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A BIM interoperable process for energy efficiency control in existing buildings

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As energy costs continue to rise, businesses need smarter energy management strategies. This paper starts with several definitions, then it discusses a method to help define a smart energy efficiency strategy in existing buildings by IT systems without realizing civil works. This method aims to develop an efficient and user-friendly Facility Management process based on Building Information Modelling and Interoperability. The case study is the Politecnico di Torino campus and the objective is to obtain a theoretical model that can be applied to wide typologies of existing buildings in Europe. In the first stage of the current research, software tools were tested and the results are shown to lead to an accurate definition of a digital model of buildings, lighting and HVAC systems that can be used in Facility Management. Preliminary results indicate that there is a possibility of obtaining smart solutions if a holistic approach is clearly defined.

Keywords*: energy efficiency, building information modelling, interoperability, 3D parametric model, facility management*

1 Introduction

The EU Energy Performance of Buildings Directive focuses on cutting energy use by 20 per cent by 2020 as a crucial element into achieving climate stabilization. The mandate is clear and must be applied also to building performance. By the use of IT technologies, opportunities exist to improve the energy performance of most existing buildings.

Several studies in recent years show that tedious manual data input for building energy performance and consumption simulation diverts time and resources from productive simulation runs, also because of the fact that data defining a building, its heating, ventilation and air conditioning (HVAC) and lighting systems and its expected pattern of use and operating schedules, is managed by different and non-interoperable software. By utilising Building Information Modelling as a data source and interoperability as format exchange for energy analysis, the data input will be more efficient and the existing data more reusable. Unfortunately, at present the BIM methodology and interoperability are still mostly used by researchers, but not widely by practitioners in building projects and management. The reason is the functional limitation of the available tools, although new software packages are daily booming.[3]

Before presenting this work and to introduce the topic, a necessary set of definitions is given about BIM and Interoperability, Energy efficient buildings and BIM-based Facility Management (FM).

Building Information Modelling is one of the most promising developments in the Architecture, Engineering and Construction (AEC) industries because it helps building owners and managers throughout a structure's life-cycle by providing visual context to performance-related data, retrofit plans and other

1 DISET - Building Engineering and Territorial Systems
2 DAUIN - Control and Computer Engineering
3 McGraw-Hill Construction (2010). The Business Value of BIM in Europe. Getting Building Information Modelling to the Bottom Line in the United Kingdom, France and German, p 4

projects intended to increase energy efficiency. As an enormous diversity of data is involved in existing buildings, the BIM methodology assists operators in capturing the building geometry and characteristics needed to conduct various aspects of architecture, structure and energy performance analysis, in relation with management activities. In this way, for example, a basic model can be created with the BIM process and used to support energy and investment-grade audits. Unfortunately BIM tools do not support easy modelling each kind of existing buildings - particularly historical - and existing data models still miss most concepts needed for energy efficiency analyses. Therefore IT plays an essential role in providing support to collaborative interoperable design and planning in a range of engineering tasks over the building life-cycle.

Software ***interoperability*** is seamless data exchange at the software level among diverse applications, each of which may have its own internal data structure. It is achieved by mapping parts of each participating application's internal data structure to a universal data model and vice versa. In our research we use interoperability for exchanging information and using the information that has been exchanged, allowing multiple experts like Architects and Engineers to work together. This is a crucial concept in the BIM process.

Energy efficient buildings is a broad and multidisciplinary domain and as is clearly described in a public REEB deliverable,[4] the increasing complexity of the buildings and the need of increasing their energy performances, create an ever-increasing demand of IT tools that make possible: a) more agile collaboration among the multiple stakeholders that interact through the building life-cycle; b) the interoperability among the increasing number of IT tools and energy management systems that are used during the building life-cycle for its design and operation (by architects, users, etc.) and its relation with external stakeholders (like utilities, local authorities, etc.); c) sharing the knowledge that is generated during the building's life-cycle.

The energy efficiency building should be managed in a holistic way through the seamless integration of the IT tools that are used in the different stages of the building life-cycle (definition, realization and usage), both in off-line and real-time processes, in such a way that the building becomes an active component in the energy networks. Therefore optimisation of energy efficiency in buildings means only using energy when it is really required and with real-time control, applying the energy that is used with the highest possible efficiency.

