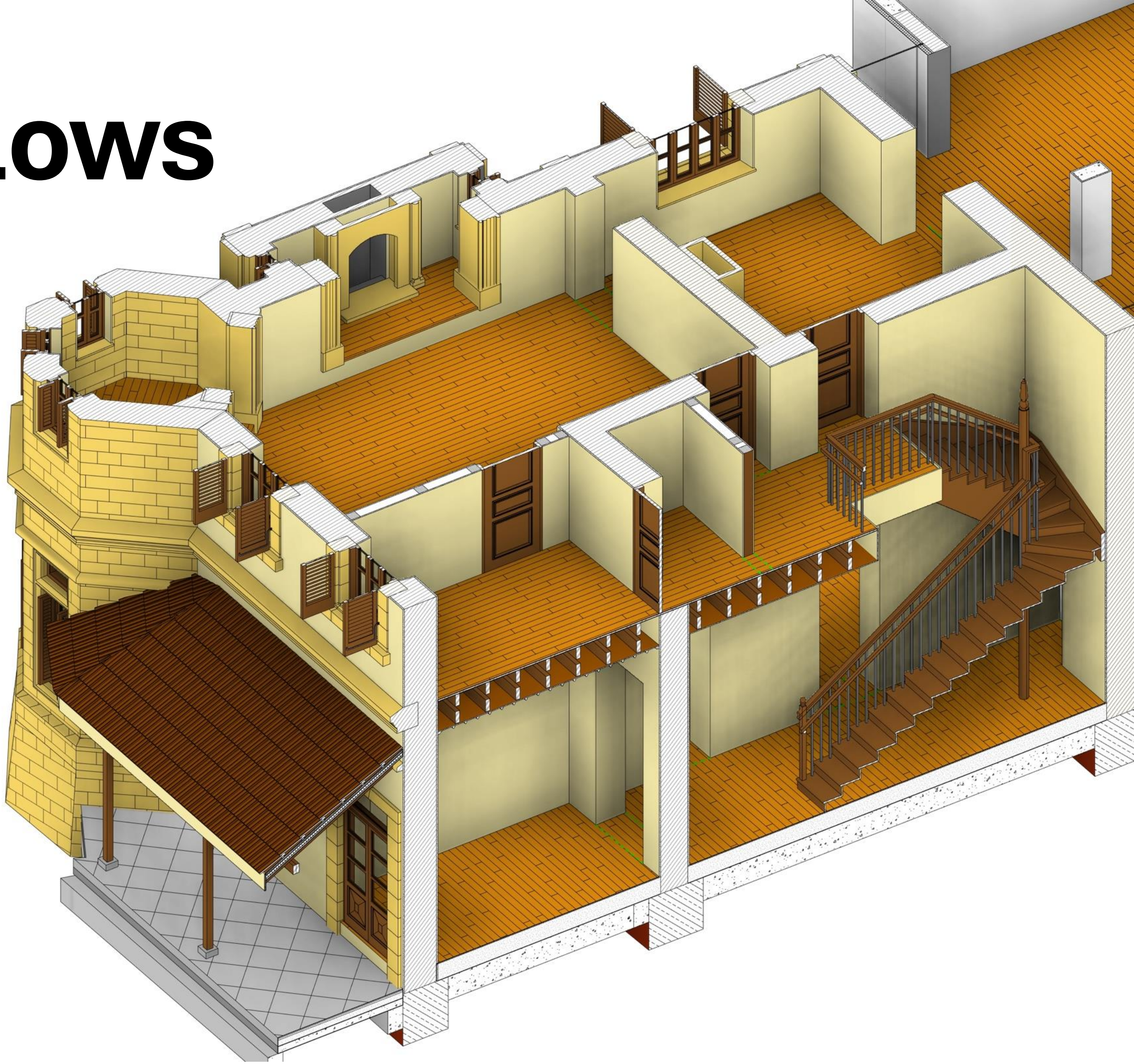
Unified Workflows

Leveraging BIM for Building Performance Simulation



Dr. Kristis Alexandrou

Associate Research Scientist

The Cyprus Institute (STARC)

30 Sept 2024

BIM & EU goals: Digitalisation of the construction sector

Grean Deal and Sustainability

Single Digital Market

Enhanced Collaboration

- Standardisation & Collaborative Platforms

Boosting Efficiency in the Public and Private Construction

- Supports modern construction techniques
- Financing mechanisms
- Public procurement

Compliance with EU Directives

- Energy Performance (EPBD)
- Environmental Regulations
- Data Management

Integration with emerging technologies

- IoT/ AI / Big Data
- Digital Twins

Cross-border Collaboration

- Remote collaboration

BIM impact on the AEC industry

- **Improved Collaboration and Communication**
  - Interdisciplinary cloud-based collaboration
- **Enhanced design planning and visualisation**
  - BIM dimensions and real-time changes
- **Reduced Cost and Time**
  - Supports modern construction techniques
  - prefabrication, modular construction, 3D Printing
  - Financing mechanisms
- **Life cycle management and maintenance**
  - Facility management / Digital twins / Smart buildings
- **Energy Efficiency**
  - Early design decision making
  - Energy modelling
  - Energy monitoring

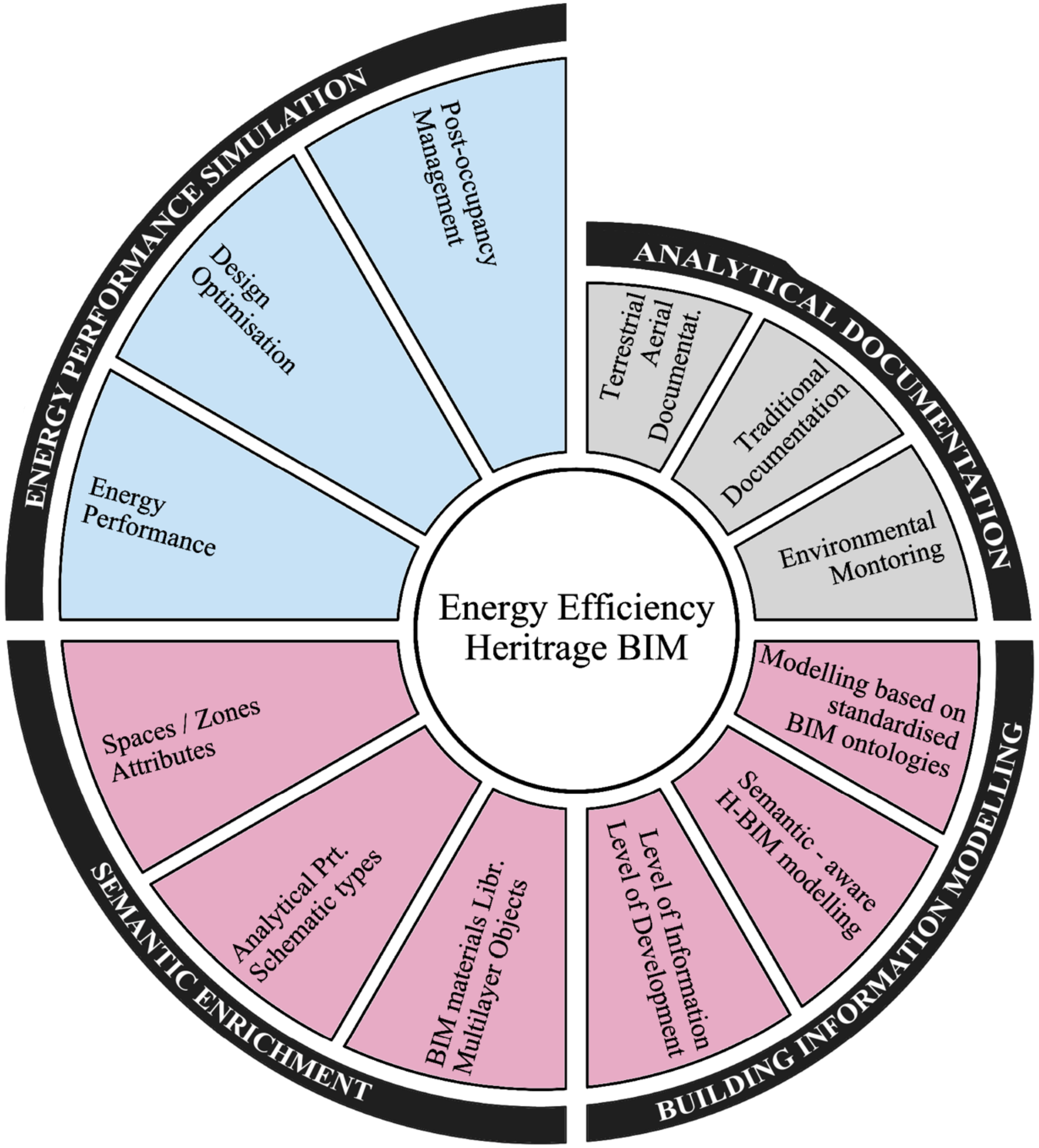
BIM for Energy Performance Simulation

➢ New Construction

Conceptual design impact	→	**Early-Stage Energy Analysis**
Thermal Zoning	→	Based on massing or early design models
Energy use analysis	→	Estimate of the building’s energy use per unit area
Solar and shading analysis	→	How much solar radiation hits different surfaces of the building at various times
Heating and Cooling Loads	→	Calculate peak heating and cooling loads based on building form, materials, climate data, and internal loads
Parametric design logic	→	**Examining architectural parameters** **Orientation, number and size of transparent envelope, building morphology, trees location etc.**

