school building (IT_05) to a nine-story multi-family building (IT_01). The surface area of the most recent building (IT_09) is approximately 820 m^2, while IT_03 spans nearly 6,500 m^2. The selection of buildings with different levels of complexity allows for an evaluation of the guidelines that accommodates the diverse range of models.

5.5.1 Input data

The documentation of the selected buildings consisted of a collection of files that have facilitated the assessment of the guidelines (Table 12). The .rvt files contained the building models from which the process to generate the inputs for the EPC tool started. The information provided by EPCs and simulation files in .idf format had a dual purpose: firstly, to verify the accuracy of the information contained in the models, and secondly, to supplement the models with data that reliably reflects the actual state of the buildings in case the models are incomplete.

Table 12. Documentation of the Italian buildings

Building	Initial graphic documentation	Initial data documentation
IT_01	Revit BIM model (.rvt)	Simulation file (.idf)
IT_02	Revit BIM model (.rvt)	Simulation file (.idf)
IT_03	Revit BIM model (.rvt)	Simulation file (.idf)
IT_05	Revit BIM model (.rvt)	Simulation file (.idf)
IT_09	Revit BIM model (.rvt)	Simulation file (.e001)

5.5.2 Application of the BIM guidelines

The application of the guidelines was conducted by software analysts from EDILCLIMA Engineering & Software, the developer of the EDILCLIMA EC700 software for EPC generation, which is authorized in Italy.

The software used in Italy was:

- BIM modelling: Revit
- IFC validation: Solibri
- EPC generation: EDILCLIMA EC700

The Italian buildings have had BIM models, allowing the verification process to begin with the correction and adaptation of these models based on the recommendations outlined in the guidelines, rather than creating them from scratch. These adaptations had an impact on the time spent in the exportation and importation process, although their characteristics were not optimal for error-free importation into the EDILCLIMA software.

The time spent in each stage of the process was monitored and can be shown in Figure 18.

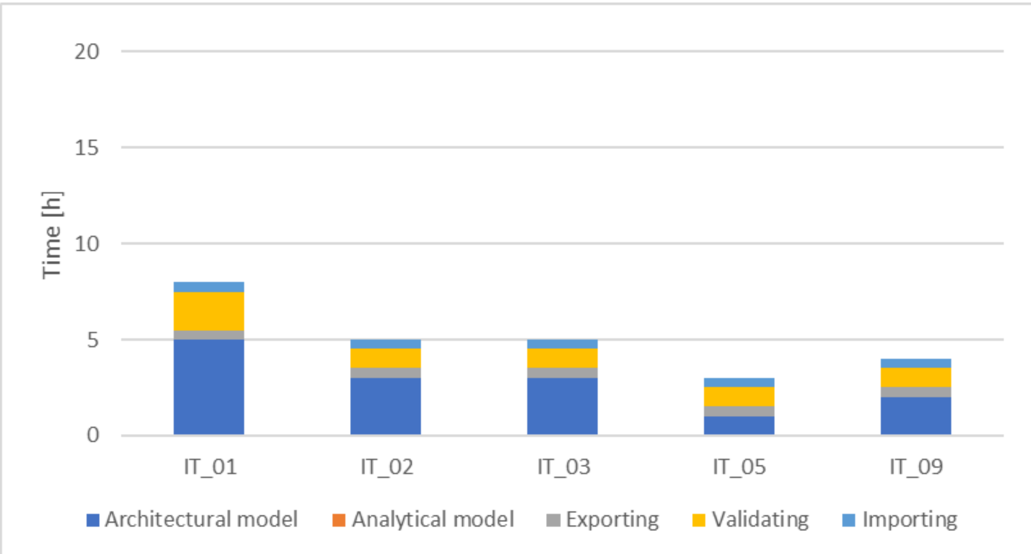


Figure 18. Time spent in hours using the guidelines for Italian buildings

Architectural models

On average, three hours were needed to validate and fix each model. However, the time spent varied across the models, and no direct correlation was observed between the surface area of the model and the time required for corrections. Consequently, it can be concluded that the time invested in this stage has primarily been influenced by the information provided by the models.

Furthermore, a clear trend of decreasing verification hours was observed from the first model to the last. IT_01 took five hours, while IT_02 and IT_03 each required three hours. IT_05 demanded one hour, and IT_09 two hours. Additionally, it should be noted that out of all the cases, only one model was created with the assistance of the guidelines.

Based on these two facts, it can be concluded that the initial model (IT_01) required more time due to the need to read and understand the guidelines. However, as the modelers gained practice and knowledge through the first model, their productivity improved, and they no longer have needed the assistance of the guidelines in the subsequent models.

Development of analytical models

The space models were not created in the BIM software but on the EPC tool.

Model export, verification, and import

The time dedicated to the model export and import phases remained consistent in all cases, with an average of thirty minutes for each model. These times are considered acceptable and adequate, providing support for the effectiveness of the guidelines in this area. However, during the verification phase, a decreasing trend in the required time has been observed when comparing the first model (two hours) with the subsequent models (one hour). Similar to architectural modelling, these results suggest that the first model required more time due to the need to read and understand the guidelines. As the modelers gained experience and knowledge throughout the development of the first model, the verification times have been reduced across the subsequent models.

Conclusions

In general, the reported times and the differences between the first and last models lead to a generalized conclusion regarding the effectiveness of the guidelines in generating BIM models tailored to EPC generation requirements and improving work times. This trend is supported by the verifiers themselves, who have affirmed that they would have spent more time on the processes without the guidelines.

In conclusion, the implementation of EPC generation guidelines based on the BIM methodology in the Italian case studies has proven to be effective in reducing times. Although the correction of existing models required additional time, an overall reduction in work durations has been observed as the models progressed. However, it is important to consider that the verifiers conducted the processes over multiple working sessions for each model, introducing a potential bias in the indicated times due to the need to resume work on different days, which also incurs additional time for organization and continuity. Therefore, these times should be interpreted with this limitation in mind.

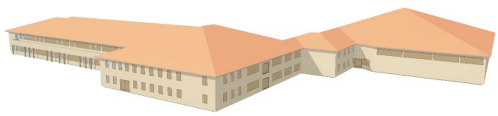
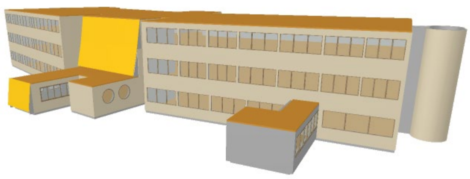
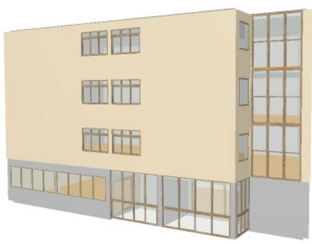
5.6 Slovenia

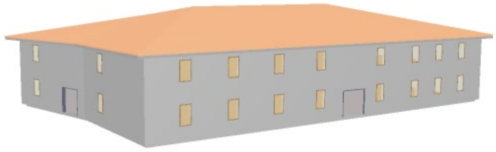
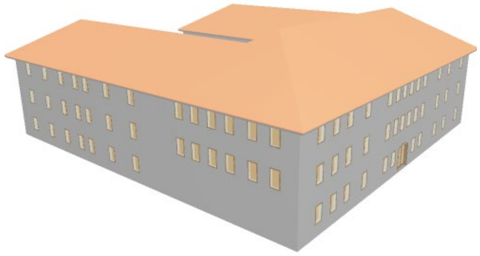
In Slovenia, the following buildings were used as case studies to replicate the BIM to EPC processes outlined in the guidelines: SL_01, SL_02, SL_03, SL_04, and SL_05. Table 13 and 14 contain the characteristics, photographs, and models of the Slovenian buildings.

Table 13. Characteristics of the Slovenian buildings

Building	Use	Year of construction / period	Square meters	Number of floors
SL_01	Other uses: Tertiary use	1976	3,174	3
SL_02	Other uses: Tertiary use	1980	3,630	3
SL_03	Other uses: Tertiary use	1963	605	4
SL_04	Other uses: Tertiary use	1980	501	1
SL_05	Other uses: Tertiary use	1975	2,527	3

Table 14. Photographs and models of the Slovenian buildings

Building	Photo	Model
SL_01		
SL_02		
SL_03		

SL_04		
SL_05		

The buildings were constructed between 1963 and 1980. Although all of them serve tertiary purposes, they exhibit varying building dimensions. The heights differ in each building, ranging from a single floor in the case of SL_04 to four floors in the oldest building (SL_03); the rest of the buildings have three floors. Likewise, the surface areas also vary considerably, ranging from 501 m^2 in the case of SL_04 to 3,630 m^2 in the SL_02 building. This diversity in the complexity of the buildings allows for the evaluation of the guidelines from a perspective that encompasses the diversity of the Slovenian building stock.

5.6.1 Input data

The documentation of the selected buildings consisted of a set of files that enabled the replication of the BIM to EPC processes following the guidelines, with the purpose of evaluating them (Table 15). All the buildings included graphic files that enabled the construction of the BIM model, in addition to the documents corresponding to the energy audits.

Table 15. Documentation of the Slovenian buildings

Building	Initial graphic documentation	Initial data documentation
SL_01	CAD plans (.pdf)	Energy Audit Report (.pdf)
SL_02	CAD plans (.dwg)	Energy Audit Report (.pdf)
SL_03	CAD plans (.dwg)	Energy Audit Report (.pdf)
SL_04	CAD plans (.dwg)	Energy Audit Report (.pdf)
SL_05	CAD plans (.dwg)	Energy Audit Report (.pdf)

5.6.2 Application of the BIM guidelines

The evaluation of the guidelines has been carried out by an engineer with experience in using BIM and EPC software.

The software programs used in Slovenia were:

- BIM Modelling: ArchiCAD
- IFC Validation: Solibri
- EPC Generation: Other (IDA ICE)

The BIM models were created from scratch, beginning with the initial 2D graphical documentation. This modelling followed the specifications of the guidelines, and all subsequent procedures have been carried out accordingly, culminating in the importation of the models into the EPC software.

Throughout each phase, the verifier monitored the time invested in every process. The obtained results are depicted in Figure 19.

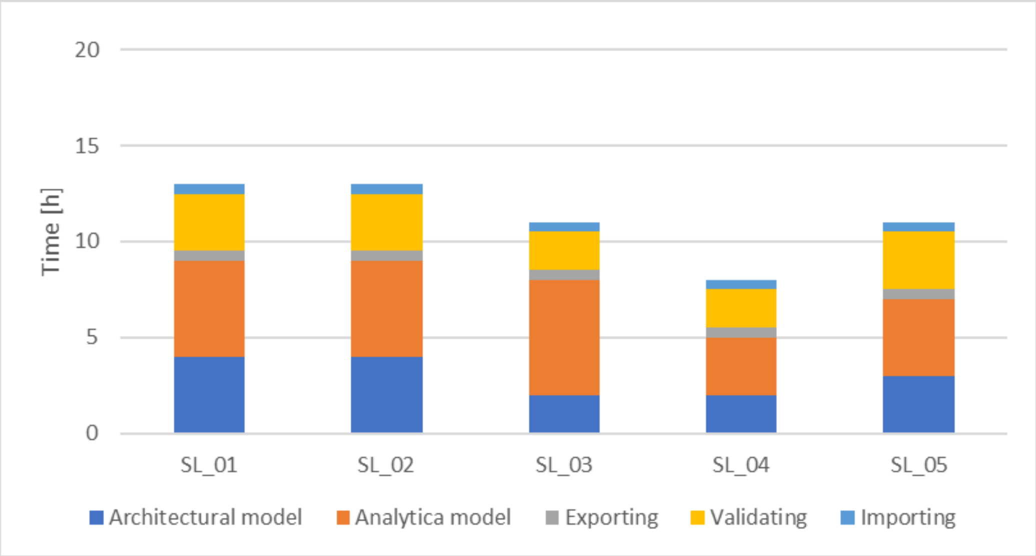


Figure 19. Time spent in hours using the guidelines for Slovenian buildings

Architectural models

Within the context of Slovenia, varying modelling times were observed for each case. Since this variability is not related to the initial state of an existing BIM model, it could be possibly attributed to the challenges arising from the quantity of initial information.

It can be affirmed that the differences in modelling times are not dependent on the prior use of the guidelines. This statement is supported by the observation that the latest model developed with the assistance of the guidelines (SL_05) required more time than the first model developed, SL_03.

In the Slovenian case, there is a clear correlation between building dimensions and modelling times. Specifically, when evaluating the buildings with similar total surface and heights, such as SL_01 and SL_02, it is observed that the modelling time is the same, four hours for both cases. In contrast, buildings with the similar smaller dimensions, SL_03 and SL_04, each required two hours of modelling time, while the intermediate dimensions building required three hours. This suggests that architectural complexity becomes less influential, or it remains relatively consistent among all buildings, with modelling times predominantly determined by the building dimensions.