The utilization of intelligent concepts is what makes energy intelligent, and it is the heart of energy-efficient technologies. Through a general *BIM-based Facility Management* and energy-intelligent control, regulation and communication, researchers expect improvements in energy yield. This is exactly the field that the *Smart Energy Efficient Middleware for Public Spaces* (SEEMPubS)[5] project is working on, because this research has essentially three objectives:

- Develop an *integrated electronic system and interoperable web-based software solution* for real-time energy performance monitoring and control of HVAC and lighting services through wireless and wired sensor networks in historical and existing buildings.
- Significantly raise people's awareness for energy efficiency in public spaces on the basis of the management philosophy of the *integrated facility*. The system will provide multidimensional visualization (BIM-based) of parameters of

4 **REEB**. European strategic research Roadmap to IT enabled Energy-Efficiency in Buildings and constructions. D4.2 Strategic Research Roadmap for IT supported Energy Efficiency in Construction, p 54 [www.IT-reeb.eu]

5 **SEEMPubS** (2010). Smart Energy Efficient Middleware for Public Spaces. FP7 Collaborative project. Coordinator: Politecnico di Torino (Enrico Macii). Partners: ST Microelectronics, Centro Ricer-che Fiat, Fraunhofer FIT, CNet Svenska AB, Katholieke Universiteit Leuven, Universitè Claude Bernard Lyon 1, Sinovia SA, Istituto Superiore Mario Boella [seempubs.polito.it]

building operations and data sharing from energy-consuming equipment and appliances.

- Define clear *standards* and *models* for existing buildings and public spaces in Europe starting from the most significant research results achieved through the project.

The project SEEMPubS started on September 2010 and therefore it is impossible to provide final results in order to compare them with other research projects. On the other hand the methodology supporting the multidisciplinary BIM process can be revealed in order to define preliminary standards on 3D parametric model, data, interoperable formats, workflow, tools, and more. However, older work results can be shown because they represent a significant base for the SEEMPubS proposal.[6]

The starting point is the set of “Senate Properties’ Building Information Model Requirements 2007”[7] and the main references are the Industry Foundation Classes (IFC) as open and neutral data formats based on ISO STEP for open BIM.[8] They are constantly under implementation by the International Alliance for Interoperability (IAI) in order to create a comprehensive, multidisciplinary and intelligent data model of buildings that defines data throughout a building’s life cycle. Secondly, the National Building Information Modelling Standard developed by the National BIM Standard organization that represents one of the most significant works in this field.[9] Moreover, in the United States, from 1992 to 2008 the Facility Information Council (FIC) worked on improving the performance of facilities over their full life-cycle by fostering common and open standards and an integrated life-cycle information model for the Architecture, Engineering and Construction & Facility Management (AEC&FM).[10] More recently the US Army presented at the National Institute of Building Sciences (NIBS) Annual Meeting the Energy Information Exchange (ENERGie) project. The goal of this project is to harmonize the requirements of Green Building XML (gbXML) and the building elements of LEED within the context of an EnergyPlus compliant Model View Definition to provide a single life-cycle oriented exchange of energy analysis information.[11]

Because in Europe 80% of the 2030 building stock already exists and today 30% of existing buildings are historical buildings,[12] retrofitting buildings one by one will never solve climate change problems, therefore the adoption of a *holistic approach*, considering technological aspects and technology integration, as well as the user will become the key for successful project impact, as shown in this paper.

2 Methodology

Starting from existing buildings, the current investigation involved a multidisciplinary approach analysis and modelling of an enormous and heterogeneous quantity of data about architecture, energy and management above all, testing the BIM process and the interoperability among different applications. The target is two-fold: to help the set-up of existing tools and the improvement of the use of new IT in both education and professional activities.

Obviously, for this research the selection of a significant case study is essential because it allows testing and handling qualitative and quantitative data in different terms. The Politecnico di Torino campus was selected because it

06Chiaia B., Cangialosi, G., Lo Turco, M., Osello A., Vitali M. and **Vozzola M.** (2008). 3D project: Politecnico di Torino is moving to BIM, in IV Seminario Internacional de Ingenieria Civil, Hidraulica y Geociencias SICHGEO, La Habana, Cuba, pp 36-43

07 www.senaatti.com/document.asp?siteID=2&docID=588

08 buildingsmart tech.org

09 www.facilityinformationcouncil.org/bim/index.php

10 /www. buildingsmartalliance.org/index.php/nbims

11 www.buildingsmartalliance.org/index.php/newevents/proceedings/energie09

12www.ectp.org

represents a significant mix of construction periods, typologies, sizes, technologies, materials, lighting and HVAC systems, conditions and uses.
A holistic approach was adopted and an iterative methodology was tested in order to define a 3D parametric model that could be used for energy efficiency control in FM using interoperability. This is one of the most important fields included within BIM that requires a change in both AEC industry and education because it is a typical example of a multidisciplinary activity that requires a new way of looking at the building, introducing the database concept, and clarifying that drawing and tables are just different ways of looking at the same database. Also, this case study highlights the potential of extracting certain data about the building that can be directly used in another application for analysis. Evidently this is a crucial point for the future because training for students, for architects and engineers should consider a significant change in the process from design to management of a building.
In short, as demonstrated with this case study, the user of a BIM application should start thinking about the building more than thinking about drafting.

2.1 Case Study: the Politecnico di Torino campus

The campus buildings that were selected in this research are located in three different sites in Turin, each one with different specificity as shown in Figure 1. The short description below helps to understand the main features of each building and the reason of their representativeness as examples of a wide range of similar existing and historical buildings in Europe.