Heritage BIM for Energy Performance Simulation

- **Existing**



BIM for Energy Performance Simulation for Heritage Buildings

- Limited or unreliable data on building materials
- Ventilation and air leakage
- Regulatory and conservation requirements
- Complex geometry and structural features
- Irregular building components
- Thermal bridging
- Lack of standardized simulation tools for Heritage Buildings
- Customization and calibration needs
- Balancing Energy Efficiency with preservation
- Preserving aesthetic integrity
- Reversible non-invasive interventions

BIM for Energy Performance Simulation for Heritage Buildings

BEEP

ENI CBCMED
Cooperating across borders in the Mediterranean

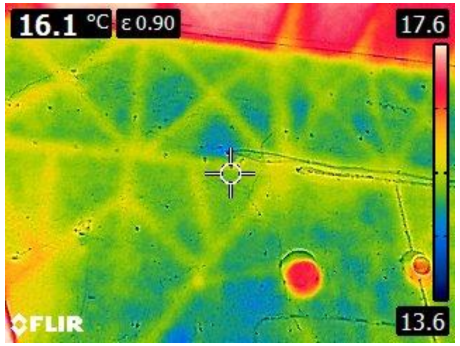
Project funded by the EUROPEAN UNION

REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA

BIM for Energy Performance Simulation for Heritage Buildings

Indoor environmental monitoring

- Emissivity of the interior coatings & identification of stratigraphy
- Thermal transmittance measurement



Outdoor Environmental monitoring

- Installation of weather station

BEEP

ENI CBCMED Cooperating across borders in the Mediterranean

Project funded by the EUROPEAN UNION

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Proprietary and OPEN BIM formats