Development of space models

The assessment of the architectural modelling cannot be directly extrapolated to analytical modelling. Notably, the time spent on developing the modelling of the second smallest building, SL_03, was six hours. In contrast, the largest building in terms of surface area, SL_02, required a total of five hours. This observed trend is consistent across all models, suggesting that a direct relationship between time and building dimensions cannot be definitively established. However, it remains possible that a correlation exists between modelling time and spatial complexity.

Conversely, in the space modelling, a clear dependence between the time required and the number of models previously developed with the assistance of the guidelines is evident. Model SL_03, being the initial one created, necessitated an additional hour compared to models SL_01 and SL_02, which were the second and third models, respectively. This pattern persisted regardless of the differences in surface area among the models SL_01, SL_02, and SL_03.

It is worth mentioning that the time spent for SL_05, the fifth model developed, was four hours, while model SL_04, being the fourth, required a total of three hours. In this scenario, the different dimensions between the two models played a fundamental role, overshadowing the impact of the number of previously developed models.

Model export, validation, and import

In relation to the exportation and importation times, it has been observed that both processes consistently require an average duration of half an hour for each model which is a short period of time.

In the validation process, a clear trend of dependence on the building dimensions becomes evident. Specifically, buildings with smaller surface areas (SL_03 and SL_04) required two hours each, while buildings with larger surface areas require three hours for each model.

Conclusions

A clear correlation emerges between the time expended in each process and the dimensions of the building. Particularly with the space modelling, it has been observed that the application of the TIMEPAC guidelines has resulted in a noticeable reduction in times, regardless of the building dimensions. Therefore, it can be stated that the utilization of the TIMEPAC guidelines has proven effective in enhancing the relative times for this process.

It is essential to underline that various factors could have influenced the reduced effectiveness of the recommendations in the Slovenian case studies. One primary obstacle may have been the utilization of a BIM modelling software (i.e., ArchiCAD) different from those included in the guidelines. This aspect may have affected the ability of the guidelines to address conflicts during the processes, consequently leading to a failure in achieving time reductions. Additionally, the division of working time for each model into multiple sessions might have introduced potential bias, as it required additional time for organization and workflow continuity.

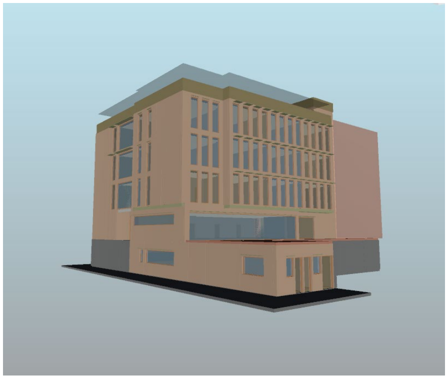
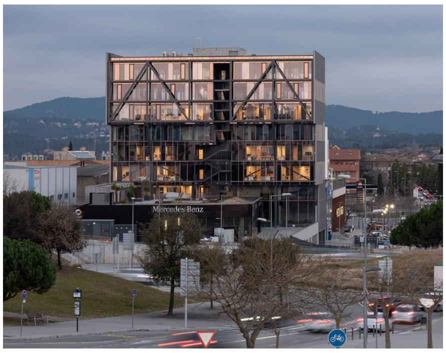
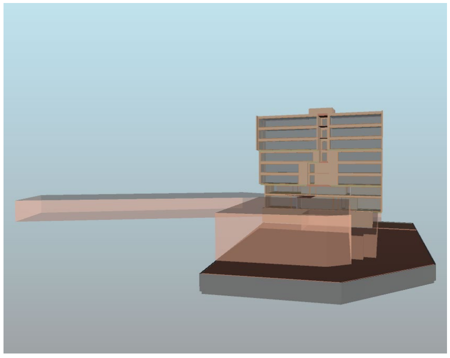
5.7 Spain

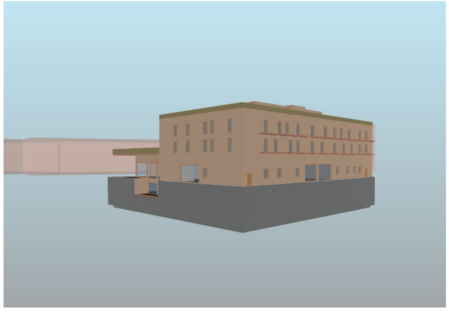
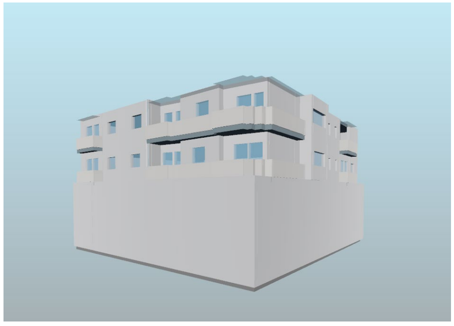
In Spain, these buildings used as case studies to replicate the BIM to EPC processes outlined in the guidelines: ES_01, ES_02, ES_03, ES_04, and ES_05. Table 16 and 17 contain the characteristics, photographs, and models of the Spanish buildings.

Table 16. Characteristics of the Spanish buildings

Building	Use	Year of construction / period	Square meters	Number of floors
ES_01	Other uses: Tertiary use	2020	2,640	5
ES_02	Other uses: Tertiary use	2021	15,411	13
ES_03	Other uses: Tertiary use	2021	6,000	5
ES_04	Residential: Multifamily building	1984	396	5
ES_05	Residential: Multifamily building	1933	360	4

Table 17. Photographs and models of the Spanish buildings

Building	Photo	Model
ES_01		
ES_02		

ES_03		
ES_04		
ES_05		

Most of the buildings have been recently constructed. Specifically, the buildings corresponding to the ES_01, ES_02, and ES_03 models were built between 2020 and 2021. The ES_04 and ES_05 models represent the oldest buildings, dating back to 1984 and 1933, respectively. The newer buildings are primarily used for tertiary purposes, while ES_03 and ES_04 models correspond multifamily residential buildings. These buildings showcase significant variations in their dimensions. The heights range from four floors in the ES_05 residential building to thirteen levels in the ES_02 building. Additionally, there are notable differences in their surface areas, with ES_05 being the smallest building (360 m^2) and ES_02 being the largest (15,411 m^2). The selection of buildings has been conducted following the consistent criterion of considering the presence of different levels of complexity, ensuring a more meaningful evaluation of the guidelines.

5.7.1 Input data

The documentation of all Spanish buildings included a BIM model (Table 18). Furthermore, all models include the files required for generating EPCs in CYPETHERM HE Plus tool (.tre) format, which served as verification files for the data contained in the BIM models.

Table 18. Documentation of the Spanish buildings

Building	Initial graphic documentation	Initial data documentation
ES_01	BIM model (.mep)	Simulation file (.tre)
ES_02	BIM model (.mep)	Simulation file (.tre)
ES_03	BIM model (.mep)	Simulation file (.tre)
ES_04	BIM model (.mep)	Simulation file (.tre)
ES_05	BIM model (.mep)	Simulation file (.tre)

5.7.2 Application of the BIM guidelines

The assessment of the guidelines was carried out by an architect with experience in using BIM software Revit and EPC software.

The software used in Spain were:

- BIM modelling: CypeMEP
- IFC validation: BIMserver.center, BIM ACCA Software
- EPC generation: CYPETHERM HE Plus

The software used during the process was dependent on the models, enabling the evaluation of the guidelines while considering the diverse scenarios derived from Cype's workflow capabilities. However, it was not possible to directly input a BIM model to Cype's certification software, because it this can only be done via an intermediate model created with Cype's tools.

Since there was a BIM model for all buildings, the application of the guidelines started with the validation phase which did not convey any modification of the models.

The time spent in each stage of the process was monitored and can be visualized in Figure 20.

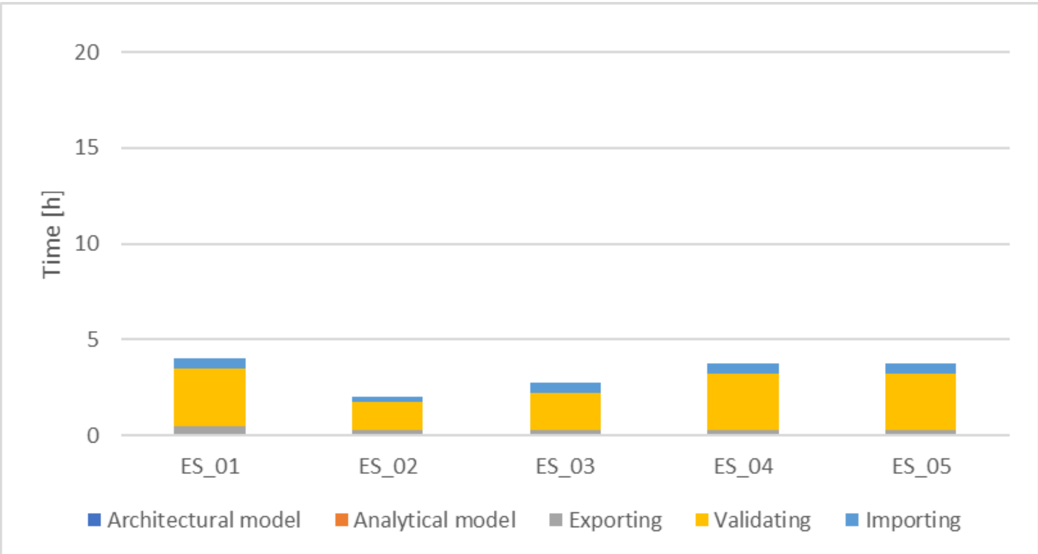


Figure 20. Time spent in hours using the guidelines for Spanish buildings

<u>Architectural models</u>

The casuistry regarding architectural BIM models in Spain has a peculiar characteristic. Specifically, there has been no time spent on modifying the existing BIM models to optimize them according to

EPC software requirements. This is because the existing models already contained all the necessary information for generating energy efficiency certificates. A justification for such can be attributed to the design of the BIM software CypeMEP, which is partly intended for seamless information exchange with EPC software. As a result, many of the required parameters that correspond to the necessary data for generating EPCs have to be entered during modelling. Furthermore, this is facilitated through the presence of architectural libraries with specific data for each construction solution that can be selected.

Development of space models

The same observations concerning architectural modelling can be extrapolated to the space modelling. Similar to architectural elements, CypeMEP is designed to provide specific data related to space analysis, which can be easily entered or selected by default by the modeler. This greatly facilitates the visualization and input of data for modelers.

Model export, verification, and import

The time dedicated to the phase of model exportation, validation, and importation does not follow a pattern directly correlated with the complexity of the buildings. However, it does seem to be related to the chosen workflow and the separation of task execution into multiple sessions or continuous sessions.

For the ES_01 model, which has been exported to IFC and reviewed with an external IFC viewer before being imported into CYPETHERM HE Plus through IFC Builder, the times for exportation, validation, and importation exceeded those required for the other scenarios. Specifically, half an hour was spent on the export phase, one hour on the import phase, and three hours on the model review.

The workflow of the ES_03, ES_04, and ES_ES_05 models required the second-highest amount of time for verification. However, the times for all phases were reduced compared to the ES_01 scenario. The exportation phase took a quarter of an hour, the validation phase took two hours, and the importation phase took half an hour.

Finally, in the case of the ES_02 model, a noticeable reduction in timing was observed due to the direct connection between both Cype software using proprietary formats. Specifically, the verification process took two quarters of an hour for the exportation and importation phases, and one and a half hours for the validation phase.

The timing coincides with the requirements of each process, the inherent benefits of the particular BIM modelling software that pays special attention to energy efficiency parameters, and the automation of exportation processes.

It is noteworthy that, for the ES_03, ES_04, and ES_05 models, guidelines were not necessary as the exportation and importation processes occurred automatically between the BIM and EPC software.

The same applies to the ES_02 case study. However, it is also emphasized that, despite being an internal workflow, some information may be lost in the IFC file and importation process if the checkbox for exporting specific data for the EPC software is not marked.

With this minor exception concerning the ES_02, none of the internal workflows required the completion of information within the EPC software. This does not apply to ES_01, which was developed following open standards. Additionally, with other BIM software, it is possible to introduce user-defined parameters within the IFC. This would allow the EPC developer not to rely on the BIM software itself to reintroduce the information. However, in this case, the verifier indicated an inability or lack of knowledge to proceed in this manner with Cype software. Thus, the EPC developer had to use a BIM file.

Conclusions

Based on the analysis of the working timing aspects involved in the process of generating EPCs from BIM models, several conclusions can be drawn.

Firstly, the adoption of specialized BIM software with diverse modules which suit the requirements of EPCs significantly facilitates the workflow compared to alternative approaches. These streamlined workflows minimize the need to duplicate data entry, thus mitigating information loss. Consequently, the automated workflow that seamlessly integrates BIM and EPC software emerges as the optimal choice within the Cype framework.