- The *Valentino Castle* is the historical seat of Politecnico and today is the campus for the Architecture Faculties. Its origins date back to the beginning of the 16th century; in 1564 it was purchased by Emanuele Filiberto of Savoy. Then king Carlo Emanuele I ceded it to Maria Cristina of France, who chose it as her favourite residence and stayed there with her court for a long time. The castle was completely restored from 1621 to 1660 by Carlo di Castellamonte and then by his son Amedeo. It has two different façades: the main one, facing the city, has the architectural features of XVII century French castles and Italian baroque buildings, while the one facing the river Po is made of fired bricks. Two grand staircases lead to the first floor, where thirteen rooms with their rich stuccos and commemorative allegorical fresco paintings are the evidence of the ancient splendour of the 17th century. This site is approximately 20.000 m^2.
- The *Corso Duca degli Abruzzi site* (named Main Campus in this paper) is the campus for the Engineering Faculties. It was inaugurated in November 1958 and its aesthetics is based on the rigour of its lines. All the buildings on this site were built in relation to their use: the heavy laboratories, with their factory-like function, have metal or concrete structures, while the other ones (classrooms and offices) are concrete only. The lining of the main building is stone, while the other is ceramic brick. This site is approximately 70.000 m^2.
- The *Cittadella Politecnica site* is the research centre of Politecnico and derives from a complex refurbishment (almost complete) of a former industrial area. It includes the area’s most interesting industrial buildings that were regained and new buildings that were built demolishing other less appealing structures. This site is approximately 100.000 m^2.

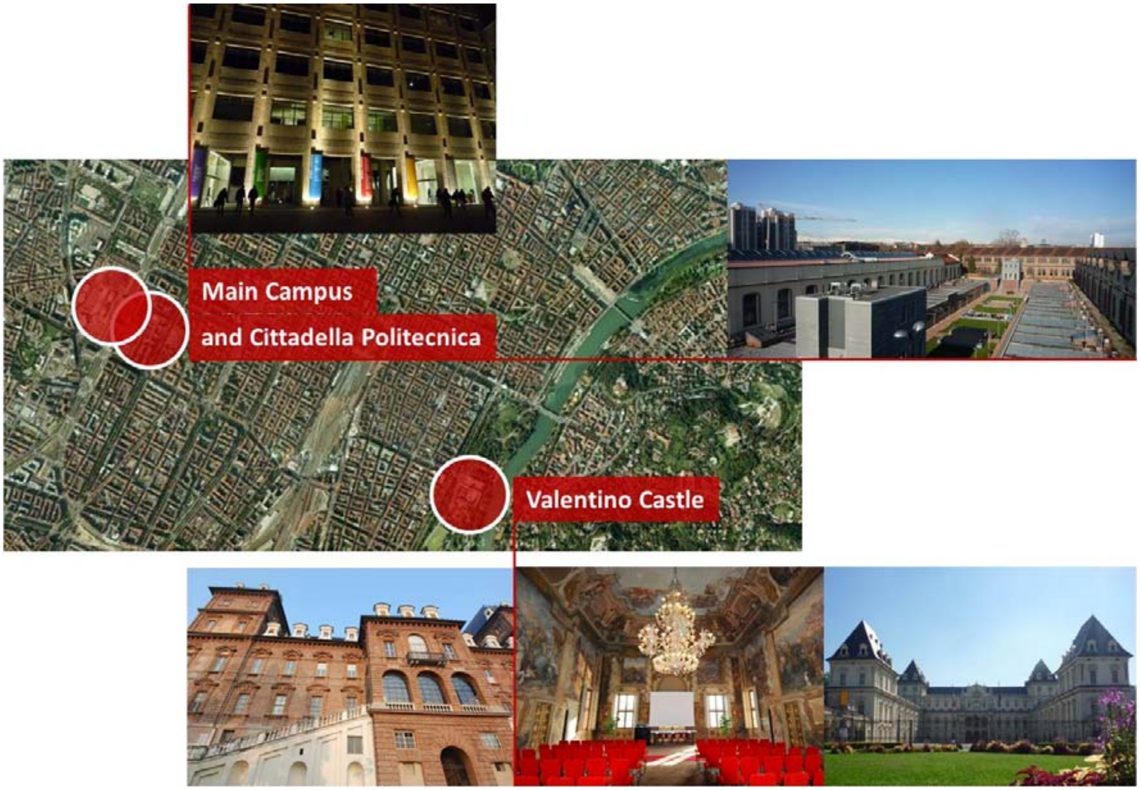

Figure 1 Case study: the Politecnico di Torino Campus

Energy modelling within BIM is clearly in its infancy. The key benefit of a building information model is the production of an accurate geometrical representation of all components of a building in an integrated data environment. Besides, a series of standardized data has to be set-up when realizing the model in detail, allowing a homogeneous use and exchange of data from the geometrical to the analytical model in an interoperable way. This is especially true for historical building like the Valentino Castle and existing buildings like the Main Campus and the Cittadella Politecnica, where the differences are considerable as shown above. Concerning this point there is often a close connection between the typology of the building and the difficulty of the definition of the standards for its modelling. This is why the case study considers different typologies of buildings.