1

LT

Trimble Connect

DataCAD

3

IFC

gbXML

2

eQUEST

EnergyPlus

DesignBuilder SOFTWARE

IES

Simulation software and the exchange schema

1

eQUEST

EnergyPlus

DesignBuilder SOFTWARE

IES

2

IFC®

gbXML

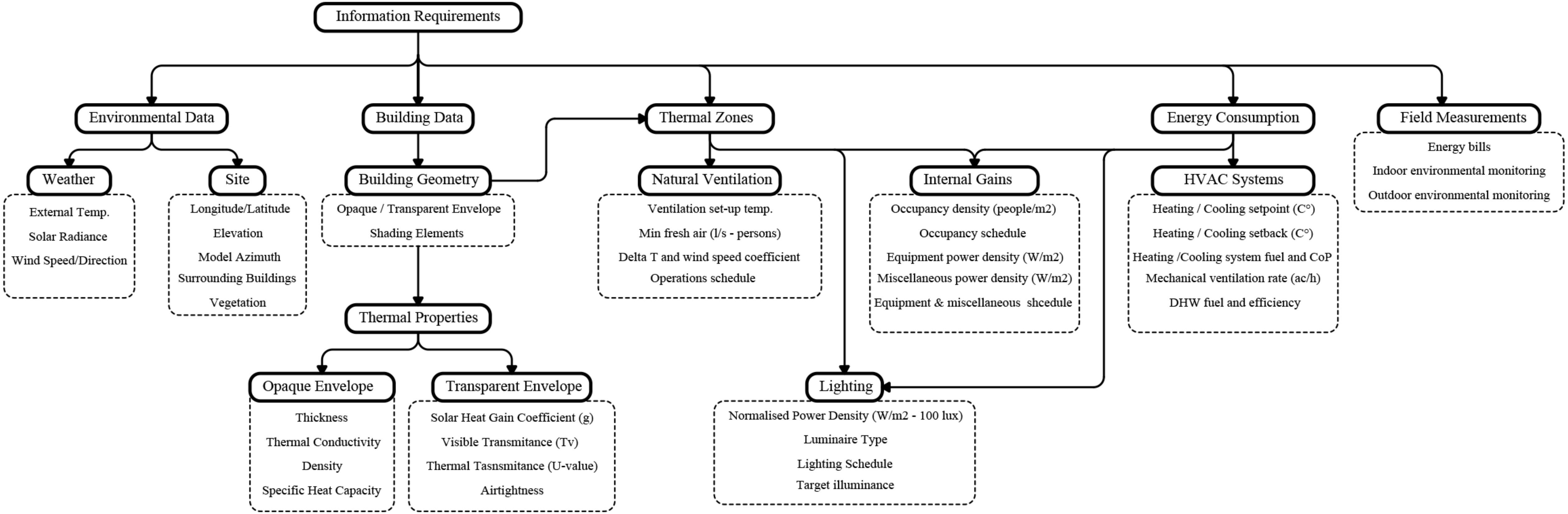
3

R LT

Trimble Connect

DataCAD®

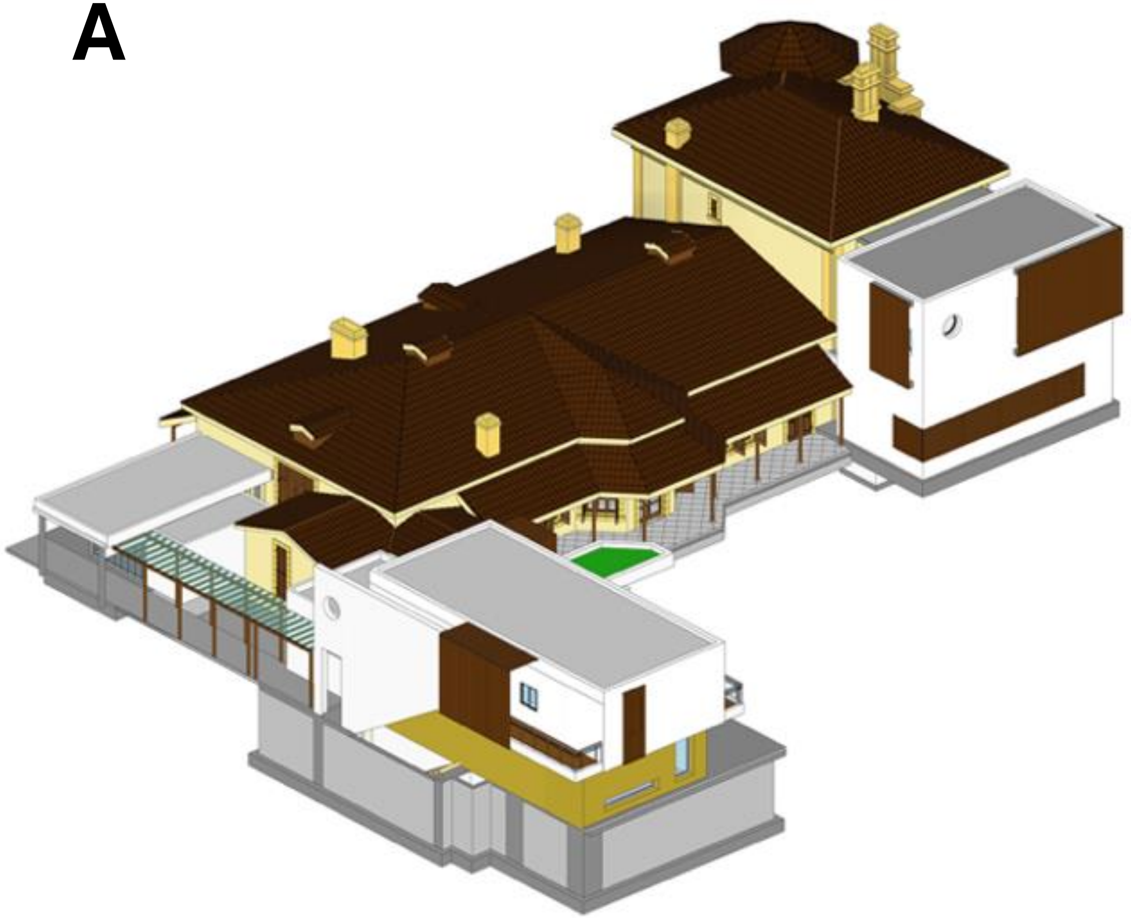
BPS information requirements



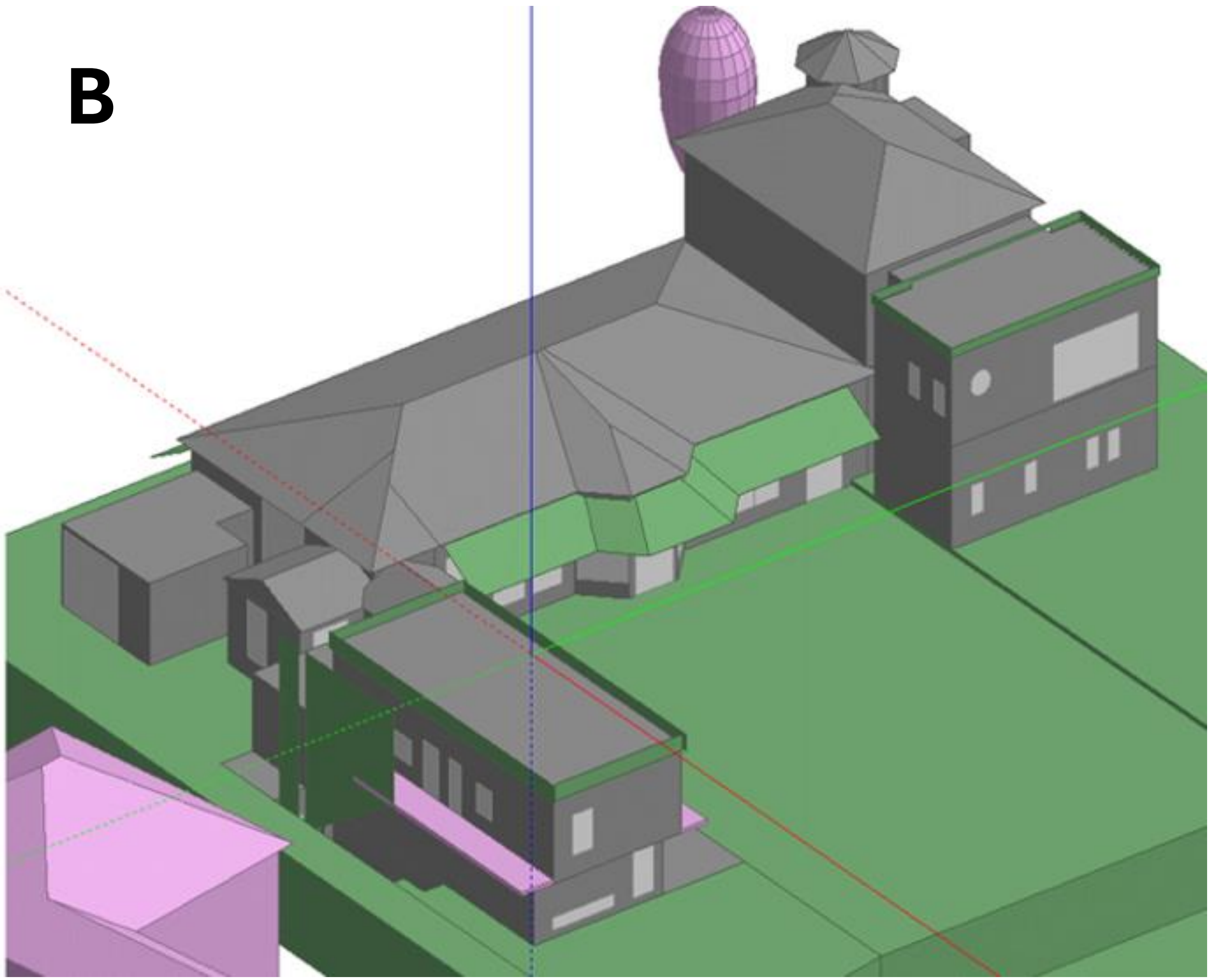
BPS information requirements

Geometric Conversion

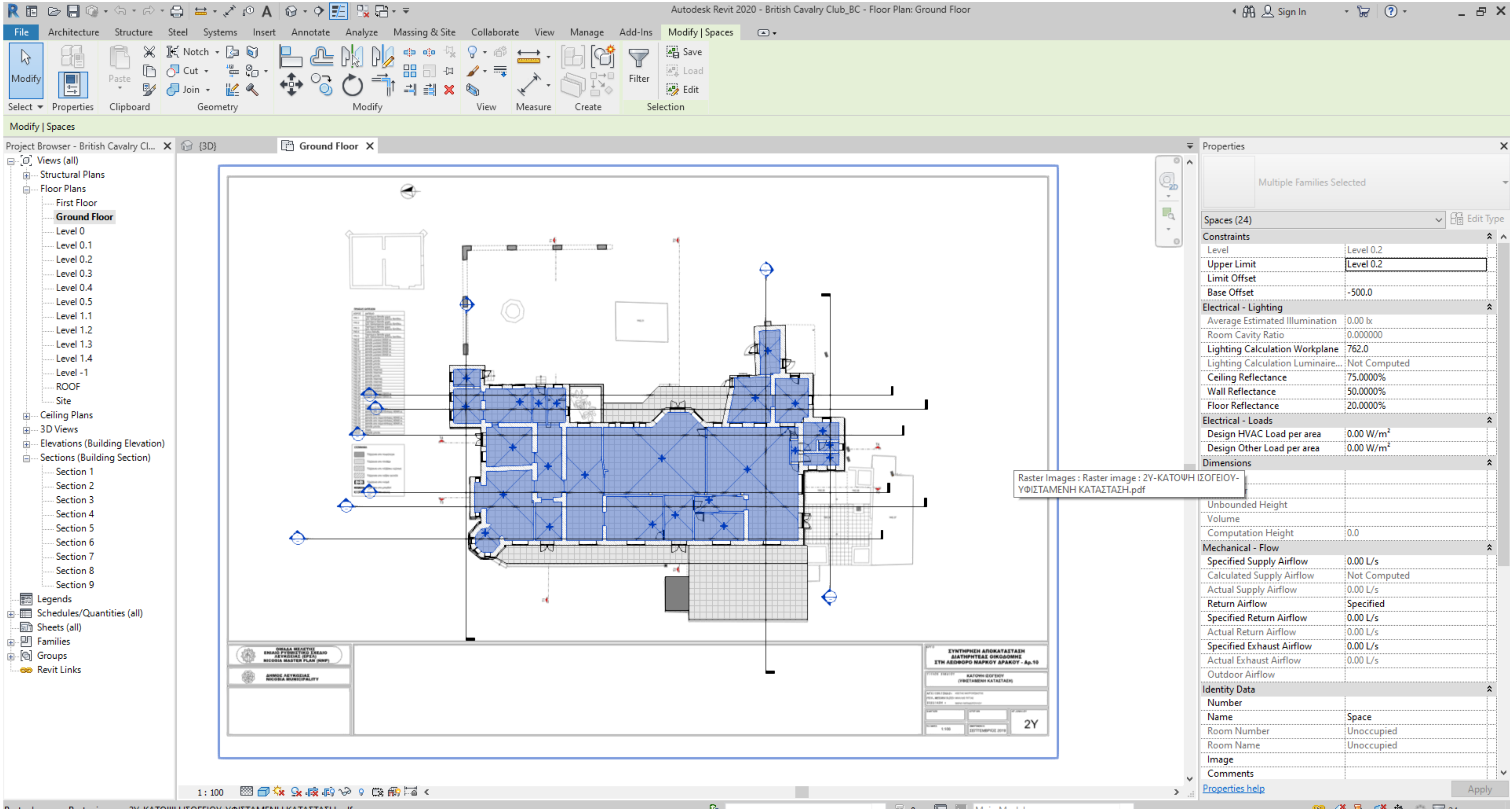
A



B



Geometric Conversion



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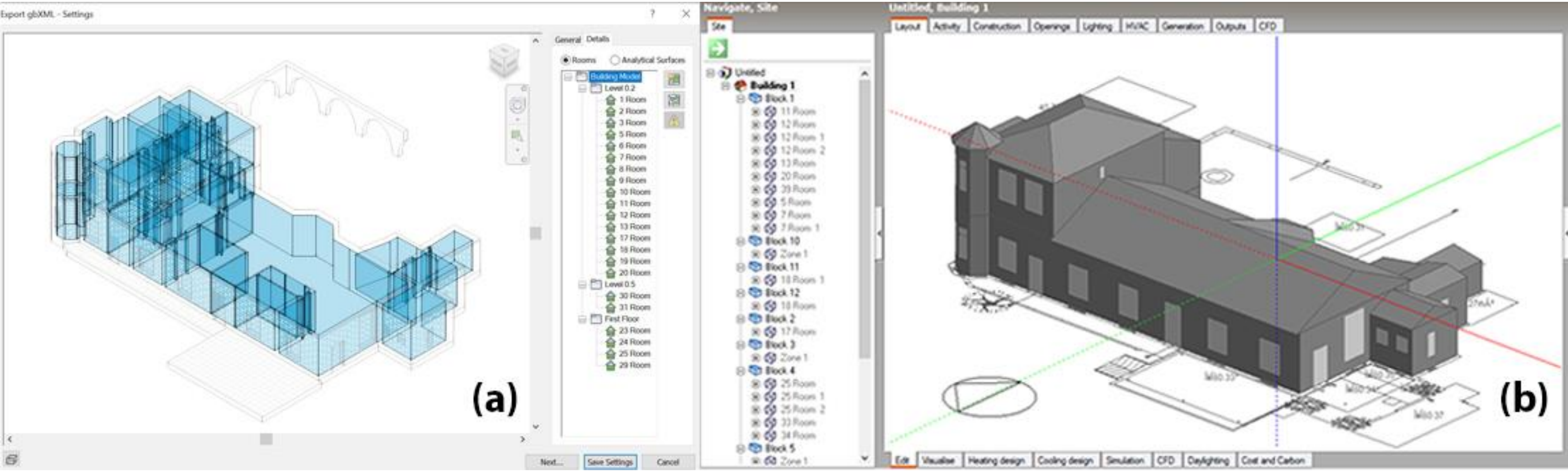