On the other hand, when relying on data exchange through open formats, preserving information becomes challenging as data progressively diminishes throughout the various processes, necessitating the reintroduction of inputs. Furthermore, the lack of information for visualization within the IFC model hinders the duplication of information.

Lastly, it is important to highlight the observations made by the person who carried out the BIM-EPC process, suggesting that the guidelines would need to put greater emphasis on open exchange formats. As a result, their utility was primarily confined to the ES_01 model, with limited applicability for the ES_03, ES_04, and ES_05 models. Specific sections of the guidelines were beneficial for the ES_02 model. However, that person emphasizes that the guidelines would have been of greater value in all models if the consideration of potential scenarios had required the modelling of the buildings from scratch.

6 Results and discussion

This chapter presents the evaluation of the guidelines employed in generating EPCs using BIM models in different countries. The evaluation results are presented in specific sections, including architectural modelling, analytical modelling, MEP modelling, exporting, validating, and importing. These sections are organized to enhance comprehension of the practical application of the guidelines within each individual process. Furthermore, the chapter concludes with a summary of the entire process for each section, providing a comprehensive overview.

Additionally, a cross-comparison section examines the BIM to EPC process across various countries, offering insights into any variations or similarities.

Finally, recommendations are provided for software developers based on the findings obtained during the development and validation of the guidelines. These recommendations serve as valuable insights for improving software tools used in the BIM to EPC process.

6.1 Austria

Architectural modelling

The responses regarding architectural modelling in the evaluation form are based on the verification and modification of existing models for AT_06a and AT_06b buildings, as well as the generation of models for the remaining buildings. As a result, some questions in the form are not applicable to all Austrian case study buildings.

It is important to note that the lack of initial information for the AT_09 model exemplifies the first issue encountered throughout the architectural modelling process. A similar problem was found in the AT_06a model, where a lack of initial information was indicated. This lack of information hindered the fulfilment of the minimum requirements for generating an optimal model to be used in EPC software or resulted in the assumption of data that does not align with reality. However, basic suggestions and recommendations for architectural modelling have been found outlined in the guidelines to be understandable and applicable to the models.

Furthermore, the complexity of the Austrian buildings' designs and the limitations of software like Revit in exporting minimum modelling requirements increased the difficulty of the process. Nevertheless, the effectiveness of the recommendations in addressing these challenges have been confirmed.

In conclusion, the overall assessment of the usefulness of the guidelines in the architectural modelling framework is highly positive. The verifier assigned an average rating of 3.5 out of 4 for the comprehensibility, usefulness, and assistance provided by the guidelines across all models. The individual ratings for each model were consistent and aligned with the overall rating.

Analytical modelling

In general, there is a positive perception regarding the description, understanding, and usefulness of the basic suggestions and minimum requirements for analytical modelling. It is worth noting that there are pre-existing minimum requirements for analytical modelling in the existing BIM models AT_06a and AT_06b.

Although the usefulness of the guidelines has been reported, some problems have arisen with models AT_06a, AT_06b and AT_09. Specifically, challenges were faced during the modelling of the minimum requirements due to the absence of initial technical documentation and the complex zoning design of the AT_09 model. Additionally, the complexity of certain roof areas in the AT_06a and AT_06b buildings posed difficulties during the remodelling of the analytical spaces. However, these problems were later resolved with the assistance of the guidelines.

The final evaluation of the usefulness of the guidelines regarding the analytical modelling process aligns with the rating assigned to the architectural modelling phase. The verifying party provided an average rating of 3.55 out of 4 for the comprehensibility, usefulness, and assistance provided by the guidelines. The individual ratings for each model were consistent, with an average rating of 3.5 for each model, except for the AT_08 model, which received a score of 3.75.

MEP modelling

No MEP models were created for any of the Austrian cases. Additionally, no existing BIM MEP models were included in the initial information for any of the buildings. Consequently, the effectiveness of the guidelines in creating MEP models cannot be evaluated.

Nevertheless, the evaluation of the guidelines regarding the relevant sections on MEP models has been carried out. The guidelines were highly rated for their usefulness in facilitating the understanding of MEP elements and the creation of MEP models, with an average rating of 4 out of 4. It is also considered necessary and recommended to create MEP models, as indicated by an average rating of 3 out of 4.

Furthermore, the average rating for suggesting the automatic reading of MEP model parts by EPC software is 4 out of 4.

Exporting

Regarding the exportation processes, the use of standardized open exchange formats for all models were reported. There is a positive perception regarding the description and comprehension of potential exportation methods and their recommendations.

It is important to note that difficulties have been encountered in exporting certain elements, such as inclined roofs and the intersections between architectural elements, in the AT_04 and AT_06a models. However, these issues were successfully resolved with the assistance of the guidelines. In opposition, it has been observed, through one particular case, that the general recommendation provided by the guidelines for solving wall and roof intersections is not always applicable to inclined roofs. The modelling issues become apparent only after the model has been exported and verified. This fact may depend on the complexity of inclined roofs and the limitations of the Revit tool in automatically joining elements in certain cases.

The average rating for the Austrian cases has been 3.70 out of 4. Each individual model received an average rating of 3.75, except for the AT_08 model, which got a rating of 3.50. No specific comments were provided by the verifying party regarding the lower rating for this particular model. However, the given rating is still close to the maximum and demonstrates the effectiveness of the guidelines in the exportation phase.

Validating

The guidelines have been reported to provide a clear and understandable explanation of the validation process. Furthermore, after conducting the verification and modelling or remodelling for each building following the recommendations, no errors were identified in the IFC models.

The compliance with the guidelines for the verification process has been confirmed by the obtained rating, with an average score of 3.8 out of 4. The individual ratings vary between models. The AT_04, AT_06a, and AT_09 models received a rating of 4, while the AT_06b and AT_08 models got 3.5. However, without any accompanying justification comments from the modeler, it is difficult to draw a conclusive interpretation from these rating discrepancies.

Import

Regarding the importation phase of the case studies in Austria, the verifier indicates a clear comprehension and a proper application of the recommendations provided within the guidelines. However, the verifying party acknowledges the presence of certain challenges during the process.

In this context, some of the issues encountered were addressed in the guidelines, and the verifier successfully resolved them by adhering to the prescribed recommendations. A noteworthy example is the case of two windows situated at different modelling levels.

On the other hand, specific challenges arose from complex building forms specific to the case, requiring the modeler to address them independently. For example, errors in importing the wall characteristics emerged due to the wall being situated between two pitched roofs, necessitating customized solutions.

In any case, the final rating for the import phase of Austrian cases achieved an average of 3 points out of 4. These results indicate that while the guidelines may not encompass every specific problem encountered, the general recommendations are useful for managing common issues and can be extrapolated to address particular challenges, leading to enhanced efficiency and reduced efforts in the process.

Conclusions

The confirmation of the effectiveness of the guidelines in each process has been supported by the overall rating provided in the feedback section of the evaluation form (Table 19).

An average rating of 3.6 has been assigned by the verifying technician for their usefulness. Furthermore, the time-saving achieved through the recommendations, the suggestion to include exemplifications of other software in the guidelines, and the willingness to recommend them to external users have received the maximum rating, with an average of 4.

In conclusion, the overall average rating of 3.9 out of 4 indicates that the guidelines are suitable for meeting the needs of the technician during EPC generation from BIM models.

Table 19. Average score given through the Austrian buildings

Opinion	Average score
General usefulness of the guidelines	3.6 out of 4
Time saving thanks to guidelines	4 out of 4
Extension of the guidelines to other software	4 out of 4
Recommendation/dissemination of the guidelines	4 out of 4
Overall rating	3.9 out of 4

6.2 Croatia

Architectural modelling

The evaluation of architectural modelling is based on the verification and modification of existing models for building HR_01 and the generation of models for the remaining buildings. Consequently, certain questions in the evaluation form are not applicable to all Croatian case studies.

One significant issue encountered during the architectural modelling process was the lack of information for the HR_01 and HR_05 models, which resulted in difficulties in meeting the minimum model requirements for optimal EPC generation. This required making assumptions that may not accurately represent the reality.

However, the verifier reported no major issues with modelling the minimum required elements or applying the basic suggestions provided in the guidelines. One exception was the HR_03 model, which presents a specific complexity with a sloped roof and an attic, for which the guidelines did not help.

The complexity of designs in buildings HR_01, HR_04, and HR_05, as well as the limitations of software like Revit in exporting models that meet the minimum requirements of an EPC certification tool, added further challenges. Nevertheless, the verifier acknowledged the guidelines' usefulness in addressing these problems and expressed appreciation for having access to them.

However, because of certain cases' specific nature were not covered in the guidelines, an issue concerning a complex wall junction in building HR_04 could not be solved. The inclusion of a new section specifically addressing such complex cases was recommended by the verifier.

The guidelines' comprehensibility, usefulness, and guidance assistance in architectural modelling were assessed by the verifier with a highly positive average score of 3.5 out of 4. Individual scores for each model have been consistent, with an average ranging from 3.25 to 3.75.

Analytical modelling

A positive perception of the explanation, understanding, and usefulness of the suggestions and minimum requirements for analytical modelling was expressed by the verifier. However, challenges were posed in developing the minimum requirements for analytical modelling in buildings without existing BIM models, due to the lack of accurate initial information. These difficulties have primarily arisen from the absence of data rather than issues with the guidelines themselves.

As with architectural modelling, the usefulness of the guidelines in analytical modelling was highly rated by the verifier, with an average score of 3.5 out of 4. Individual scores of 3.5 points for each model were consistent.

MEP modelling

In the Croatian cases, no MEP models were created for either the existing BIM model or the cases where BIM models created from scratch. As a result, the evaluation of the guidelines' usefulness for MEP modelling was not considered.

However, the guidelines' usefulness in understanding the elements and creating MEP models was rated by the verifier with a score of 4 points on average. It has also been recommended to create MEP models despite the limitations of EPC software in reading them, as the minimum modelling requirements would have required minimal time and provided all the necessary information within the IFC model. The potential benefits of automatic reading of MEP models by EPC software to optimize the BIM methodology processes were further emphasized by the verifier.

Export

The verifier in the Croatian case study expressed a positive perception regarding the explanation and understanding of the possible export methods and their recommendations. However, there was a slight lack of understanding of the export guidelines specifically for the HR_01 model.

Nevertheless, through practice and re-reading, a better understanding was achieved. This fact is closely related to the export times of the HR_01 model, as discussed in the previous section.

Due to the characteristics of the BIM software used, the verifier encountered difficulties in achieving a proper export of the models. However, these difficulties were solved with the help of the guidelines.

The average score given by the verifier for the Croatian cases, 3.50 out of 4, demonstrates the effectiveness of the guidelines for the export phase. However, the scores for each individual model vary. The score for the HR_02 model (3.2 out of 4) is the lowest mainly due to the difficulties to export certain parameters from Revit due to the peculiarities of the BIM software, which are still unsolved by its developers. On the other hand, the lower score for the HR_01 model can be attributed to a different reason, as the verifier's comment suggests a better understanding of the export processes from this model, which could have influenced the score.

In the Croatian cases, a positive perception was expressed by the verifier regarding the explanation and understanding of the possible export methods and their recommendations. Nevertheless, a slight lack of understanding of the export guidelines was encountered during the export of the HR_01 model. However, a complete understanding was achieved for subsequent models through practice and re-reading. This fact is closely related to the export times of the HR_01 model, as discussed in the previous section.

Difficulties were encountered by the verifier in achieving a proper export of the models due to the characteristics of the BIM software used. Nonetheless, these difficulties were solved with the help of the guidelines.

The effectiveness of the guidelines for the export phase is demonstrated by the average score given by the verifier for the Croatian cases, which is 3.50 out of 4. However, the scores for each individual model vary. On the other hand, the lower score for the HR_01 model can be attributed to a different reason, as suggested by the verifier's comment, which implies a better understanding of the export processes from this model, and this understanding could have influenced the score.

Validation

Regarding the validation process, the high level of comprehensibility of the guidelines in explaining the validation processes has been mentioned by the person responsible for the verification process. After each building was verified and modelled or remodelled according to the guidelines' recommendations, no errors were found in the geometric and non-geometric data in the IFC model, which includes all the required parameters for import into the EPC software.

The compliance with the guidelines for the verification process was confirmed by the score obtained for this phase, with an average of 3.8 out of 4. The individual scores for the HR_01, HR_02, and HR_04 models show no fluctuations, as all of them have scored the maximum points. However, for the HR_03 and HR_05 models, the score for the guidelines is 3.5. Since there were no comments from the modeler regarding the decrease in the usefulness of the guidelines or the validation process itself, no conclusion can be drawn. Nevertheless, it is important to note that the validation process is considered of great importance by the verifier to avoid errors in future steps of EPC generation.