Moreover, since the placing of new sensors and control systems in addition to the existing ones needs results from energetic simulations of each building or room, results deriving from modelling and interoperability within BIM, make it easier to design and check specific solutions. In this case study, for instance, the Cittadella Politecnica is a new building equipped with a basic demotic system and the energy efficiency can be improved by simply optimizing the present system regulation; in the Main Campus it is feasible to install new sensors with wired technologies; and, in the Valentino Castle, the historical value of frescos and stuccos does not allow an easy installation of sensors and each room requires

a specific solution using only wireless sensor networks.
Within the campus of Politecnico a simultaneous and iterative modelling of each building was needed in order to optimize and standardize the data that could be set-up step by step as detailed below.

2.2 System definitions, data sources, standards and 3D parametric model

Because this research needs to evaluate the energy performance and to propose changes for a significant number of existing buildings in Europe, the process must be practical, repeatable, and scalable. Therefore the 3D parametric model definition was the essential starting point of this work.
Data obtained in previous studies shows that the ideal workflow for energy performance simulation tools is divisible into six phases:[13]

- defining the location of the building that provides a link to weather data
- providing information of 3D geometry; construction and materials definitions; and space types - by importing data from a building information model
- aggregating spaces into "thermal" zones starting from these geometry definitions
- assigning space or lighting loads to the specific appropriate space types that have been imported via the BIM link
- defining HVAC and lighting systems and components
- performing simulation

In a similar way, we organized the activity in five steps in order to optimize the BIM process for our case study.
The *first step* was setting up the BIM standards in order to allow the possibility of collaborative work: the model was divided into separate files (architectural, mechanical, lighting, etc.) based on certain rules, so that more people can work on a single model at the same time maybe in different locations.
The *second step* - related to a pre-site inspection - was quickly modelling the existing structure on an urban scale, easily usable for each typology of buildings. The basic model captured building location, typology, size, volume, and construction period.
The *third step* was the definition of software usable in an interoperable way like Revit Architecture, Revit MEP, Ecotect Analysis, EnergyPlus, 3DStudioMax (all by Autodesk®), DIALux (Dial Light+Building®), Daysim® and Radiance®, Archibus®, and so on. In this phase a significant number of experiments on interoperability were vital for comparing preliminary results.[14] This was done knowing that interoperability with life-cycle information technologies was essential for the project, but absolutely not easy to carry out with the tools available at present because the use of exchange formats like Green Building XML (gbXML) or Industrial Foundation Classes (IFC) need significant implementations. Moreover the process is not reversible at all times!
The *fourth step* - related to a site inspection – was producing a preliminary architectural model by adding details (using simple roof, wall, floor, and opening dimensions) to support further design and analysis for energy efficiency (lighting and HVAC systems). Of course, there were several issues connected with this phase. The obvious one was guaranteeing 100% accuracy. The starting point was – if available - a series of old drawings on paper, or 2D CAD like current drawings used by the Building and Maintenance Office (not always updated), or

13 Maile T., Fischer M. and **Bazjanac V.** (2007). Building Energy Performance Simulation Tools - a Life-Cycle and Interoperable Perspective, Stanford University, CIFE Working Paper #WP107, p 36

14 Lo Turco M. (2007), Software interoperabili a supporto della progettazione edilizia. Trasmissione e condivisione dei dati tra progetto architettonico e modello di calcolo strutturale. Analisi condotta sul progetto del nuovo ristorante Ferrari a Maranello, PhD thesis, Politecnico di Torino, Dottorato di ricerca in Disegno e Rilievo per la Tutela del Patrimonio Edilizio e Territoriale, XIX Ciclo original as-built (not always verified). A quick survey was essential in two different ways (at present for the Main campus only): a) using a total station and a GPS receiver in order to establish precise GPS coordinates on the essential building elements outside (location, volumetric, windows and doors) and inside (corridors, lift-shafts and stairwell position); b) employing electronic distance meters (EDM lasers) to quickly take room by room measurements.

All architectural modelling and data input that was conducted in the field, at present are considered a V01 version. The BIM and Database will become a V02 when all site inspection information will be incorporated for each building. Because there are significant differences in data structure between CAD (based on traditional 2D drawings) and BIM (focused on individual objects and providing various levels of information associated with the objects), it was necessary to extract or export drawings as independent objects and to define standards for 3D oriented-objects. The solution in this case was not easy because it was necessary to define a common model applicable to different kinds of buildings (from a historical castle with its stuccos and frescos to a new and demotic-equipped building) and objects (walls, windows, floors, roofs, HVAC and lighting systems, etc.), with a series of elements that have to be used in different ways (from survey to design and simulation, from management to maintenance, and so on).