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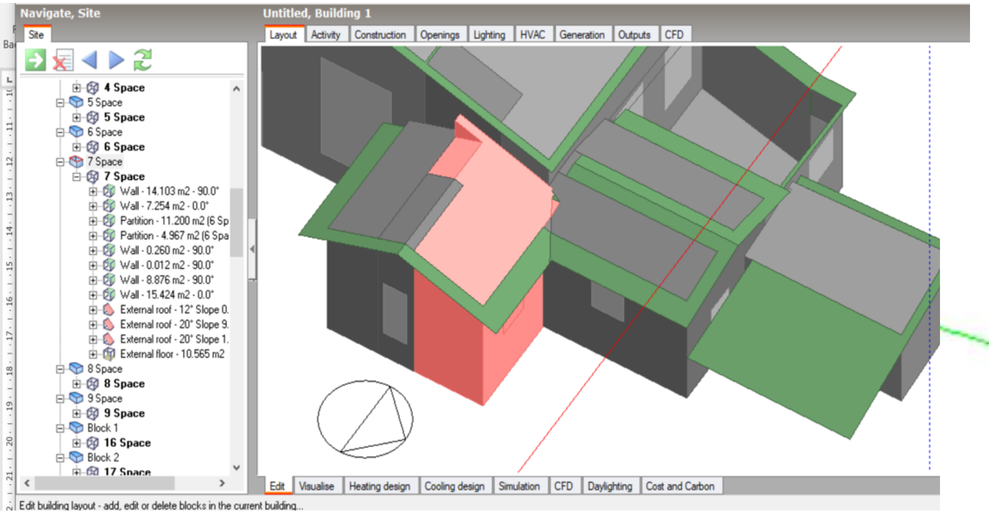
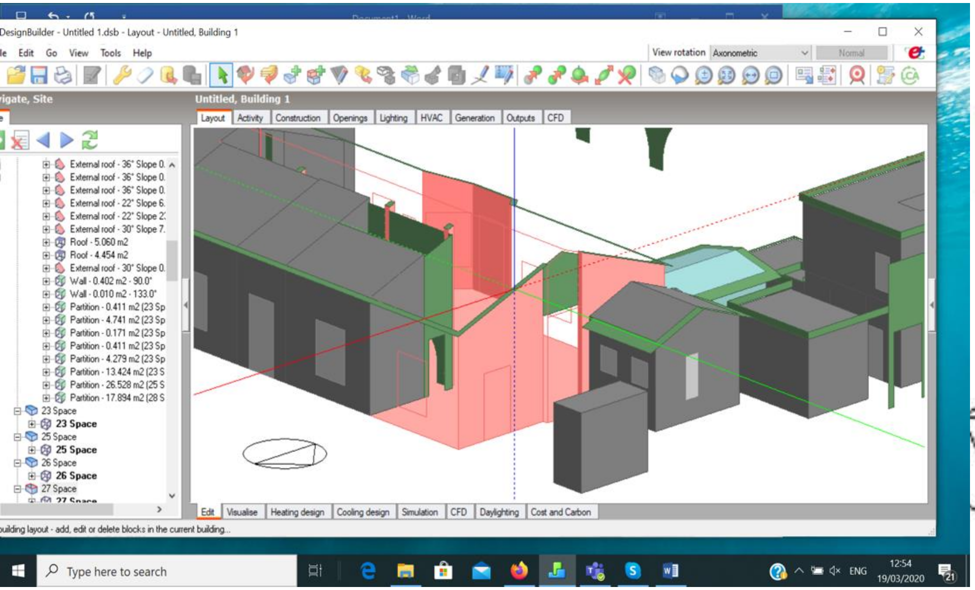
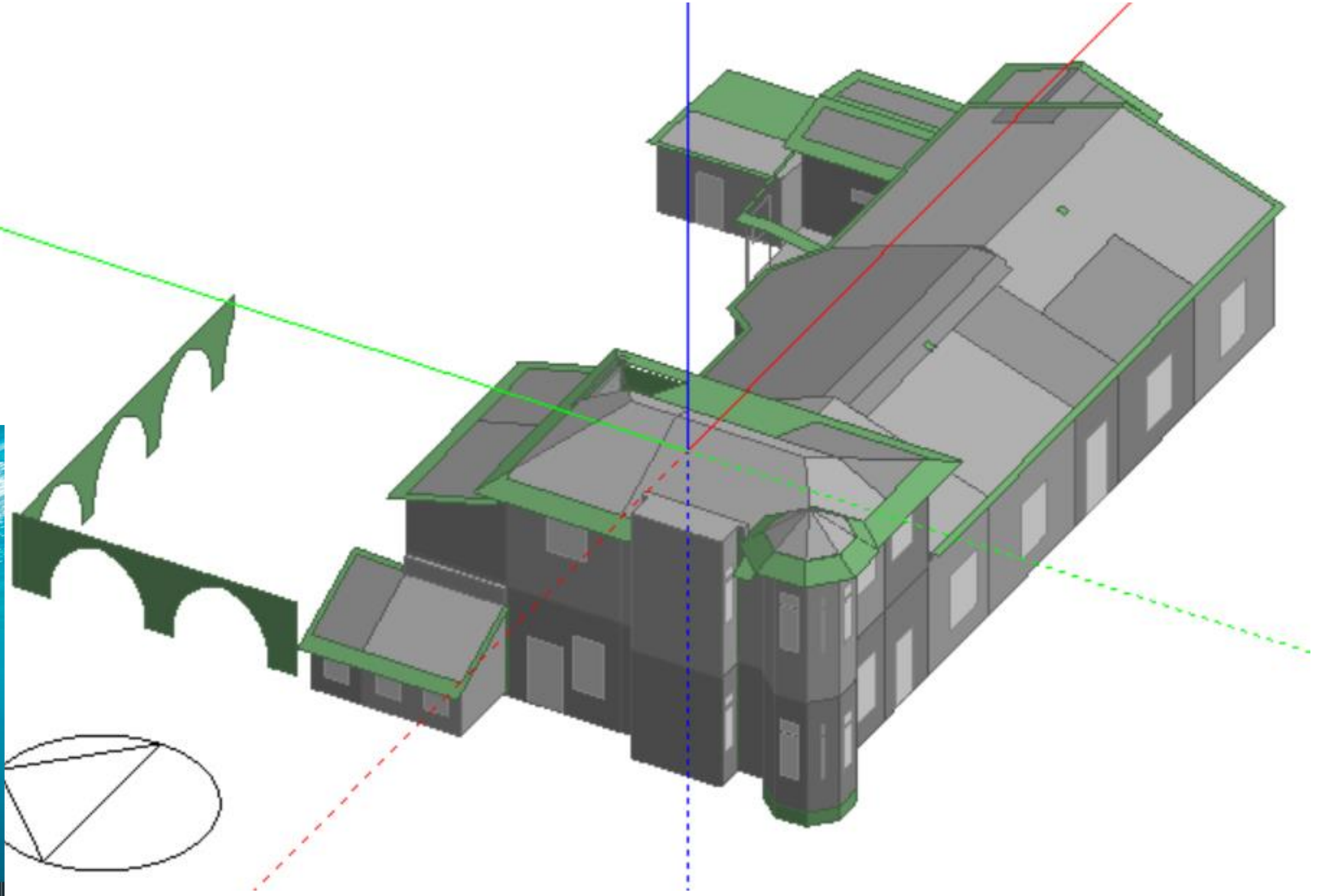
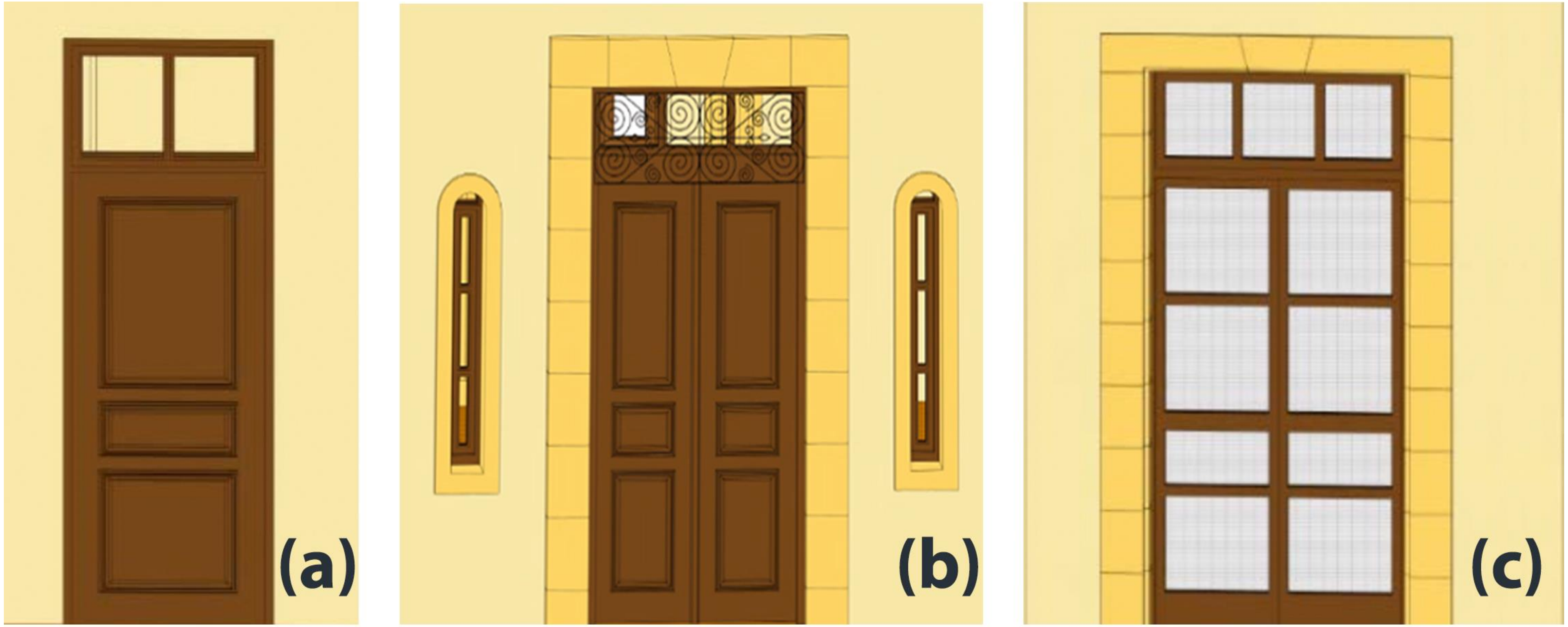