Conclusions

The specific evaluation of each process in the Croatian cases was favourable, despite encountering difficulties in certain tasks. This conclusion is supported by the overall score of the guidelines provided in the evaluation feedback.

The utility of the guidelines for optimizing EPC generation processes from BIM models was highly rated by the evaluating technician. The scores varied across the HR_01 to HR_05 models. The rating of the HR_01 and HR_02 models may have been lower due to the lack of specific guidance in the general guidelines. The guidelines were recognized by the technician as a valuable time-saving resource compared to conducting the processes without any recommendations. The guidelines have been featured for providing prompt and practical solutions to encountered challenges.

Additionally, the annexes sections of the guidelines, particularly useful for modelling processes in specific BIM software like Revit and Cype, were highlighted by the technician. This feedback correlates with the suggestion of expanding the guidelines with additional software examples.

Simultaneously, the extension of the guidelines to other software and even domains was suggested, improving compatibility among technicians using different software within the BIM methodology. The recommendation of the guidelines has been positively acknowledged.

Table 20. Average score given through the Croatian buildings

Opinion	Average score
General usefulness of the guidelines	3.6 out of 4
Time saving thanks to guidelines	4 out of 4
Extension of the guidelines to other software	4 out of 4
Recommendation/dissemination of the guidelines	4 out of 4
Overall rating	3.9 out of 4

6.3 Cyprus

Architectural modelling

The responses obtained from the questionnaire regarding architectural modelling indicate that the verifier initiated the architectural models for all the buildings from scratch. Consequently, some questions in the questionnaire were found to be inapplicable to all the Cypriot case study scenarios.

The understanding and applicability of the suggestions and recommendations provided in the guidelines were highly positively assessed for all the models. However, it is important to note that none of the architectural models were entirely completed in accordance with the minimum requirements outlined in the guidelines. The verifier explains that this is due to the lack of initial information required by the guidelines.

Furthermore, it should be noted the geometric complexities encountered in the CY_01 and CY_02 models. Specifically, the presence of intricate geometries in both models presented an additional challenge in achieving optimal architectural modelling for EPC generation. This fact can also account for the time invested in architectural modelling for these buildings, and it could be considered as an aspect to be taken into account, in addition to those defined in the previous chapter.

The difficulties encountered in these two models were overcome by the verifier with the assistance of the guidelines. This is considerably significant as the verifier himself indicates that the solutions he would have chosen in the absence of the guidelines would have differed from what the recommendations suggest, potentially leading to export or import issues.

Despite the challenges faced and considering that the absence of minimum information requirements is primarily attributable to the lack of initial information, as indicated by the verifier, the overall assessment of the usability of the guidelines for architectural modelling has averaged at 3.95 out of 4 points. This implies that, in addition to being highly comprehensible, the guidelines can be well adapted to models of varying complexity.

Analytical modelling

The applicability of the guidelines for analytical modelling in the Cypriot cases were assessed very positively, akin to architectural modelling.

Similarly, the various problems associated with the lack of initial information encountered by the verifier during the development of the architectural models have also been observed in the case of analytical spaces. Specifically, for the CY_01, CY_02, CY_03, and CY_04 models, the absence of initial information resulted in none of the analytical models adhering to the recommendations outlined in the guidelines or having been developed with all the required minimum elements necessary for optimal EPC generation.

Since the problems in this case were exclusively attributed to a lack of initial information, as stated by the verifier, they have not affected the final score assigned to the content of the guidelines. The average assessment for all models, which stands at 3.9 out of 4 points, has demonstrated the applicability and usability of the guidelines for analytical modelling in the Cypriot case studies.

MEP modelling

MEP models were not created for the Cypriot case due to the lack of initial information. Therefore, the evaluation of the guidelines for MEP modelling cannot be conducted. However, based on the comments from the verifier, it has been judged important to rate the guidelines, as they found the explanations helpful (4 out of 4 points).

Furthermore, it was recommended to create MEP models, despite the limitations of EPC software in reading them (average of 3 out of 4 points). Additionally, an automatic reading of parts of MEP models by EPC software was deemed useful, receiving an average rating of 4 out of 4 points.

Export

Regarding the export processes, a positive perception was expressed by the verifier concerning the explanation and understanding of the possible export methods and their recommendations.

It is worth mentioning that, despite the guidelines being easily understandable, a series of issues were encountered by the verifier during the export processes for the CY_01 and CY_03 models. These issues are related to the complexity of certain geometries in both models, which could not be adequately interpreted by the EPC software.

However, the general assessment of the difficulty involved in the export process was considered almost negligible with the use of the guidelines (3.8 out of 4 points). Furthermore, it was indicated by the verifier that the guidelines had been extremely helpful during the export process, assisting both in general and in solving unexpected problems. This statement is supported by an average rating of 4 out of 4 points for these aspects.

Validation

Regarding the validation process, the clear comprehensibility of the guidelines in explaining the processes was emphasized by the person responsible for verification. Furthermore, it was indicated that, after verifying and remodelling each building according to the guidelines' recommendations, no errors were found concerning geometric and non-geometric data in the IFC model, except for the lack of information dependent on the absence of an initial source of building information.

This statement was confirmed by the score obtained, with an average of 3.8 out of 4. The individual scores for each model show significant fluctuations, except for the CY_02 and CY_04 models, with a one-point difference compared to the others, for assistance with unexpected problems and general assistance during the verification process, respectively.

However, due to the lack of comments from the modeler about the reasons for assigning a lower score to these models, no conclusion can be drawn.

Conclusions

The specific evaluation of each process was demonstrated to be favourable in the cases of Cyprus, notwithstanding the difficulties experienced in certain processes, as shown in the preceding section. This statement is supported by the overall rating of the guidelines, which has been provided in the opinion section of the evaluation form and averages 3.95 out of 4 points.

The guidelines were highly valued by the verifying technician as a significant aid that contributed to time savings compared to undertaking the processes without any recommendations. At the same time, it was recommended expanding the scope of the guidelines to encompass other domains.

In the conclusion, it was further indicated that the optimization of BIM processes, including software compatibility, should be a priority in the construction sector to ensure the proper adoption of the BIM methodology for certification purposes.

Table 21. Average score given through the Cypriot buildings

Opinion	Average score
General usefulness of the guidelines	3.8 out of 4
Time saving thanks to guidelines	4 out of 4
Extension of the guidelines to other software	4 out of 4
Recommendation/dissemination of the guidelines	4 out of 4
Overall rating	3.95 out of 4

6.4 Italy

Architectural modelling

The evaluation of the Italian cases is based on the verification and modification of existing BIM models. Consequently, some inquiries are not applicable to the case studies. However, the outcomes are applicable to all models and demonstrate a proper comprehensibility, usability, and helpfulness of the guidelines in terms of the minimum required elements, basic recommendations, and the ability to address problems arising from architectural BIM models. It is noteworthy that the IT_09 model presented difficulties related to its complexity; nevertheless, the guidelines proved instrumental in resolving these complexities, as confirmed by the verifiers. Furthermore, despite the differing nature of the case study buildings and the resulting individuality of the models, the guidelines have helped to address the issues effectively.

This conclusion is confirmed by the evaluation scores for the effectiveness of the guidelines during the architectural modelling phase, with an average score of 3.68 across all models. This score remains consistent when assessing each model individually, ranging from 3.67 to 3.75.

Analytical modelling

Generally, there is a positive perception regarding the explanation, understanding, and usefulness of the basic suggestions and minimum requirements regarding analytical modelling. However, the verifiers indicated that in the Italian cases, the guidelines exceeded in suggesting parameters for space modelling.

The verifiers have assigned a general average score of 3 out of 4 to the usefulness of the guidelines for space modelling. This score remains consistent when evaluating the individual scores of each model.

MEP modelling

In the context of the Italian cases, the evaluation of MEP modelling can be considered inconclusive due to the absence of MEP models.

However, the verifiers acknowledged the MEP modelling usefulness despite the limitations of EPC software in reading such models, assigning a score of 4 out of 4 to the usefulness of the guidelines. Simultaneously, they mentioned that they do not agree with improving such software to exchange MEP data, giving a score of 1 out of 4 for each model.

Export

Regarding the export processes, the verifiers maintained a positive perception regarding the clarity and comprehensibility of the available export methods and associated recommendations. Overall, the utility of the guidelines during the export processes was rated with the highest score and considered to be of low difficulty.

Furthermore, the verifiers assigned an average punctuation of 3.67 out of 4 to the usefulness, lack of difficulty, and helpfulness of the guidelines during exportation process.

Validation

The verifiers indicated the guidelines can facilitate comprehension of the validation procedures. They further confirmed that that following the verification and remodelling of each building according to the guidelines, no errors were detected in relation to geometric and non-geometric data in the IFC model. The IFC model contained all the required parameters for successful importation into the EPC software.

The verifiers assigned the highest value to the usefulness of the guidelines during the validation phase, awarding an average score of 4 out of 4 to this particular aspect of the guidelines.

Import

Positive perceptions regarding the clarity and guidance provided by the guidelines throughout the process were consistently reported. Furthermore, the final average score for the usefulness of the guidelines in this process was 4 out of 4.

Given that the verifiers responsible for the importation processes within EDILCLIMA are also part of the developing team of their certification software, this aspect of the guidelines' assessment holds significant importance.

Conclusions

In the preceding section, it has been demonstrated that the specific evaluation of each process is favourable in the Italian cases. This assertion is corroborated by the overall rating assigned to the guidelines in the opinion section of the evaluation form.

The technicians expressed a highly positive perception of the guidelines in the EPC generation processes from BIM models, attributing the highest rating to their utility and their ability to save working time compared to undertaking the processes without any recommendations.

Despite being aware of the ongoing development of similar guidelines by the developers of the EDILCLIMA software, the verifying technicians believe that the guidelines developed in TIMEPAC enable the transformation of BIM models into suitable models for generating EPCs using their EDILCLIMA EC700 software. This assessment substantiates the perceived utility of the guidelines. However, based on this response, it could be useful to undertake a comparative analysis of the perception of the guidelines developed for TIMEPAC with similar initiatives to assess potential synergies or discrepancies among them, and identify opportunities for enhancement. Lastly, the Italian verifiers positively appreciated the inclusion of other software in the guidelines in the future.

Table 22. Average score given through the Italian buildings

Opinion	Average score
General usefulness of the guidelines	4 out of 4
Time saving thanks to guidelines	4 out of 4
Extension of the guidelines to other software	3 out of 4
Recommendation/dissemination of the guidelines	4 out of 4
Overall rating	3.75 out of 4

6.5 Slovenia

Architectural modelling

The responses obtained from the questionnaire referred to models created from scratch for all buildings. Consequently, some questions posed in the questionnaire may not be applicable to all Slovenian cases.

The overall assessment of the guidelines, as expressed by the verifier in the Slovenian cases, is positive and consistent across all models. Specifically, it is highlighted the adequate comprehension and application of the suggestions and recommendations provided in the guidelines for the architectural modelling. This is reflected in the obtained score for this process, with an average rating of 4 out of 4.

However, several challenges that emerged during the process which hindered the complete implementation of the recommendations. Moreover, it was indicated that not all these difficulties could be fully resolved with the assistance of the guidelines. Specifically, the encountered issues seem to be linked to errors stemming from the initial building information, such as window dimensions or overhangs, as well as the lack of description and properties related to the building envelope. Despite these challenges, the modeler underscores his ability to address and resolve these conflicts without relying solely on the guidelines.

Analytical modelling

Regarding the modelling of analytical spaces, the verifier also emphasized the proper comprehension of the fundamental suggestions, minimum requirements, and recommendations outlined in the guidelines. However, it was noted that not all the recommendations could be fully implemented in the generated models.

If the absence of difficulties regarding the complexity of space designs is considered, this fact could again be attributed to the use of a different BIM software (i.e., ArchiCAD) than the ones used as examples for the development of the guidelines (Revit, Cype). Consequently, the specific features of this software might have led to increased problems during the modelling process.

Notwithstanding, the verifier offers an overall positive assessment for all models in terms of the general applicability of the guidelines, with an average rating of 3.75 out of 4. However, it should be mentioned that this rating slightly diminishes in relation to the suggestions for modelling analytical spaces, obtaining an average score of 3 points out of 4.

MEP modelling

The verifier pointed out the implementation of MEP models in all cases, making Slovenian the application case where the assessment of guidelines concerning MEP modelling could be applied.

The evaluating party's assessment of the comprehensibility and applicability of the guidelines in the processes of creating MEP models was highly positive, despite the use of a different BIM software than the one employed as the basis for developing the recommendations.

The guidelines' elucidation regarding the concept of MEP modelling, its implementation, and its minimum requirements achieved an average rating of 4 out of 4. This score was given despite the guidelines’ recommendations were presented in a more generalized manner due to information exchange challenges inherent in this type of modelling.