The *fifth step* - related to a post-site inspection - was starting the set-up of the methodology that would guarantee a continual cross-checking and updating of data in order to assure that the BIM will be as accurate as possible. In this way the model can be used by a variety of Assessment teams. This includes expert teams on architecture, HVAC and lighting systems, space utilization, energy audit, space protection, etc. As this is a real case study, in order to effectively test this BIM process, Politecnico - as user - has to change their current processes. Figure 2 schematizes the new one. Working with the users during the BIM research development since the kick-off ensures that datasets carry the data that each of them normally requires. Furthermore, understanding that all the necessary data was not developed during the BIM design phase was important in educating the users on the need to continue data collection during the daily use of the system. Because managing and maintaining the building information model after planning represented new and profitable income strategy for Politecnico, users need to be educated through specific training in order to create awareness about the new opportunities that this method generates.

The last step of this research will work on the integration of the data listed above and the data deriving from an innovative Intelligent Control System, using different types of sensors for lighting and HVAC measurements and control. A Living Lab and a specific web site will be dedicated to spreading accurate real-time consumption because sharing the data is one of the keys to improve awareness in end users.

Finally, the convergence of all data to a single virtual model will guarantee the preservation of a single database during the Life Cycle Assessment (LCA) of a building as planned at Politecnico di Torino (Figure 2). This is a crucial point for a real and efficient BIM process, and the elimination of the data replication thanks to interoperability must be the target of the future for the AEC industry. Of course this will be possible only with the support of the software houses improving the present technologies.

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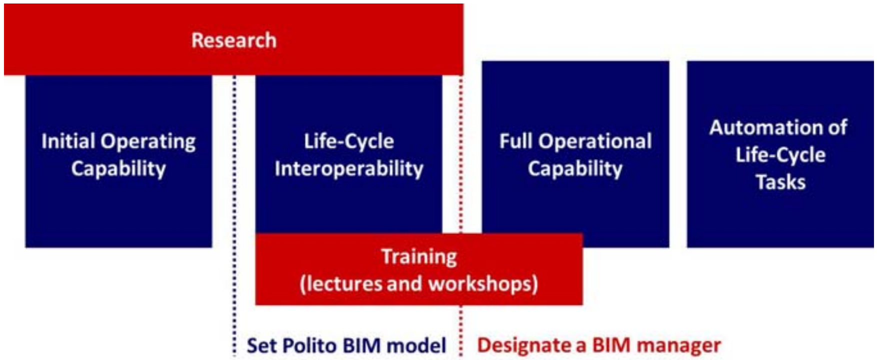

Figure 2 The Politecnico di Torino BIM process diagram was defined from research to daily use and implementation

3 Results

Building information models and interoperability are rapidly becoming the critical parts of BIM and it is necessary to work fundamentally on three questions:

1. What functionality is expected of building information models?
2. Full interactivity or just a static visualization of the model?
3. If interactivity is needed, is it acceptable to input the same data more than once during the BIM process?

Once the data production workflow in the BIM process is defined and the subsequent data use is established, it becomes possible to define a preliminary set of standards for each of the interoperable software on what data to capture in each phase of the work. The convergence of building data into a single 3D parametric model on the one hand provides for the creation of a single process, but on the other hand it needs a perfect interchangeable model and the collaboration must be based on interoperability. Standards and rules have to be well defined from the beginning and an experimental phase is essential, as the real risk is to set-up a model that does not work because it is too simplified or too complex. Obviously, as the building information model serves all elements of LCA, the data for energy efficiency analysis and for FM are an integral part of the other ones. Due to the early stage of the project, a significant set of results is not yet available. The following paragraphs summarize the state of the art of the on-going work. Several tests have been carried out in a significant number of elements in order to discuss and test the various types of data that had to go into creating a model, and the different types of uses for the finished product.

The *first test* was on the *basic model* identifying location, typology, size, volume, and construction period. In a few hours the models were built for the Main Campus, the Cittadella Politecnica (together because adjoining) and the Valentino Castle (Figure 3).

The *second test* concerned the 3D building analysis of the principal aspects of the *building's performance*, with a particular emphasis on energy efficient and sustainable design and maintenance. Using the sun path's on-screen controls as shown in Figure 4, it was possible to create solar studies by placing the sun at any point along its daily path, and at any point along its analemma. The resulting image was used to determine the hours of direct sun that a part of a site would receive.