Geometric Conversion



Guidelines – Good Practices – Practical Solutions

- **Object simplification:** Architectural/structural elements serving aesthetic or non-critical functions (e.g., roof tiles, cornices, pediments, etc.) are identified as redundant and simplified for energy model export. Complex geometries are remodelled into regular polygonal shapes.

- **Segmentation & repair:** Irregular objects, such as curtain walls, complex structural elements, and curved objects, are decimated or separated into distinct objects to streamline segmentation and reduce repair time during energy model export.

- **Exclusion of non-essential elements:** Trees, vegetation, and some complex heritage objects (e.g., opaque doors with transoms) are excluded or remodelled for manual energy model adjustments post-export, optimizing the process.

- **BIM & BPS collaboration:** A simplified version of the BIM model is created in collaboration between the BIM operator and BPS expert, ensuring proper object segmentation and energy modelling alignment during export.

- **Ornamental and complex objects:** Decorative and complex objects are modelled separately, or excluded from the export process, to be manually adjusted later in the imported energy model, saving time and improving accuracy.

Guidelines – Good Practices – Practical Solutions

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Energy and environmental improvement of built heritage: HBIM simulation-based approach applied to nine Mediterranean case-studies

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[a]ISPC Institute of Heritage Science, CNR National Research Council, Montelibretti (RM), Italy; [b]EEWRC Energy, Environment & Water Research Center, The Cyprus Institute, Nicosia, Cyprus; [c]STARC Science and Technology in Archaeology and Culture Research Center, The Cyprus Institute, Nicosia, Cyprus

ABSTRACT
The architectural engineering and construction sector accounts for about 30-40% of global energy consumption. The European goal of reducing this consumption and the linked greenhouse gas emissions calls for an increased capacity to implement building renovations. Building Information Modelling (BIM) and Building Performance Simulations (BPS) are among the most promising tools for fostering interdisciplinary, efficient processes and feasible analysis and design solutions to support this goal. Of the whole building stock, heritage buildings represent the most challenging part, although their potential as a driver for mitigating climate change and supporting sustainable development is being increasingly recognized. This paper presents a Heritage BIM and BPS-based workflow to support the energy and environmental improvement of publicly-owned historical buildings, that was applied to 9 case studies of 7 different Mediterranean countries. The overall aim of this research is to enhance the capacity of public local administrations and professionals to upgrade the historical building stock and demonstrate the scalability of the proposed workflow to the entire building stock of the Mediterranean area.

ARTICLE HISTORY
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KEYWORDS
Built heritage; Heritage BIM; building performance simulation; energy efficiency; interdisciplinary approach; interoperability

Introduction

Building Information Modelling and Building Performance Simulation for the energy efficiency of the AEC sector

The building sector accounts for around 50% of global energy consumption, considering also the construction and demolition phases (Santamouris, 2016). In Europe, buildings are responsible for about 40% of total energy consumption and 36% of greenhouse emissions for their use (Renovation Wave Strategy, 2020; Hertwich et al., 2020; UNEP DTU, 2020). Also, refurbishment accounts for 59% of the total workload of architecture activities (Mirza & Nancy Research Ltd., 2017). The attention of Europe to the energy efficiency of the Architectural Engineering and Construction (AEC) sector is demonstrated by the Energy Performance of Buildings Directives (2002/91/EC, 2002; 2010/31/EU, 2010; 2018/844/EU, 2018). It has also received a recent boost from the adoption of the European Green Deal (EC, 2019), Next Generation EU (2020) and Renovation Wave initiative (2020), which aims to at least double the energy renovation rate of EU building stock by 2030. To achieve Climate Target Plan 2030 (2020), the EU Commission proposes to: reduce buildings' greenhouse gas emissions by 60% and their final energy consumption by 14%; introduce stronger obligations for energy performance certificates and mandatory minimum energy performance standards for existing buildings; extend the requirements to all public administration levels. This also calls for an increased capacity to implement such interventions (Renovation Wave Strategy, 2020). To this aim, Building Information Modelling (BIM) and Building Performance Simulation (BPS) are among the most promising tools.

BIM is defined as the shared digital representation of the physical and functional characteristics of a built asset, as well as the process to achieve such representation, combining geometric and alphanumeric information (ISO 19650, 2018; National BIM Standard buildingSMARTalliance, 2007). A BIM approach also encompasses a collaborative data-sharing environment, the Common Data Environment (CDE), that is a repository of files for collecting, organizing and disseminating models and documents among the actors involved (ISO 19650, 2018). The European Commission is interested in the capability of BIM-based processes to reduce costs and resources and is promoting BIM use in public

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Heritage-BIM for energy simulation: a data exchange method for improved interoperability

Kristis Alexandrou [a], Stavroula Thravalou [a] and Georgios Artopoulos [b]

[a]Energy, Environment & Water Research Center, The Cyprus Institute, Nicosia, Cyprus; [b]Science & Technology in Archaeology and Culture Research Center, The Cyprus Institute, Nicosia, Cyprus

ABSTRACT
The use of Building Information Modelling (BIM) for Building Energy Simulation (BES) is challenged by inadequate data integration and unreliable data and geometry conversion. Despite recent efforts to address critical interoperability issues, the effective exchange of data between the two digital environments remains a non-truly fulfilled promise of the digital transformation agenda for the industry. To contribute to the broader community effort in mitigating this deficiency, the present article proposes an alternative method for securing an improved BIM to BES workflow for existing and heritage buildings. The proposed method suggests an alternative way for integrating environmental analysis data to the Heritage BIM model, as well as an easy to develop visual programming process for missing data recovery, through auxiliary exchange operations. The article also presents lessons learned for the geometrical conversion of BIM elements with non-standard and irregular attributes, evaluated through the energy retrofit application of a colonial heritage building. The proposed method demonstrates how visual programming tools and common data exchange formats can supplementary assist existing practises to deal with major interoperability obstacles. The overall findings contribute to current efforts in the field, for the establishment of good practices of using Heritage BIM for energy retrofit architectural interventions.

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Received 3 January 2023
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KEYWORDS
Heritage Building Information Modelling (H-BIM); Building Energy Simulation (BES); energy retrofit; green building extensible markup language (gbXML); interoperability

Introduction

The energy footprint of the building sector

Building refurbishment is responsible for 59% of the total workload of architectural operations (Mirza & Nacy Research Ltd, 2017). Meanwhile, the improvement of energy performance has become one of the key objectives of interventions in existing buildings. Deep renovation projects are promoted by the amended Directive for Energy Performance of Buildings (EPBD) and the ambitious Renovation Wave strategy, which forms a part of the European Green Deal agreement (European Parliament, 2018; Li et al., 2019). The action plan described in the strategy involves the financing of incentive measures to boost deep renovation and meet the objective of doubling the annual energy-retrofit rate of existing buildings by 2030. As estimated, there are 25 billion sqm of total useful floor space in the EU27, Switzerland and Norway (Economidou et al., 2011), which is distributed as follows: 50% north-western Europe, 14% central-eastern Europe, and 36% southern Europe. Within these numbers, there is a high percentage of historic buildings (built before 1945). Specifically, 30% in north-western Europe, 20% in central-eastern Europe, and 25% in southern Europe (Dol & Haffner, 2010).