Moreover, there is a perceived necessity and recommendation to carry out MEP modelling (average rating of 4 out of 4), despite the limitations of EPC software in reading such models. Furthermore, the feasibility of possible automatic reading of parts of MEP models by EPC software is highlighted as convenient (average rating of 3 out of 4).

Export

Regarding the exportation processes, the verifier of the Slovenian cases reported the utilization of open standard formats for all of them. Additionally, a positive perception was observed regarding the clarity and comprehensibility of the potential exportation methods and their corresponding recommendations.

It is noteworthy that the verifier encountered a series of challenges during the exportation processes for all models. These issues arose due to disparities in the export capabilities of the BIM software used. Nonetheless, the verifying party indicated that they were able to comprehend and solve these issues with the assistance of the guidelines, rating the efficacy of this support with an average score of 3 out of 4.

However, the overall assessment of the difficulty involved in the exportation process was considered relatively low, receiving a rating of 3 out of 4 points. Furthermore, the verifier expressed that the recommendations provided during the exportation process were highly valuable, even when employing a different BIM software is used. This assertion was supported by an average score of 3.33 out of 4 points in these aspects.

Validation

The verifier highlighted the clear comprehensibility of the guidelines in explaining the verification processes. Furthermore, upon conducting verification for each building according to the guidelines' recommendations, no errors were found concerning the minimum required elements. However, errors related to accuracy, completeness, or other data were confirmed in the final reviewed models.

Due to the absence of comments from the modeler, a detailed explanation regarding the nature of these errors, or whether they were subsequently solved or assumed, cannot be provided.

Notwithstanding the challenges encountered during the verification process, high conformity with the guidelines was established, as evidenced in the score obtained for this phase, with an average of 3 out of 4 points.

Import

Regarding the importation phase, a favourable overall perception of the guidelines' comprehensibility during the process was noted, and any unexpected issues were encountered.

However, it is important to highlight that due to the utilization of a different EPC software than the one specified in the guidelines, the verifier highlighted the lack of applicability of the guidelines for the Slovenian case.

Notwithstanding this limitation, a mean score of 3.5 out of 4 was assigned. It should be noted that this score pertains exclusively to the comprehensibility of the guidelines and does not encompass their applicability in the case studies.

Conclusions

The Slovenian case, when compared to other countries, presents several additional challenges arising from the use of software different from those exemplified in the TIMEPAC guidelines. Consequently, certain issues remained unresolved despite relying solely on the guidance provided.

This finding emphasizes the necessity of expanding the guidelines to encompass a broader range of BIM and EPC tools. The verifier explicitly supports this proposition, assigning a score of 4 out of 4 (with 0 indicating total disagreement and 4 representing total agreement) to emphasize the importance of such an extension.

Despite these challenges, the overall perception of the guidelines' usefulness is highly positive. The verifier's evaluation yielded an average score of 4 out of 4 in these aspects, indicating that the guidelines offer substantial benefits in various contexts.

In conclusion, while the guidelines are deemed to be useful, the observed difficulties underscore the need for tailored adaptation to specific cases in each country and software environment. By addressing these contextual variations, improved process management and reduced working times can be achieved, even though the guidelines' current effectiveness in reducing working times received a significant average score of 3 out of 4.

Table 23. Average score given through the Slovenian buildings

Opinion	Average score
General usefulness of the guidelines	4 out of 4
Time saving thanks to guidelines	3 out of 4
Extension of the guidelines to other software	4 out of 4
Recommendation/dissemination of the guidelines	4 out of 4
Overall rating	3.75 out of 4

6.6 Spain

Architectural modelling

The responses given in the evaluation form related to the architectural modelling were based on the verification and modification of existing models. Consequently, certain questions were not applicable to all Spanish case studies.

The feedback collected for the architectural modelling indicates a comprehensive understanding and application of the suggestions and recommendations of the guidelines. However, as emphasized by the verifier, the evaluation regarding complex building models and their associated recommendations could not be conducted since none of the cases fell in that category.

Nevertheless, the usefulness of the guidelines for architectural modelling was positively evaluated, with an average score of 3.20 out of 4. It is noteworthy that the ES_01 case received an individual average punctuation of 4, compared to the other cases which have been scored with 3 points. This disparity could be attributed to the perception that the guidelines are particularly valuable in intricate and time-intensive processes, as opposed to internal or automated procedures where information exchange is tailored specifically for EPC generation purposes.

Analytical modelling

Regarding analytical modelling, the evaluation was akin to the architectural modelling. The suggestions and recommendations expressed within the guidelines were recognized as beneficial and understandable. Nevertheless, an assessment of their usefulness in facilitating the development of both simple and complex analytical modelling was not carried out.

Notwithstanding this limitation, the average evaluation of the usefulness of the guidelines has been scored with 3 out of 4 points.

Furthermore, the data input capabilities of CypeMEP BIM regarding the analytical spaces were highlighted by the verifier. In fact, certain parameters can be automatically incorporated when assigned to the spaces. Consequently, it is suggested that the recommendations for space analysis may have greater applicability during the validation phase if using CypeMEP software.

MEP modelling

In the case of Spain, the existing BIM models did not encompass any MEP models. Thus, the evaluation of the guidelines' assistance in MEP modelling could not be considered.

Despite the absence of MEP models, the verifier evaluated the guidelines on this aspect, with an average score of 4 points for their utility in understanding MEP models, and an average score of 3 points for their efficacy in helping to create the MEP models.

Regarding the utility of the minimum information exchange requirements of the guidelines, the verifier’s opinion indicated great usefulness (4 out of 4) for the use of open formats (ES_01). However, this score diminishes for the other cases wherein data transfer occurs automatically or via proprietary formats, receiving a score of 2 out of 4.

This score reduction can be attributed to the verifier's comments. The internal and automated workflow between CypeMEP and CYPETHERM HE Plus facilitates data exchange for MEP models. Therefore, the recommendations provided in the guidelines hold limited utility in this context. Nevertheless, it was considered essential and advisable to create MEP models, as evidenced by an average score of 4 out of 4.

The average punctuation for considering an automatic data reading of MEP model components by the EPC software is 4 out of 4 for all models. This score suggests the extension of the ease of data exchange in Cype's internal workflows to workflows involving open formats.

Export

A positive assessment is evident regarding the explanation and comprehension of potential exportation methods and their recommendations.

The average score provided by the verifier was 3.33 out of 4, indicating the effectiveness of the recommendations outlined in the guidelines for exportation processes. This punctuation varied between the ES_01 model and the remaining models, with a score of 4 for the former and 2 for the latter. This variation may be attributed to the perception that the guidelines are more applicable to complex exportations, while no recommendations were considered necessary for simpler and automated internal workflows.

This observation was confirmed when assessing the scores related to the complexity of exportation processes. Higher ratings were given to those processes that use open exchange formats (3 out of 4), whereas the automated processes between BIM software and EPC software received the lowest scores (1 out of 4).

Another interesting observation is that the usefulness of the guidelines for exportation processes was found to be dependent on the chosen workflow. The ES_01 model received the highest score, while the ES_02 model has received a score of 2 out of 4, and the remaining models have obtained 3 out of 4 points. This observation may be attributed to the fact that the BIM guidelines appear to be primarily focused on processes that allow the exportation of BIM models using IFC files. The lack of specific guidance for automatic exportation processes in each software resulted in a lower utility of the recommendations in those particular cases.

Validation

A comprehensive understanding of the explanations pertaining to the validation processes was indicated by the verifier. Moreover, it was highlighted that the ES_01 model was the only one still presenting information gaps after the verification phase, which could not be rectified with the aid of the guidelines. This lack of solutions may be attributed to the verifier's incapacity to introduce customized parameters into the IFC format from the BIM software.

Nevertheless, the necessity of validation processes and the usefulness of the guidelines in these instances was reaffirmed. The overall average score obtained in this regard stands at 3.5 out of 4 and remains consistent regardless of the model.

Import

The importation phase exhibits the greatest disparities among models. Despite the positive evaluation of understanding and implementation of the guidelines' recommendations, a deficiency in the importation of some ES_01 model parameters within the EPC software were highlighted. For the ES_02 model, since importation occurs automatically, all information is exchanged between software. Finally, for the rest of the models, the need for an appropriate selection of options during the exportation phase was indicated to avoid information loss.

These challenges are reflected in the scores obtained for this phase. Concerning the question of the utility of the guidelines during the importation phase, the ES_01, ES_03, ES_04, and ES_05 models achieved a score of 3 out of 4. However, the ES_02 model's automatic information exchange received a score of 0, indicating that the guidelines provide no information regarding this particular case.

Conclusions

The overall score of the guidelines highlights discrepancies among the models, which are closely linked to the workflow followed. The technician responsible for evaluating the guidelines assigned an average score of 3.75 for the utility of the guidelines in the ES_01 model, 3 for the ES_03, ES_04, and ES_05 models, and the lowest score (2.5) for the ES_02 model.

As indicated by the verifying technician, the recommendations are effective when the workflow involves the use of different BIM and EPC software. If the EPC software tools have a direct connection with the BIM software through proprietary exchange formats, many of the problems, needs, and solutions addressed in the guidelines are already solved by the software developers. However, this implies the need to use specific software tools for all project collaborators within the BIM methodology, which may not always be feasible.

Finally, despite the verifying technician's awareness of similar guidelines, the overall perspective remains positive for the specific case of the TIMEPAC guidelines, and it was found convenient to extend their coverage to encompass more specific scenarios involving other software tools.

Table 24. Average score given through the Spanish buildings

Opinion	Average score
General usefulness of the guidelines	3 out of 4
Time saving thanks to guidelines	3 out of 4
Extension of the guidelines to other software	3 out of 4
Recommendation/dissemination of the guidelines	3.3 out of 4
Overall rating	3.1 out of 4

6.7 Reliability of BIM models

One of the main reasons for promoting the use of BIM methodology is its foundation on reliability and transparency. The generation of EPCs from BIM models is also founded on this premise.

To assess the reliability of a BIM model, a comprehensive comparison should be conducted between the model and actual building data. This entails examining design documentation for new constructions and conducting on-site studies for existing buildings.

The list of elements used for the comparison includes:

- Building's surface area in square meters.
- Clear height per floor in meters.
- Surface area of windows and walls in the building.

The percentage deviation was calculated for each element in two scenarios:

- EPC generated without BIM, compared to the architectural plans.
- BIM model compared to the architectural plans.

The most significant deviation in both the EPC and BIM data relative to the building plans was observed regarding the total surface area of the buildings. Nevertheless, despite this variability, the BIM models are positioned as more reliable when compared to the EPC data. The discrepancies between the BIM models and the plans are limited to values of 0.06%, 0.15%, and 0.13% of average deviation for the AT06a, HR01, and CY01 case studies, respectively (green bars in Figure 21). The deviations of the EPCs in this context escalate to values of 0.28%, 0.23%, and 0.56%, respectively for the same case studies (blue bars in Figure 21).

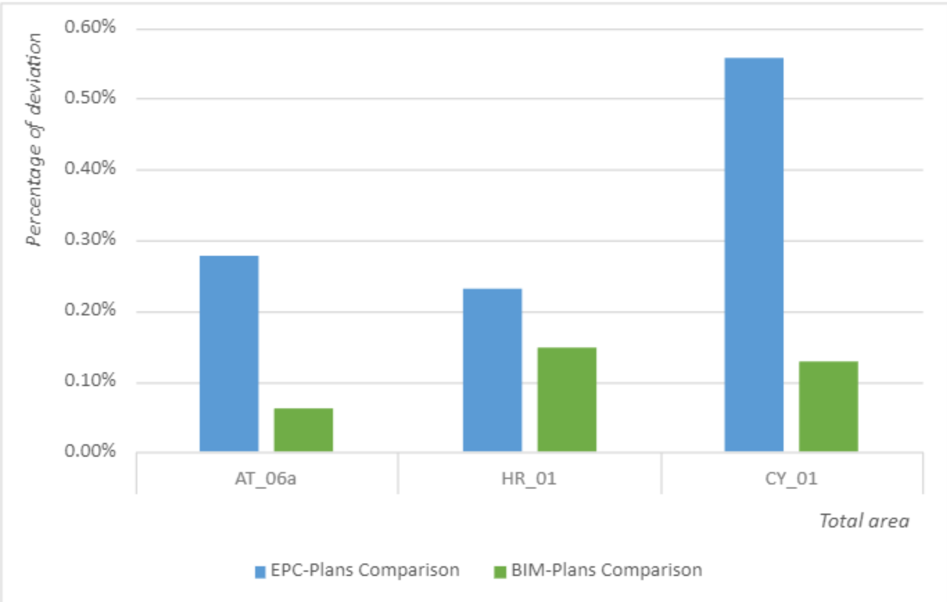


Figure 21. Building surface's percentage of deviation among different initial documentation for the AT_06a, HR_01, and CY_01 case studies

Another influential and significant factor in generating EPCs is the clear height of the space. In this case, the average deviations of the parameter in the EPC relative to the architectural plans are 0.10%, 0.49%, and 4.48% for the cases of Austria, Croatia, and Cyprus, respectively (blue in Figure

22). Conversely, the deviations of the BIM models from the same graphical information remain consistently at 0% across all cases.