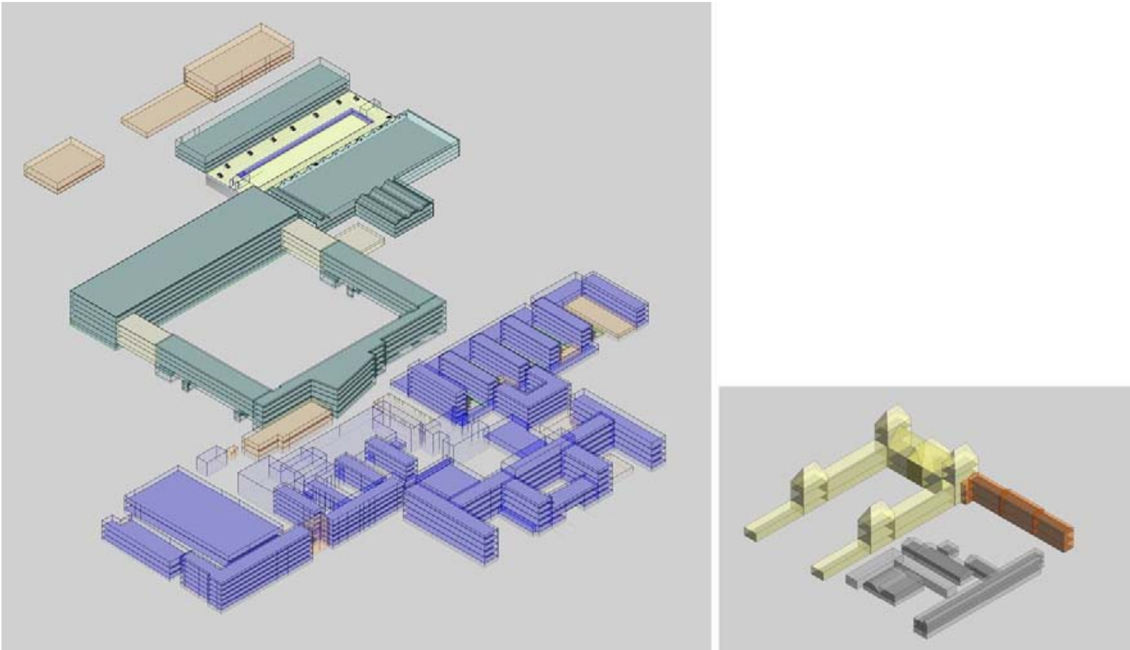

Figure 3 The main campus with the Cittadella Politecnica (by Mariapaola Vozzola) and Valentino Castle (by Paolo Piumatti) basic model were created using Revit Architecture masses tools

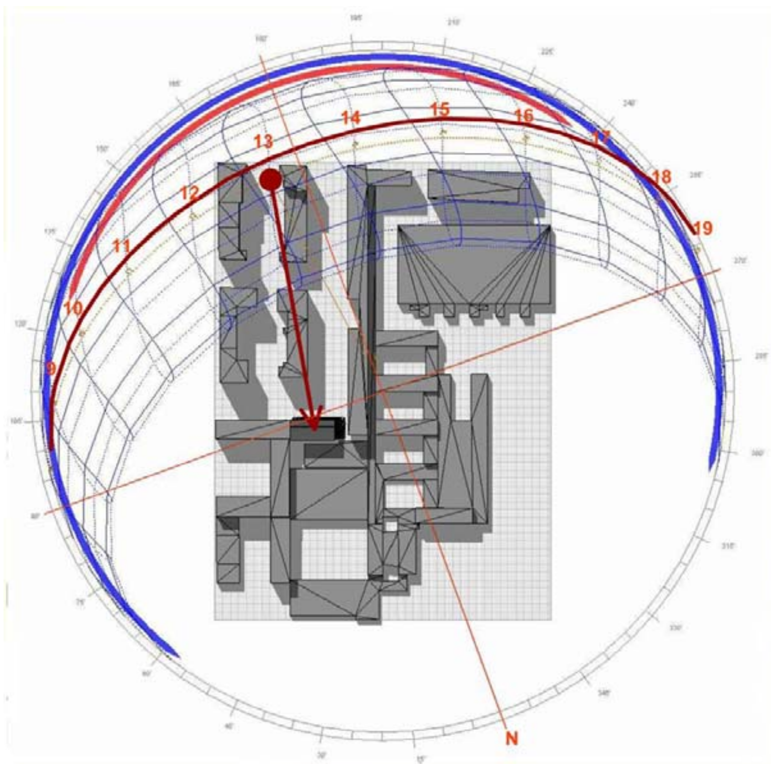

Figure 4 A detail of the Main campus and some adjoining buildings was imported from Revit Architecture to Ecotect Analysis (by Ettore Eramo) and the sun path was calculated. A preliminary interoperability was tested and some elements have been remodelled