In this context, the need for an integrated performance-based design and planning workflow is becoming a matter of paramount importance (Hetherington et al., 2011; Lewis et al., 2019). The use of integrated digital workflows enables the synchronous control and optimization of design parameters such as: Energy-Efficiency (EE), decarbonization and integration of Renewable Energy Sources (RES), life-cycle and circularity aspects, affordability, and indoor air quality, while also addressing aesthetics and architectural values (European Commission, 2020). It can also empower the use of new market opportunities and emerging incentives (Ringel, 2021). In new constructions, energy simulation during the early design stages is becoming a vital part of the process for reaching sustainable and low energy consumption design solutions (Bracht et al., 2021; Collin et al., 2017; Kim et al., 2015). A performance-based design methodology becomes even more critical for the energy retrofitting of existing and heritage buildings, as the result of this approach will directly

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Heritage BIM and Performance Simulation Interoperability: Methodological framework and comparison of two case studies

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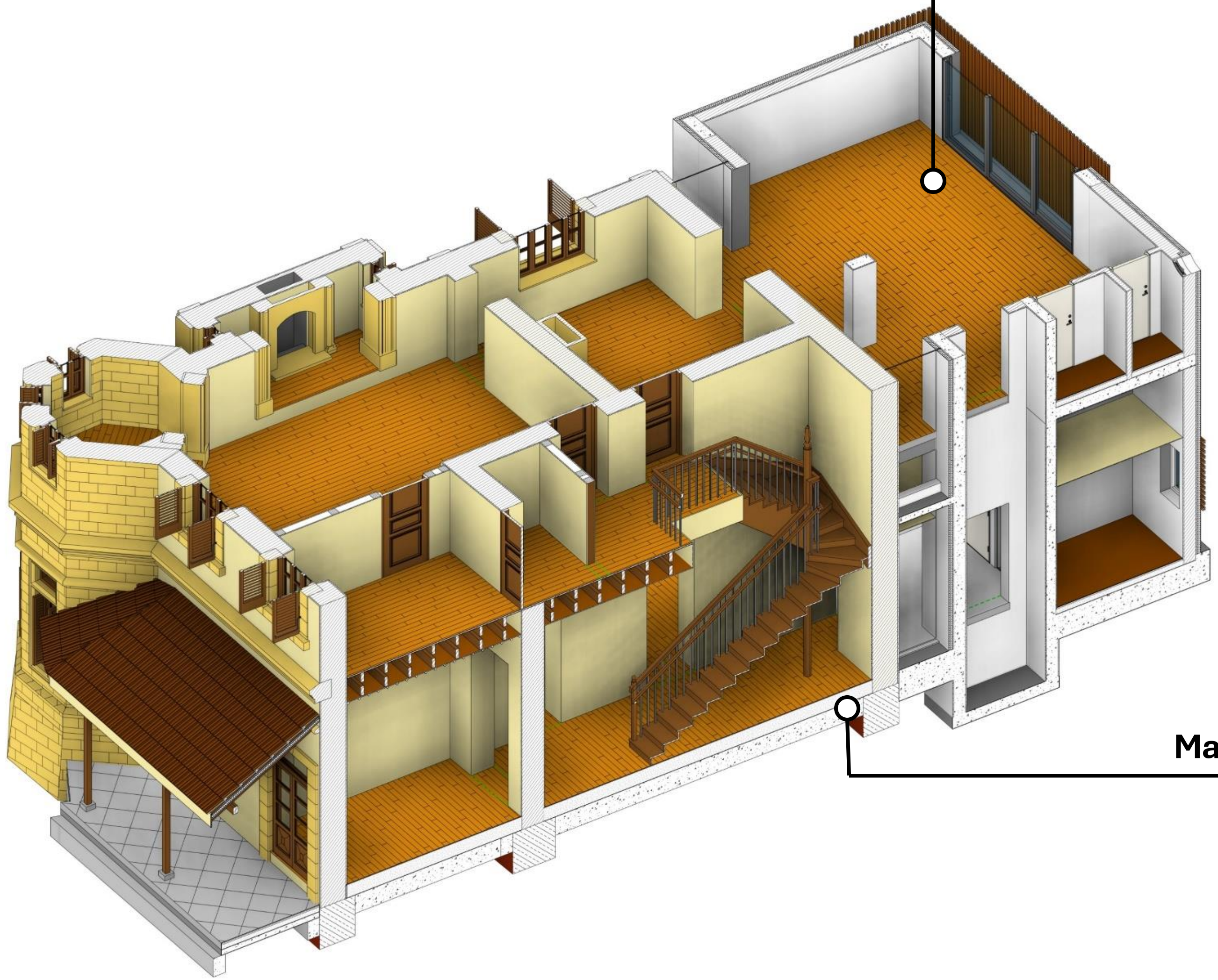
Abstract

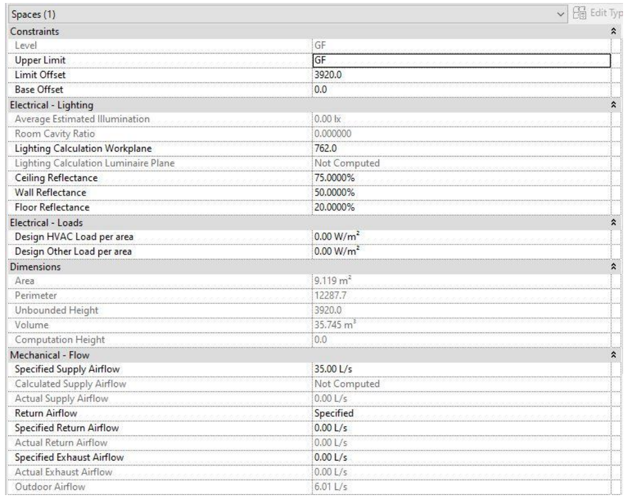
BIM advances for the AEC industry's digital transformation agenda is hindered by poor data interoperability with Building Performance Simulation (BPS) software. In an effort to identify the causes of this barrier and address possible directions to overcoming challenges, this paper presents two semi-automatic BIM to BPS workflows for heritage buildings, following the employment of the gbXML and the IFC exchange schemas respectively. Each workflow encompasses the integration of dynamic energy simulation data, as well as the conversion of morphologically complex geometries from BIM to the streamlined requirements of the respective numerical simulation engines. These parallel workflows are implemented and assessed through their application for the energy and environmental improvement of two heritage buildings, located in Cyprus and Italy. These buildings are studied as specific cases to drive the development of an energy simulation-based Heritage BIM (HBIM) workflow presented here. The findings of this research offer methodological insights into BIM data integration strategies and best practices in modelling for the schema-based workflows presented. Finally, the paper discusses impending methodological framework improvements, and it argues for the impact of specific roles and expertise on the process, in an effort to establish an adequate interoperability maturity level of BIM models in said operations.

Keywords: Heritage Building Information Modelling (HBIM); Building Performance Simulation (BPS); interoperability; green building extensible markup language (gbXML); Industry Foundation Class (IFC)

Data Exchange

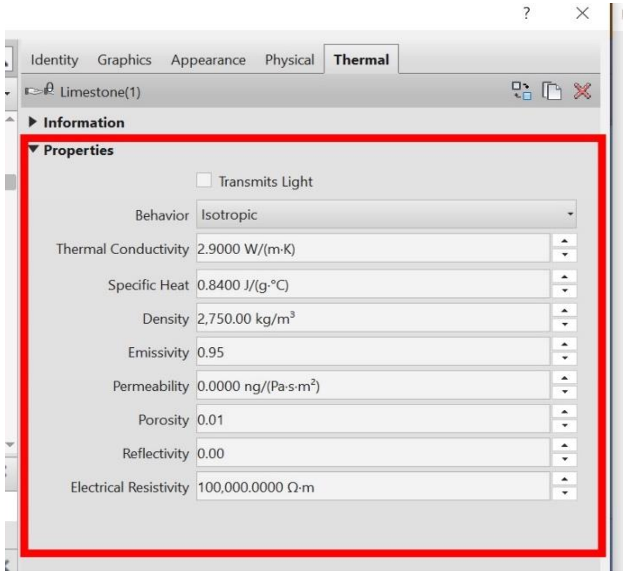


Space properties



Spaces (1)	
Constraints	
Level	GF
Upper Limit	GF
Limit Offset	3920.0
Base Offset	0.0
Electrical - Lighting	
Average Estimated Illumination	0.00 lx
Room Cavity Ratio	0.000000
Lighting Calculation Workplane	762.0
Lighting Calculation Luminaire Plane	Not Computed
Ceiling Reflectance	75.0000%
Wall Reflectance	50.0000%
Floor Reflectance	20.0000%
Electrical - Loads	
Design HVAC Load per area	0.00 W/m²
Design Other Load per area	0.00 W/m²
Dimensions	
Area	9.119 m²
Perimeter	12287.7
Unbounded Height	3920.0
Volume	35.745 m³
Computation Height	0.0
Mechanical - Flow	
Specified Supply Airflow	35.00 L/s
Calculated Supply Airflow	Not Computed
Actual Supply Airflow	0.00 L/s
Return Airflow	Specified
Specified Return Airflow	0.00 L/s
Actual Return Airflow	0.00 L/s
Specified Exhaust Airflow	0.00 L/s
Actual Exhaust Airflow	0.00 L/s
Outdoor Airflow	6.01 L/s