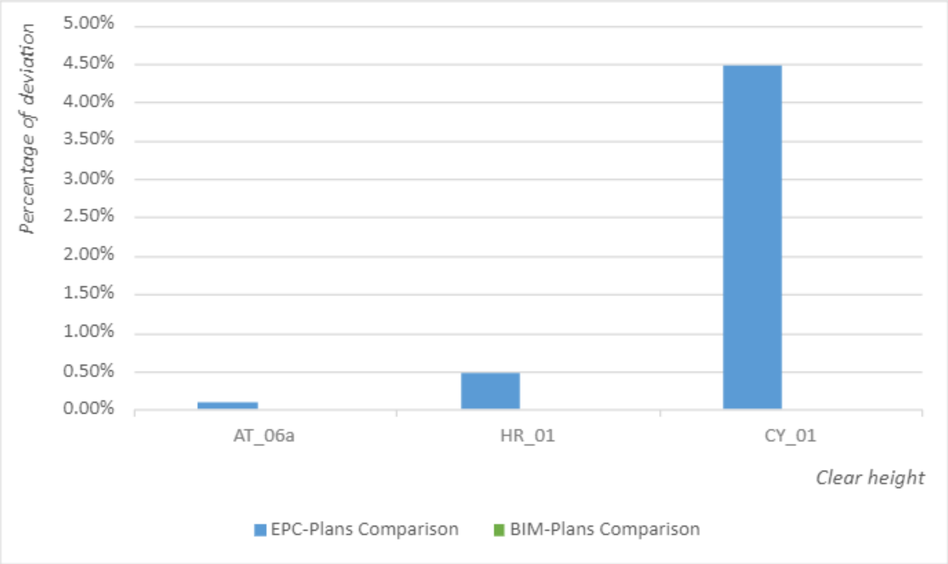


Figure 22. Building clear height's percentage of deviation among different initial documentation for the AT_06a, HR_01, and CY_01 case studies.

To be specific, the average deviation of the façades surface area in the BIM models in contrast to the plans amounts to 0.10%, 0.13%, and 0.03% for the AT_06a, HR_01, and CY_01 models (green bars in Figure 23). In contrast, the EPCs revealed an average percentage deviation of 3.02%, 1.39%, and 1.72% for the façades surface area, and of 14.47%, 1.45%, and 5.96% for the windows' surface area for those same cases (blue bars in Figure 23).

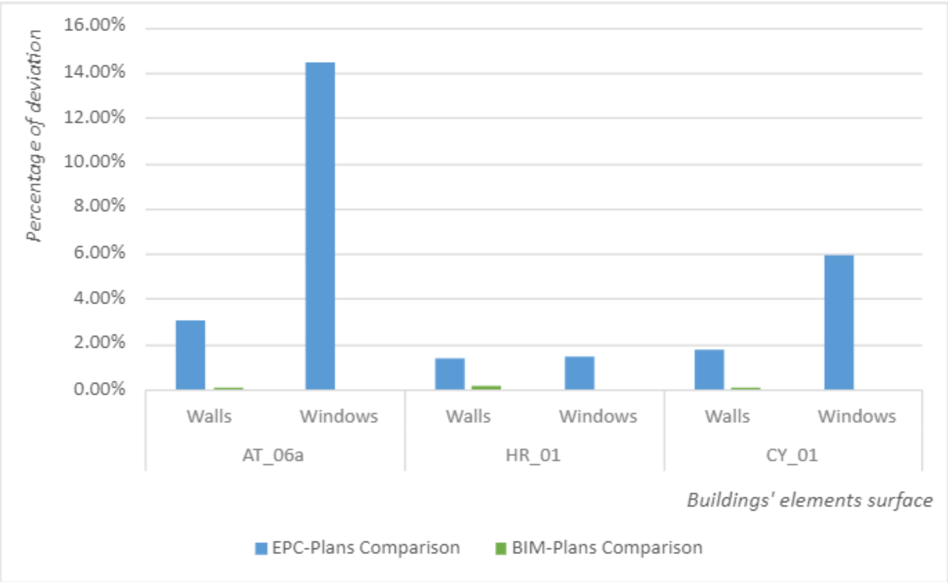


Figure 23. Percentage of deviation of the surface of construction elements between different initial documents for the AT_06a, HR_01, and CY_01 case studies

Although there are noticeable differences in values between the EPC and BIM results, some variations also exist within the BIM models regarding the initial graphical information. These differences might be due to minor discrepancies that occurred during the BIM graphical representation process.

The EPC deviations may be attributed to accumulated errors during the process of data input or modelling within the EPC software. Conversely, it is plausible to assume that the BIM modelling process provides for greater control over, primarily due to the capabilities offered by software to visualize and measure information in both 2D and 3D. This enables higher precision and reduced deviations, resulting in values closer to reality.

Concerning the windows, the deviation could be a result of the inclusion of a greater or lesser number of windows compared to those actually present in the building, the simplification of irregular windows in cases where EPC software does not permit comprehensive modelling and restricts the input to windows' width and height data, or interpretation or measurement errors assumed by the modeler.

The findings of the comparison reveal a positive disposition towards the adoption of BIM models. In general, a noticeable reduction in percentage deviation is observed in the BIM models when compared to the 2D architectural plans, in contrast to the deviation observed between the data obtained from the EPC and the same building plans.

The obtained results strongly support the initial hypothesis regarding the effectiveness of BIM models in generating Energy Performance Certificates. The study also highlights the importance of creating BIM models, despite the inherent limitations of EPC software in reading and interpreting them. BIM offers an advanced level of control and the ability to visualize errors through 3D modelling, which helps prevent significant interpretational inaccuracies from carrying over into later stages of the modelling process. Adopting BIM models proves highly advantageous for both the certifier and the overall outcomes of the certification process.

6.8 Cross country comparison

The TIMEPAC BIM-to-EPC guidelines were applied in 30 case studies of diverse characteristics across six partner countries. The evaluation revealed that the guidelines were successful in reducing process time and were considered useful with an average rating of 3 (2.99) out of 4 for all countries (Figure 24). This indicates that the guidelines are not only effective for specific cases in particular locations but also adaptable to other contexts. As a result, one of the key objectives of the guidelines, which is to be generic enough for broader application, has been validated by addressing common problems related to software interoperability.

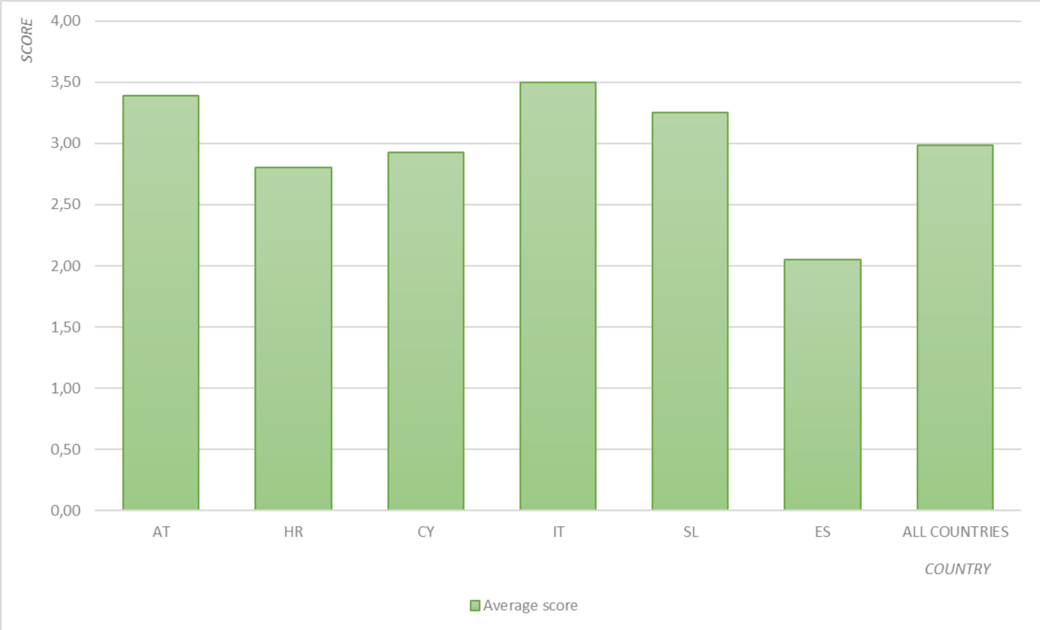


Figure 24. Average score of the guidelines by country

Nevertheless, during the validation process, some limitations were observed.

Building Complexity:

The reality of the built environment is inherently complex. While certain buildings may share common features, they also exhibit particularities that hinder the applicability of the guidelines for BIM model generation.

The in-depth study addressed specific constructive cases, but for more complex cases like architectural domes, facade alignments, or sloping roofs, the guidelines' usefulness diminished, leading to longer processing times and evaluations. However, efforts by verification parties to relate guideline cases with real-world study cases helped resolve challenges before significant impacts on overall processes occurred.

This observation underlines the replication potential of the guidelines. However, it is important to acknowledge that the buildings studied represent only a limited sample and a wider range would need to be considered to confirm this assertion.

Quantity and quality of Initial Information:

Inaccurate building descriptions often makes it difficult to generate reliable EPCs. In the absence of accurate information, technicians can make justified assumptions based on, for example, the construction year. These assumptions can be further supported by the options offered by the EPC software libraries.

In addition, the generation of an EPC often entails the simplification of graphical information, which can impact the reliability of the energy performance certification. For instance, in some of the Italian cases, simplified simulations required adjustments to the EPC software. Conversely, the lack of information in some Austrian, Croatian, and Cypriot models posed challenges in meeting the minimum requirements to create an optimal IFC model to import in the EPC software, resulting in assumptions that significantly deviated from reality.

BIM emerges as a tool to address inconsistencies between reality and models, as well as between processes involved at any stage of a building's lifecycle. However, starting from an existing BIM model for EPC generation is uncommon, especially for older residential buildings.

All these scenarios have been thoroughly considered in the creation of the TIMEPAC guidelines. The frequency of these issues was demonstrated during their validation process through the study cases. The results underscored the importance of addressing the problem of insufficient building descriptions to enhance the reliability of EPCs.

Specifically, the presence or absence of BIM, along with the information provided by other sources, influenced the final reliability of the IFC models. Having a BIM ensured that the building information was preserved through the processes and was aligned with reality, despite potential inadequacies in the EPC software, necessitating remodelling following the guidelines.

Moreover, in cases where non-graphical information from EPCs or energy reports was available from start, the user had to assume input data for the EPC software. Although the person who prepared the reports most probably did not have the actual building information, software simplification processes or document management procedures contributed to reducing the amount of information present in these documents. However, the significant lack of information required for EPC generation rendered some models impossible to complete, as the assumptions were too general to produce viable results (Figure 25).

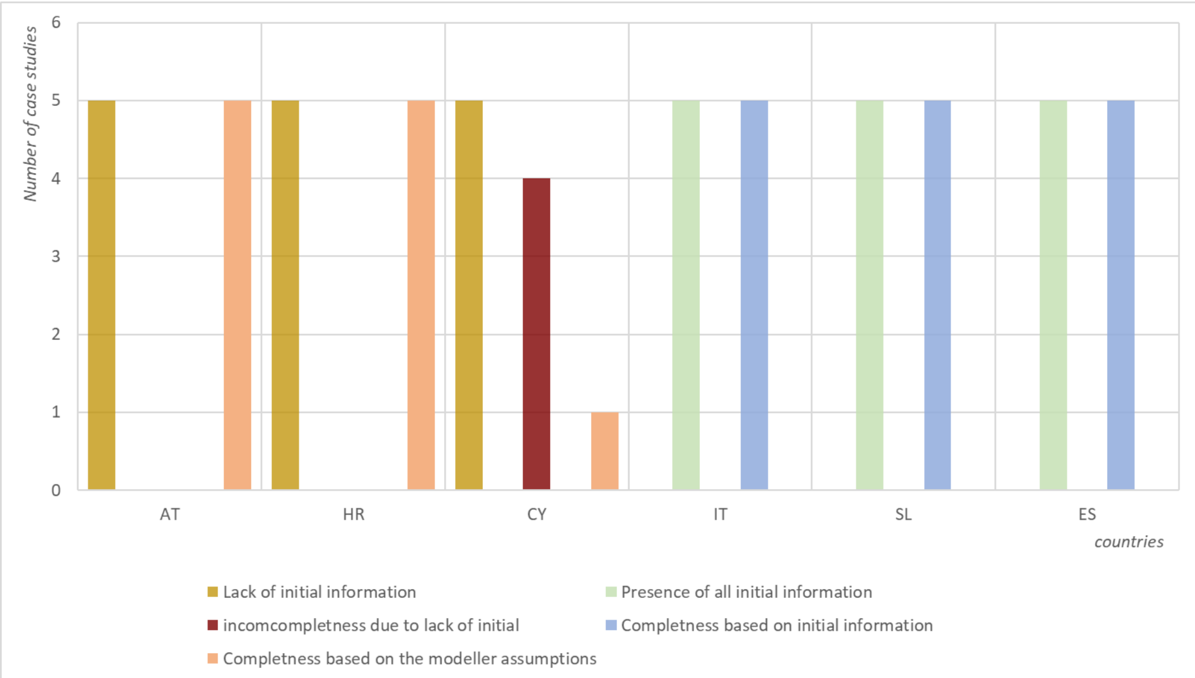


Figure 25. Relationship between initial information and final modelling by country

These problems arose with independence of the usability, applicability, and replicability of the guidelines. The assessment of the guidelines remained positive in all cases. Nevertheless, these are issues to consider when managing the processes of EPC generation from BIM models. Furthermore, it justifies the necessity of having a BIM methodology for creating reliable and reality-appropriate documentation for building modelling.