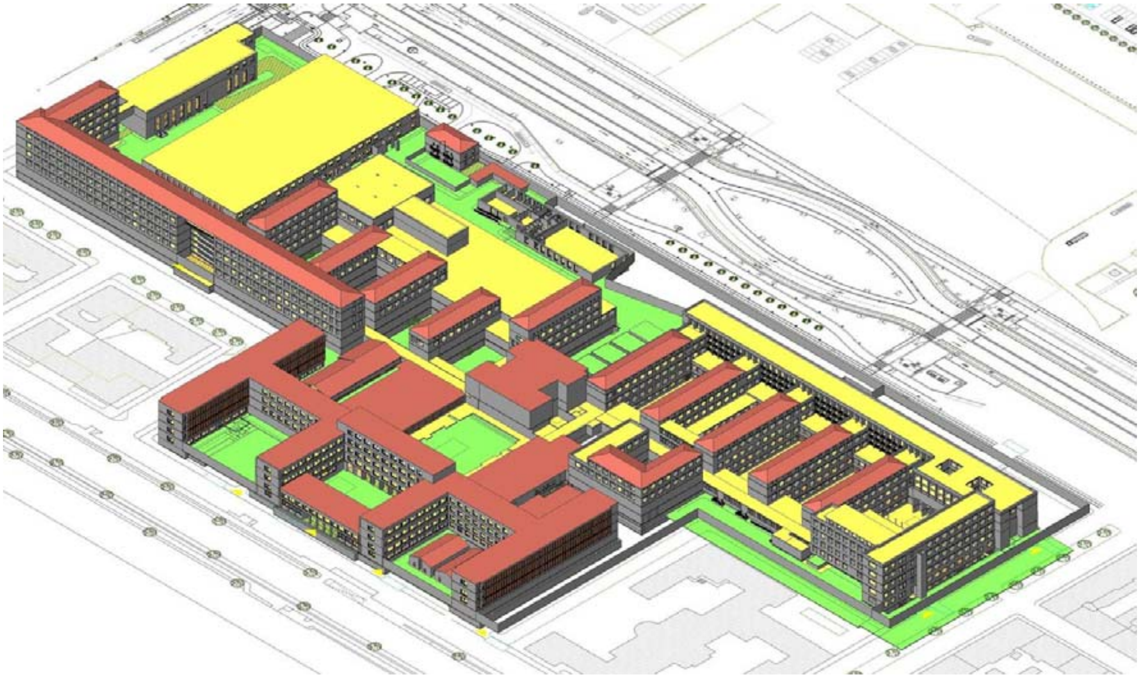

Figure 5 The Main campus preliminary model was created in a parametric way using Revit Architecture (by Daniele Dalmasso)

The *third test* was the creation of the *preliminary model* as shown in Figure 5. The key of this work was to be smart about the contents of the model - selecting essential elements such as floor, roof, walls, and windows - and precise in the component measurements. Upfront accuracy in this phase was important, as this model forms the basis for the initial energy analysis as well as detailed performance analysis further downstream in the review and implementation process. A few working weeks were dedicated to this model and it will be revised as soon as the survey campaign will be finished.

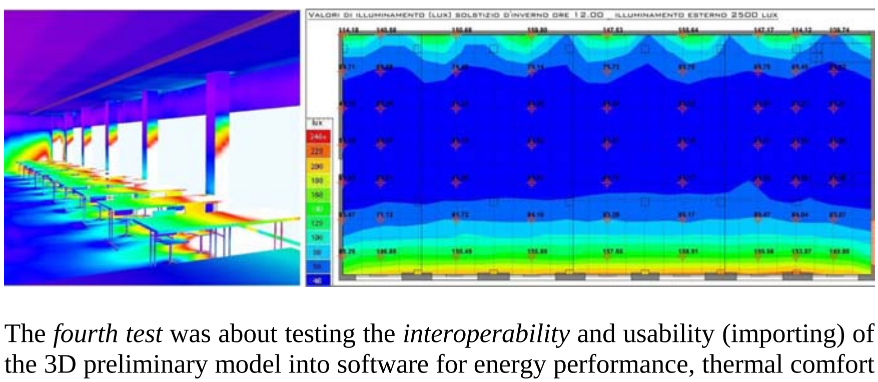

Figure 6 The Main campus preliminary model interoperability was tested among Revit Architecture, Dialux and Ecotect Analysis (by Ettore Eramo). Some elements (e.g. windows) have been remodelled because the interoperability did not run well

The *fourth test* was about testing the *interoperability* and usability (importing) of the 3D preliminary model into software for energy performance, thermal comfort and lighting models as shown in Figure 6. In this case IFC and gbXML formats were used and significant results were obtained, even though not all data were perfectly transferred. These interoperability tests were essential because they represented the starting point of the BIM process in optimizing the communication process. To know exactly what kind of data and among which software they can be exchanged has needed interesting consideration about the standards that must be used during the preliminary modelling phase in order to optimize the design activities on the management phase.

In this interoperability phase a lot of tests were needed for both the setting up of the data elements into the architectural model (Figure 7) and identifying the software that really are interoperable. Sometimes the use of additional software “as bridge” assures better results as shown in Figure 12, but of course this is not the right way, because only a wide utilization of format based on standard like open IFC will guarantee a perfect BIM process.