Material properties



Identity Graphics Appearance Physical **Thermal**

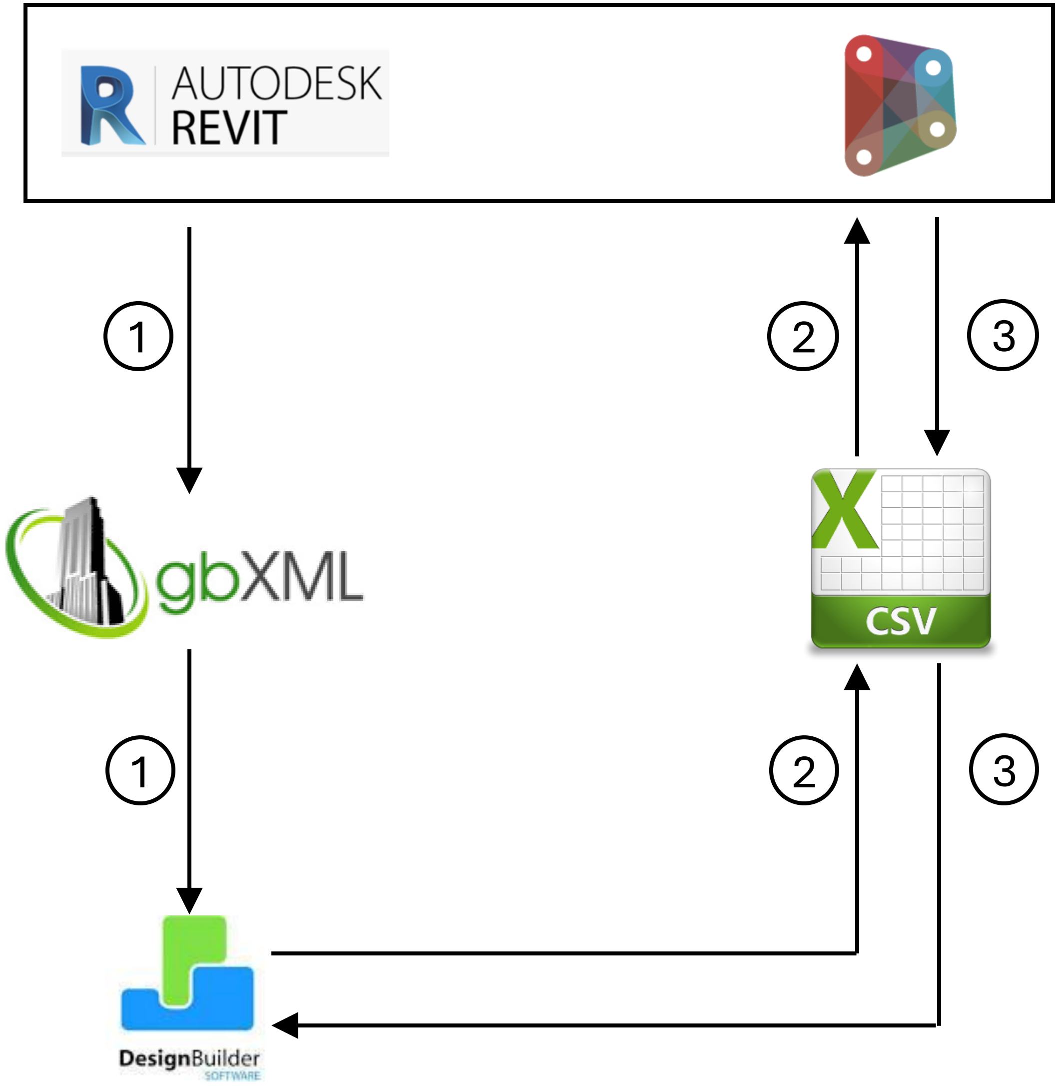
Limestone(1)

Information

Properties

	Transmits Light
Behavior	Isotropic
Thermal Conductivity	2.9000 W/(m·K)
Specific Heat	0.8400 J/(g·°C)
Density	2,750.00 kg/m³
Emissivity	0.95
Permeability	0.0000 ng/(Pa·s·m²)
Porosity	0.01
Reflectivity	0.00
Electrical Resistivity	100,000.0000 Ω·m