Model category and information:

Throughout the development of the TIMEPAC guidelines, a classification system was established to categorize different types of BIM models based on distinct aspects of the building design and construction process. Specifically, these aspects included architecture (architectural modelling), building analysis (analytical modelling), and engineering (MEP modelling). This classification helped to define the minimum requirements needed to create an EPC from an existing BIM model, or its remodelling, in the case of collaborative modelling processes. Therefore, it streamlined the management of BIM models with relevant data, leading to the creation of a final energy model. Moreover, the classification aligns with the widely embraced BIM methodology, which recognizes the involvement of specialized technicians from multiple domains during various stages of the construction process.

This categorization was applied in the evaluation phase of the guidelines to systematically assess their applicability. The evaluation showed positive results in the modelling and geometric information exchange processes for the architectural and analytical models. However, when it came to the exchange of non-geometric information, common limitations were identified across nearly all participating countries. Notably, certain EPC software demonstrated an incapability to read either complete BIM models or their specific components. Additionally, the MEP modelling, which plays a crucial role in obtaining EPC results, proved challenging and could not be fully evaluated as intended in the guidelines. It is important to emphasize that this limitation primarily lies in the software development rather than the creation and applicability of the guidelines, although the latter may be affected to some extent.

It can be stated that one of the most remarkable limitations in the applicability of the guidelines lies in the interoperability capabilities of the software involved. This limitation also extends to some modelling software and the information exchange formats utilized. While the former may not allow the exportation of certain information, the latter may restrict data exchange due to an incomplete specific standardized structure.

Within the overall framework of the guidelines, an effort has been made to address this issue from a standpoint that considers the perspectives of both modelling and EPC experts. The ultimate goal is to identify challenges and opportunities so that software developers can act appropriately.

It is important to highlight the contrasting perspectives between modelling and certifying technicians and software developers regarding the interpretation of MEP modelling information by the EPC software. For the former, having such capabilities is seen as a valuable way to save time and effort in the BIM-to-EPC processes, emphasizing its significance. However, developers did not provide reasons to significantly undervalue this proposition, so it is unclear how they evaluated it. Nevertheless, it is reasonable to assume that the complexities surrounding the need to focus on essential information for simulation processes in EPC generation, along with the high information capacity of BIM software and the standardization of IFC exchange format, pose challenges that may not be immediately feasible or cost-effective to address.

Software utilization:

One of the main limitations in the applicability of the guidelines is associated with the choice of software to be used. This limitation has become evident during the assessment of case studies in Croatia, Cyprus, Slovenia, and Spain.

In Croatia and Cyprus, the certification software could not read BIM models. In these cases, using guidelines for BIM modelling would be meaningless. However, in these cases might make sense to create a BIM model to verify the reliability of the existing building information.

About the Slovenian case, the applicability of the guidelines is the limited because the chosen BIM software and EPC software are not included in the guidelines. Since some capabilities of the software are not described or evaluated, and no specific recommendations are highlighted, some parts of the guidelines could not be applied to the case studies.

In the case of Spain, a significant advantage lies in the ease of information exchange facilitated by proprietary formats, such as Cype’s, as compared to open standards. The interconnected BIM and EPC software help to reduce time, effort, and information requirements. Consequently, this BIM software incorporates the essential parameters for EPC generation without providing excessive or insufficient information.

Furthermore, it is imperative to emphasize that irrespective of the EPC software, challenges concerning the interpretation of intricate geometric information are common across all models used, notwithstanding with varying degrees of intensity.

Despite all the aforementioned limitations, the final perspective indicates that the objectives of applicability, reliability, and replicability of the guidelines have been achieved. Throughout their development, efforts have been made to address these limitations to the best extent possible, always from the perspective of the user responsible to generate an EPC from a BIM model. However, there remains much work to be undertaken in order to establish standard processes that enable a seamless EPC generation from BIM. This would require not only experts in BIM and EPC but also software developers.

6.9 Recommendations for software developers

To enhance the interoperability between BIM software and EPC software, the following recommendations are provided for software developers:

Revit exportation options:

Currently, users may rely on custom exportation methods from Revit to IFC to generate the required elements and parameters for Energy Performance Certification. However, this may lead to inconsistencies and inaccuracies. By updating the exportation process to conform to the IFC standardized format, all necessary data for EPC software needs to be included in the IFC file. For example, when exporting a Revit model to IFC for EPC purposes, the software should include thermal properties, materials, and other energy-related parameters included in the IFC schema.

Aligning the exportation process from Revit to IFC schema entities ensures consistency and completeness in the data exported for EPC generation. It reduces the reliance on user-defined methods, minimizes errors, and improves interoperability, as the IFC format is widely accepted in the BIM domain.

Update exportation characteristics of Cype suite for linking with other software using open standards:

To facilitate collaboration and enable seamless data exchange between Cype and other software, the exportation characteristics should be updated to adhere to open standard methods like IFC. This allows for a smooth exchange of information between different BIM-enabled applications. Cype software uses proprietary formats for exporting part of the data, but fully using open standards like IFC would ensure the compatibility with other BIM applications.

Updating exportation characteristics to IFC would align Cype with the broader BIM community and foster collaboration among stakeholders. Open standards facilitate data exchange, promote interoperability, and avoid data loss or discrepancies when importing into other BIM tools.

Define a standardized subset of IFC for energy assessment:

Considering that not all the required information and parameters for Energy Performance Certification are currently considered by IFC, software developers should collaborate to establish a standardized subset of IFC specifically tailored for energy assessment purposes. This subset should include all the information necessary for building energy assessment.

By defining a standardized subset of IFC for EPCs, software developers can ensure consistent data exchange and compatibility between various BIM and EPC software solutions. This will streamline the process of generating EPCs and reduce the risk of missing critical information.

Establish a collaborative effort among software developers:

Software developers working on IFC, BIM, and EPC tools should collaborate and communicate to facilitate the seamless exchange of information required for energy performance certification. Each software system may have unique capabilities and limitations, and by sharing insights and expertise, developers can collectively identify the essential data and parameters needed for accurate energy performance evaluation. This shared effort would result in a more efficient data transfer process between different software systems, ultimately benefiting end-users and stakeholders involved in the EPC generation process. For example, BIM software developers can provide valuable input on the types of data that can be easily extracted from BIM models and how to structure it in IFC. On the other hand, EPC software developers can contribute their knowledge of certification standards and specific data requirements. This cross-disciplinary collaboration ensures that the resulting IFC subset caters to the needs of both BIM and EPC software, improving the overall quality of energy analysis.

Collaboration among software developers will lead to a more comprehensive understanding of the specific energy evaluation requirements for EPCs. It will also allow for the identification of

gaps in the current IFC data model and enable the addition of new parameters and elements necessary for energy analysis.

Develop plugins based on the IFC standard:

Instead of creating specific plugins for individual software platforms, developers could focus on building plugins that adhere to the IFC standard. This would ensure broader compatibility with a wide range of BIM authoring tools and platforms, making it easier for users to integrate the EPC software into their existing BIM workflows. For example, a developer could create an IFC-based plugin for popular BIM software like Revit, ArchiCAD, and Tekla Structures. This plugin would enable users of these BIM applications to directly export their building models to the EPC software without any loss of information.

By adopting the IFC standard for plugin development, developers can save time and effort in maintaining multiple plugins for different software platforms. This would also safeguard the EPC software against future changes in the BIM ecosystem and ensures a consistent user experience across various BIM applications.

Proper handling of imported models and element recognition:

To streamline the energy performance certification process, the EPC software needs to accurately recognize and categorize building elements imported from BIM models. This includes elements such as skylights and glazed envelopes, which are critical components affecting a building's energy efficiency. For example, when importing a BIM model into the EPC software, the tool should automatically detect and identify elements like skylights and glazed surfaces, assigning to them the properties required for the certification calculations.

Proper handling of imported models and accurate element recognition reduce the need for additional remodelling or manual adjustments in the EPC software. This saves time and minimizes potential errors during data conversion, ensuring consistent and reliable energy performance certification results.

Inclusion of all possible parameters from BIM models:

To maximize the accuracy of energy performance certification, EPC software should include all relevant parameters available in BIM models. This involves extracting and utilizing data related to materials, thermal properties, insulation levels, glazing types, and other energy-related characteristics. For example, the EPC software could access BIM data to determine the type of glass used in windows, the insulation material in walls, and the properties of roofing materials, among other parameters.

By including all possible energy related parameters from BIM models, the EPC software can generate more comprehensive and accurate energy performance certificates. This ensures that the certification reflects the actual energy characteristics of the building, leading to more informed decision-making for building owners and policymakers.

Automatic correlation between BIM parameters and EPC software libraries:

To simplify the data input process for users, developers can establish an automatic correlation between parameters in BIM models and the corresponding ones available in the EPC software libraries. This correlation can be based on standardized naming conventions or semantic mapping. For example, when importing a BIM model into the EPC software, a tool could automatically identify the relevant parameters from the model and map them to the corresponding elements in the software's library for energy performance calculations.

An automatic correlation between BIM parameters and EPC software libraries streamlines the data input process, reduces the likelihood of manual errors, and improves user experience. It encourages broader adoption of the EPC software among BIM practitioners, ultimately leading to more widespread and accurate energy performance certifications.

7 Conclusions

The ultimate goal of the TIMEPAC project is to improve the quality and reliability of EPCs within the European Union. The specific focus of Task 2.1 “TDS 1- Generating enhanced EPCs with BIM data” is on leveraging BIM to address current challenges in data standardization and reliability in EPC generation processes. The main work carried out in this task was dedicated to developing BIM-to-EPC guidelines to facilitate the creation and export of BIM models using IFC. These guidelines have been designed based on the BIM and EPC tools available in the partner countries and are intended for broad applicability across all Member States.

A key challenge lies in data interoperability, and overcoming it requires the collaboration of multiple stakeholders. Industry organizations play a crucial role in promoting open standards and fostering improved communication among stakeholders involved in building performance assessment. Government and regulatory bodies can influence standards adoption through project requirements and codes. AECO professionals can advocate for better interoperability solutions and contribute to advancements in the field. Researchers and academia can drive technological improvements. Collaborative efforts from these actors are essential to surmount the complexities and achieve greater data interoperability between BIM and EPC.

While we continue striving towards a better collaboration among the stakeholders involved, what we can do with the existing technologies is to develop procedures to apply them in the most effective way. This is the purpose of the guidelines we have developed: to facilitate the creation of BIM models and their subsequent export to certification tools using IFC.

The guidelines have been used in 30 cases carried out across six partner countries. These cases involved buildings with diverse characteristics, including different typologies and locations, and encompassed varying levels of information, ranging from detailed BIM models to simple plan drawings. Despite this diversity, the guidelines proved to be applicable in all cases.

However, during the validation of the exported IFC data, some limitations were observed, particularly when dealing with complex buildings or encountering inaccurate information in the BIM models or drawings. On the other side of the process, it was evident that some certification tools were not fully equipped to read IFC data derived from BIM models, leading to challenges in the certification process. These observations underscore the importance of continuous efforts to improve data interoperability between BIM and EPC software, ensuring smoother and more accurate energy performance assessments.

The effectiveness of the guidelines has been assessed by users, who also provided suggestions for improvements.

The results of the reliability assessment using BIM strongly confirm our initial hypothesis that using BIM models improves the quality of the input data for EPC generation. Consequently, the EPC becomes more reliable compared to the same process done without BIM.

The next steps involve verifying the applicability of the guidelines with external stakeholders, which will be carried out as part of WP3 "Verification Scenarios” and using them as training materials in the courses to be delivered in WP4 "EPC Standardisation, Training, and Capacity Building".