Data Exchange

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  <Description>CYI_ARCH_ExteriorDoor_E1a</Description>
  <LayerId layerIdRef="lay-OakDOOR"/>
  <U-value unit="WPerSquareMeterK">2.33</U-value>
</Construction>
<Layer id="lay-OakDOOR">
  <MaterialId materialIdRef="mat-Oak"/>
</Layer>
 <Material id="mat-Oak">
  <Name>mat-Oak</Name>
  <Description>mat-Oak</Description>
  <Thickness unit="Meters">0.05</Thickness>
  <Conductivity unit="WPerMeterK">0.19</Conductivity>
  <Density unit="KgPerCubicM">700</Density>
  <SpecificHeat unit="JPerKgK">2390</SpecificHeat>
</Material>
```

Guidelines – Good Practices – Practical Solutions

Material Thermal Properties Assignment

- Thermal properties (e.g., conductivity, specific heat, density) assigned to multi-layered BIM objects.
- Complex envelopes like doors/windows had thermal properties manually defined via the "schematic type" method in Revit.

Spaces and Thermal Zones Creation

- Revit "spaces" and "thermal zones" were created to capture data on lighting, natural ventilation, internal gains, and HVAC systems.
- Dynamo code was developed to export BIM zone data into CSV format for manual import into Design Builder due to gaps in gbXML exchange.

Metadata Limitations

- Revit lacks customization for lighting and occupancy schedules between weekends and weekdays; input resolution is too low for accurate energy consumption analysis.
- Frame & Glazing Conversion Issues
- gbXML export does not properly capture transparent envelope frame and glass percentage; manual corrections are needed in Building Performance Simulation (BPS) software

Overall Interoperability Evaluation

Technical documentation

- Drafting of reports.

Infra-Red thermography

- Processing of IR images and drafting of a report to support wall characterization and HFM analyses.

HFM analysis for the opaque envelope

- Processing with HFM software and drafting of a report containing the hypothesis of the stratigraphy of the building walls analyzed and of the related construction materials.
- Needed. For complex building components, U Value calculations are performed manually.

Transparent envelope analysis

- Geometric survey, field surveys, notes, sketches and definition of a window schedule.
- Needed. Calculations for the total U Value of transparent objects are performed manually

Indoor Environmental monitoring

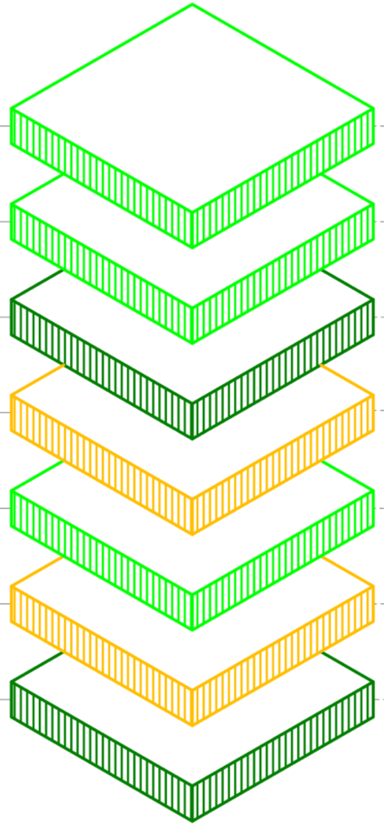
- Processing of the data collected, mainly through spreadsheets and graphs.

Active system analysis

- Processing of data according to the renovation proposal and technical documentation of the HVAC systems.
- Needed.

Occupancy and systems schedules analysis

- Processing of data according to the renovation proposal and end-user occupancy.
- Needed.

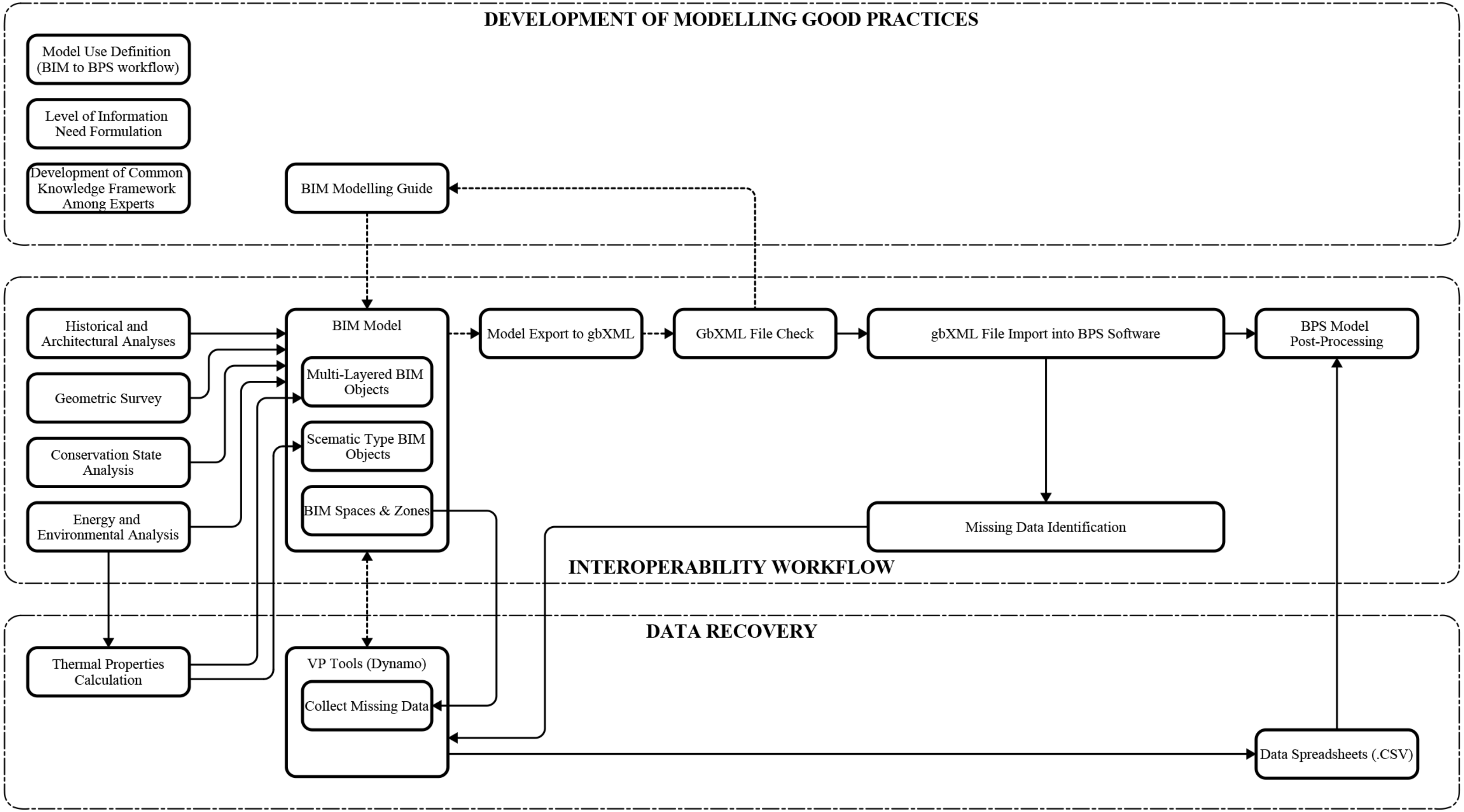


- Possible. Reports are integrated in the form of Portable Document Format.
- Possible. Selected IR images are integrated into the BIM model elements as textures to assist the evaluation and decision making of the rehabilitation measures.
- Possible. Measured and calculated U Values are manually inserted into the constructions.xml file. These are then directly recognized in the BIM environment and assigned to BIM object's analytical properties.
- Possible. Calculated U Values are manually inserted into the constructions.xml file. These are then directly recognized in the BIM environment and assigned to BIM object's analytical properties. In the case of complex transparent objects are exempted and directly modelled in the BPS software instead.
- Possible. Reports can be integrated in the form of Portable Document Format.
- Integration of active systems data are not evaluated in this study. These are modelled directly in the BPS software.
- Possible, however, Revit data input fields for schedules does not provide the necessary level of input detail compared to the respective BPS software. This information is transferred to the BPS simulation software using the auxiliary data recovery method developed by the team.

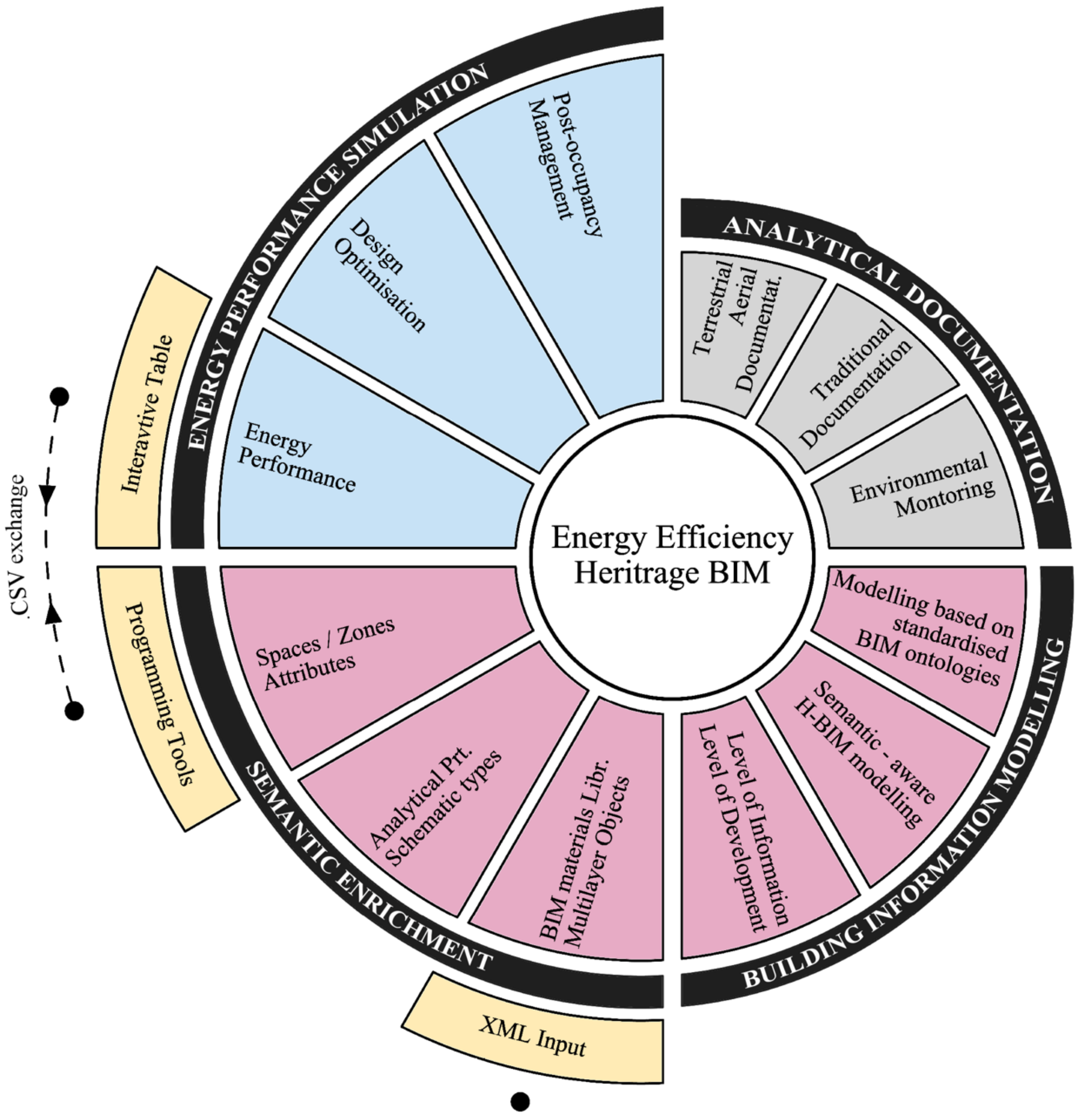
ENERGY AND ENVIRONMENTAL ANALYSIS DATA INTEGRATION TO BIM

- Raw data processing
- Elaboration of BPS input parameters
- Full integration
- Integrated with manual elaboration
- Limited integration / Not tested

Semi-automatic Workflow



Fully Automatic BIM to BPS Integration



- Avoid **unnecessary re-modelling** processes.
- Avoid **human-prone errors** during the transferring of information from one platform to another.
- Enables the full utilisation of **BIM parametric capabilities** for design optimisation.
- **Accelerate the planning phase** of a building.

Conclusions

- BIM models are highly detailed 3D elements, while Building Performance Simulation (BPS) models require simpler 2D planar surfaces, causing **inaccuracies during conversion.**
- The **default conversion traces detailed BIM** elements and simplifies them into planar surfaces, often resulting in offset gaps, especially with complex or non-uniform materials.
- **Collaboration between BIM operators and BPS experts** is essential to manage assumptions, simplify geometry, and maintain simulation accuracy.
- Well-identified objects causing discrepancies **can be excluded from export**, requiring manual adjustment post-import for precision.
- The **gbXML schema** struggles to effectively store space and thermal zone data, impacting data exchange reliability.

Built Heritage

- **Historical climatic adaptation**

  Many heritage buildings were designed with passive climate control strategies tailored to the local environment, such as thick walls for thermal mass or specific window placements to maximize ventilation.

- **Climate change and modern expectations**

  Heritage buildings may face increased energy demand due to changing climate conditions, such as hotter summers or colder winters, which were not anticipated in the original design. Simulating energy performance under these new conditions requires adaptation of traditional building methods to meet modern comfort standards.

Successful Exchange & Future Research

Key Factors for Success

- Effective interdisciplinary collaboration
- Strategic simplification of complex geometries
- Customised workflows are essential to ensure accurate simulations

Future Research Focus

- Better geometry optimisation
- Enhanced BIM tools to address current limitations, i.e., Improving energy data integration, transparent envelop design (complex fenestration modelling)