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Annex A – Evaluation form

BUILDING MODEL IDENTIFICATION											
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HR_02	HR_03	HR_04	HR_05	CY_01
GENERAL DATA OF USERS											
Name											
Institution											
Role											
USER PROFILE											
Is this the first time you have used a BIM software?											
How many times have you used a BIM software before?											
Is this the first time you have used an IFC viewer software?											
How many times have you used an IFC viewer software before?											
Is this the first time you have used an EPC software?											
How many times have you used an EPC software before?											
TYPE OF BUILDING											
Use											
Year of construction *(write a year)*											
Sq meters of the buiding or premise *(Write a number)*											
Number of floors of the building *(Write a number)*											
SOFTWARE USED											
BIM software used *(Mark below with an X all the software used)*											
Revit											
Cype Architecture											
OpenBIM Analytical											
OpenBIM construction systems											
Cypecad MEP											
Other											
IFC viewer software used *(Write your response)*											
EPC software used											
USE OF GUIDELINES											
How many models have you modelled by following the guidelines? *(write a number)*											
TIME SPENT USING THE GUIDELINES											
How many hours did you spent in developing the architectural model? *(write a number)*											
How many hours did you spent in developing the analytical model? *(write a number)*											
How many hours did you spent in exporting the models? *(write a number)*											
How many hours did you spent in reviewing and fixing the models? *(write a number)*											
How many hours did you spent in importing the models? (write a number)											
Were the hours spent on each task continuous or spread out over multiple sessions?											
Do you think you would spend more time on the processes without the guidelines?											
COMMENTS											
[Writte any problems, suggestions or other opinions about all the questions made in this section]											

Figure A. 1. Evaluation form: General sheet

BUILDING MODEL IDENTIFICATION											
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HR_02	HR_03	HR_04	HR_05	CY_0
GUIDELINES HELP WITH THE ARCHITECTURAL MODEL											
If you developed the model, were you able to model all the minimum required elements? (See architectural model chapter: What elements are part of the architectural model?)											
If the answer is no, please write why. If the answer is some of them or most of them, please write down what elements you were not able to model and why.											
If the model was already developed, did it have all the minimium required elements? (See architectural model chapter: What elements are part of the architectural model?)											
If the answer is some of them or most of them, please writte down what elements were not in the model.											
If the model was already developed, did you have trouble modelling any of the minimum required elements that were not present in the model you had?											
If the answer is yes, please write why. If the answer is some of them or most of them, please write down what elements you were not able to model and why.											
Were you able to understand and apply all the basic suggestions for the architectural model? (See architectural model chapter: What elements are part of the architectural model?)											
If the answer is no, please write why. If the answer is some of them or most of them, please write down what suggestions you were not able to follow and why.											
Were you able to understand and apply all the recommendations for the architectural model? (See architectural model chapter: Minimum required categories subchapters)											
If the answer is no, please write why. If the answer is some of them or most of them, please write down what recommendations you were not able to apply and why.											
If the BIM software that you used is different from Revit or Cype, were you still able to apply the guidelines to develop the architectural model?											
If you used a BIM software that cannot export some minimum required elements, did you understand, find usefull, and use any of the alternative solutions? (See architectural model chapter: Minimum required categories of the materials subchapter)											
Some difficulties may happen when importing complex design architectural models. Thus, they have to be adequately modelled to be interpreted by EPC software. Did you experience any of these difficulties? (See In Depth Study Chapter: IFC importation of the complex design model subchapter - Architectural model elements)											
If the answer is yes, please write down what elements did you model.											
In relation with the previous question, were you able to solve them with the help of the guidelines?											
If the answer is no, please write why. If the answer is some of them or most of them, please write down what elements you were not able to model and why.											
In relation with the previous question, could you solve them without the help of the guidelines?											
USEFULNESS OF THE GUIDELINES FOR THE ARCHITECTURAL MODEL											
Did the guidelines help you to develop the architectural model? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")											
Did you find the basic suggestions for the architectural model useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")											
Did you find the the recommendations for the architectural model useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")											
Did you find the the recommendations for the complex design models with the architectural model useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")											
COMMENTS											
[Writte any problems, suggestions or other opinions about all the questions made in this section]											

Figure A. 2. Evaluation form: Architecture sheet

BUILDING MODEL IDENTIFICATION									
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HR_02	HR_03	HR_04
GUIDELINES HELP WITH THE ANALYTICAL MODEL									
Could you understand and apply all the basic suggestions for the analytical space modelling model? (See Analytical spaces modelling chapter: How to create analytical spaces for energy purpose?. Basic suggestions subchapter)									
If you developed the space model, were you able to model all the minimum required properties? (See Analytical spaces modelling chapter: How to create analytical spaces for energy purpose?. Minimum required properties of the spaces and Minimum required properties of the zones subchapters)									
If the answer is no, please writte why. If the answer is some of them or most of them, please writte down what properties you were not able to model and why.									
If the model was already developed, did it have all the minimuim required properties?									
If the answer is some of them or most of them, please writte down what properties were not in the model.									
If the model was already developed, did you have any trouble modeling all the minimum required properties that you could not find in the model you had?									
If the answer is yes, please writte down what troubles did you have.									
Could you understand and apply all the recommendations for the analytical spaces model?									
If the answer is no, please write why. If the answer is some of them or most of them, please write down what recommendations you were not able to apply and why.									
If the BIM software that you used is different from Revit or Cype, could you still apply the guidelines to develop the analytical spaces model?									
Some difficulties may happen when importing complex design space models. Thus, they have to be adequately modelled to be interpreted by EPC software. Did you experience any of these difficulties? (See In Depth Study Chapter: IFC importation of the complex design model subchapter - Analytical space model elements)									
If the answer is yes, please write down what elements did you model.									
In relation with the previous question, could you solve them with the help of the guidelines?									
If the answer is no, please write why. If the answer is some of them or most of them, please write down what elements you were not able to model and why.									
In relation with the previous question, could you solve them without the help of the guidelines?									
USEFULNESS OF THE GUIDELINES FOR THE ANALYTICAL MODEL									
Did the guidelines help you to develop the analytical model? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
Did you find the basic suggestions for the analytical model usefull? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
Did you find the the reccommendations for the analytical model useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
Did you find the the reccommendations for the difficulties with the analytical model useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
COMMENTS									
[Write any problems, suggestions or other opinions about the analytical modelling part of the guidelines]									

Figure A. 3. Evaluation form: Analytical sheet

BUILDING MODEL IDENTIFICATION						
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01
GUIDELINES HELP WITH THE MEP MODEL						
Did you developed a MEP Model? (See MEP Modelling Chapter)						
If the building model was already developed, did it have the MEP model? (See MEP Modelling Chapter)						
If the BIM software that you used is different from Revit or Cype, could you still apply the guidelines to develop the MEP model?						
USEFULNESS OF THE GUIDELINES FOR THE MEP MODEL						
Did the guidelines help you to understand what is the MEP model? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")						
Did you understand how to create a MEP model? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")						
Did you find the the minimum requirements for the information exchange of the MEP model useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")						
PERSONAL OPINION ABOUT THE MEP MODEL IN THE EPC						
Since the EPC software usually cannot read MEP models, do you think it is useful to develop a MEP model? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")						
Do you think it would be usefull to try to update EPC software to be able to read MEP models or parts of them? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")						
COMMENTS						
[Writte any problems, suggestions or other opinions about the MEP modelling part of the guidelines]						

Figure A. 4. Evaluation form: MEP sheet

BUILDING MODEL IDENTIFICATION							
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HR_0
EXPORTATION PROCESS							
Which method did you use to exchange information from BIM to EPC? (See Information Exchange for EPC Assessment Chapter - How Information can be exchanged to generate EPCs?)							
GUIDELINES HELP WITH THE EXPORTATION PROCESS IN REVIT							
Could you understand and apply the guidelines to export the different models to IFC in Revit? (See Information Exchange for EPC Assessment Chapter - IFC exportation and exchange. How to exprot from Revit to IFC?)							
If the answer is no, please write why.							
Did you export any parameters that are not a default Revit or IFC parameter? (See Information Exchange for EPC Assessment Chapter - IFC exportation and exchange. What to do if the EPC parameter is not a dfault Revit Parameter?)							
In relation with the previous question, did you understand the different methods of the exportation process?							
If the answer is no, please write why. If the answer is some of them or most of them, please write down what methods you did not understand and why.							
In relation with the previous question: What method did you apply?							
Did you encounter any problems with the exportation process related to unsolved problems of the Revit BIM software? (See Information Exchange for EPC Assessment Chapter - IFC exportation and exchange. REVIT exportation: Unsolved problems that depends on the REVIT software.)							
If the answer is yes, please detail them.							
In relation with the previous question, did you understand and apply the suggestions to solve these problems?							
PERSONAL OPINION ABOUT THE EXPORTATION PROCESS IN REVIT							
Did you find the different options of the guidelines useful for exporting all the parameters generated in Revit? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")							
Did you find the different options of the guidelines useful for solving unexpected problems reglated to the BIM software? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")							
Rate the difficulty of the exportation process from 0 to 4, with 0 being great difficulty and 4 being no difficulty							
GUIDELINES HELP WITH THE EXPORTATION PROCESS IN CYPE							
Could you understand and apply the guidelines to export the different models to IFC according to the cype software that you used? (See Information Exchange for EPC Assessment Chapter - IFC exportation and exchange. How to exchange IFC using Cype?)							
If the answer is no, please write why.							
PERSONAL OPINION ABOUT THE EXPORTATION PROCESS IN CYPE							
Did you find the different options of the guidelines useful for exporting all the parameters generated in Cype? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")							
Rate the difficulty of the exportation process from 0 to 4, with 0 being great difficulty and 4 being no difficulty							
USEFULNESS OF THE GUIDELINES FOR THE EXPORTATION PROCESS							
Did the guidelines help you to with the exportation process? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")							
If another BIM software was used instead of Cype or Revit, did the guidelines help you with the exportation process? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")							
COMMENTS							
[Writte any problems, suggestions or other opinions about the Exportation process with regard to the guidelines]							

Figure A. 5. Evaluation form: Exportation sheet

BUILDING MODEL IDENTIFICATION									
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HR_02	HR_03	HR_04
GUIDELINES HELP WITH THE VALIDATION PROCESS									
Did you easily understand how to validate the IFC model? (See IFC Validation Chapter)									
If the answer is no, please write why.									
Did you easily understand how the IFC model data was organized by following the guidelines? (See IFC Validation Chapter)									
If the answer is no, please write why.									
Did you find all the required elements or parameters of the different models in the IFC model?									
If the answer is not yes, please please write down what elements or parameters did you not find.									
Did you find any errors in accuracy, completeness or other data included in the IFC? (See IFC Validation Chapter)									
If the answer to the previous question is not "No", were you able to easily find how to solve them?									
USEFULNESS OF THE GUIDELINES FOR THE VALIDATION PROCESS									
Did the guidelines help you to with the verification process? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
Do you think the validation processes was necessary or helpful in avoiding unexpected problems with the importation process into the EPC software? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
COMMENTS									
[Writte any problems, suggestions or other opinions about the Validation process with regard to the guidelines]									

Figure A. 6. Evaluation form: Validation sheet

BUILDING MODEL IDENTIFICATION									
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b	HR_01	HR_02	HR_03	HR_04
GUDELINES HELP WITH THE IMPORTATION PROCESS									
Could you understand and apply all the recommendations for importing the different IFC models into the EPC software? (See IFC importation in EPC tools subchapter)									
Did you understand how to import the IFC file in the EPC software that you use? (See IFC importation in EPC tools subchapter - Cypetherm HE Plus, EDILCLIMA EC700, or ETU)									
Did you encounter any unexpected problems during the importation process that are not described in the guidelines? (See In Depth Study Chapter: IFC importation of the complex design model subchapter)									
If the answer is yes, please write down those problems.									
USEFULNESS OF THE GUIDELINES FOR THE IMPORTATION PROCESS									
Did the guidelines help you to with the importation process? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
If another EPC software was used, did the guidelines help you with the Importation process? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")									
COMMENTS									
[Writte any problems, suggestions or other opinions about the Importation process with regard to the guidelines]									

Figure A. 7. Evaluation form: Importation sheet

BUILDING MODEL IDENTIFICATION					
TIMEPAC building model ID	AT_06a	AT_09	AT_04	AT_08	AT_06b
GENERAL OPINION ABOUT THE GUIDELINES					
Did you find the guidelines useful? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")					
Did the guidelines help you save time in the process from BIM to EPC? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")					
Do you find interesting to extend the guidelines to other BIM or EPC software? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")					
Would you recommend the guidelines? (scale from 0 to 4 being 0 "totally disagree" and 4 "totally agree")					
Were you aware of any previous development of similar guidelines by other authors?					
If the answer to the previous question is positive, please write down the name and authors of the guidelines.					
COMMENTS					
[Write any problems, suggestions or other opinions about the guidelines]					

Figure A. 8. Evaluation form: Opinion sheet