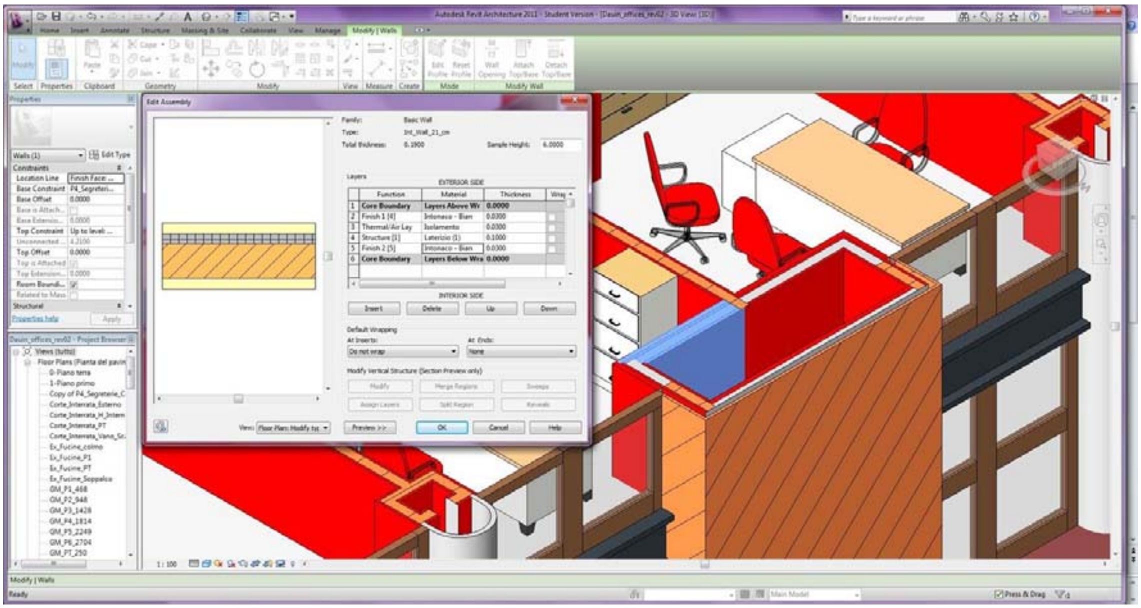

Figure 7 The Cittadella Politecnica architectural model in Revit Architecture including details for lighting analysis like colours of walls and furniture (by Daniele Dalmasso and Laura Blaso)

In addition to that, the interoperability was tested uploading the data from the architectural model to a real FM process. Unfortunately in this phase most data were lost because it was impossible to use the 3D parametric model. For this reason the model was transformed into 2D drawings (Figure 8). This was the most critical part of the work that will need improvement because it is impossible to imagine that this problem can persist for a long time!

The *fifth test* was about the creation of the 3D parametric *integrated model* with architectural and HVAC and lighting system data as shown in Figure 9. In traditional 2D design, lines and patterns are used to represent floor plans and additional lines and patterns are drawn on top to represent Mechanical, Electrical, and Plumbing (MEP) systems. In a 3D parametric model, the building is actually modelled in three dimensions: walls have heights, floors have thicknesses - as described previously - and ductwork have depths. Moreover, mechanical schedules and lighting fixture schedules can be used by referencing parameters that are tied to mechanical equipment families and lighting fixture families inherent in the model. In existing buildings normally it is not easy to know this kind of information because different data sources (from original project, preliminary survey and technical survey like thermography or others) must be interpreted and integrated and an in-depth survey must be done. Normally it needs relevant resources, but at the end of the work, the management advantages could be incalculable.

Figure 8 The Main campus (administrative offices) test of uploading data from the preliminary model built with Revit Architecture to the 2D CAD drawings supported in Archibus (by Daniele Dalmasso)

The *sixth test* was about modelling of a *historical building* characterized by monumental elements like frescos, spiral columns, false statues, painted architecture or stuccos as shown in Figure 10. The modelling approach in this case was necessarily different because the essential part was the architectural data (not always easy to model as vaults and irregular walls). In order to obtain a satisfactory result, specific tools were selected and the architectural model was built. The model has then been enriched by incorporating all systems (heating, cooling and electricity) that become readily available to the operators on-site through the use of QR code and Augmented Reality (AR), under testing. The model of the HVAC and lighting systems will be uploaded in a dedicated web database (strictly linked to the FM data) and the address of each model will be printed as a QR code tag that will be placed in specific points in the rooms. Therefore the systems 3D model visualization becomes possible in a very simple and efficient way for all certified technicians through a common smart phone. Of course, the use of this kind of model is more spectacular than the technical one but the experimentation of the AR could be interesting for the management process. A parametric model without so much architectural data (but with the HVAC and lighting system ones) must integrate this information and will work in parallel where energy efficient technologies need to be tested and suggested.

In short, the basic model is completely defined (test 1); at present it is possible to use it for the general building performance (test 2) and in the future it will be possible to add all rooms in depth as described in test 3. The Main campus is completely defined, the Cittadella Politecnica is in the modelling phase, and the

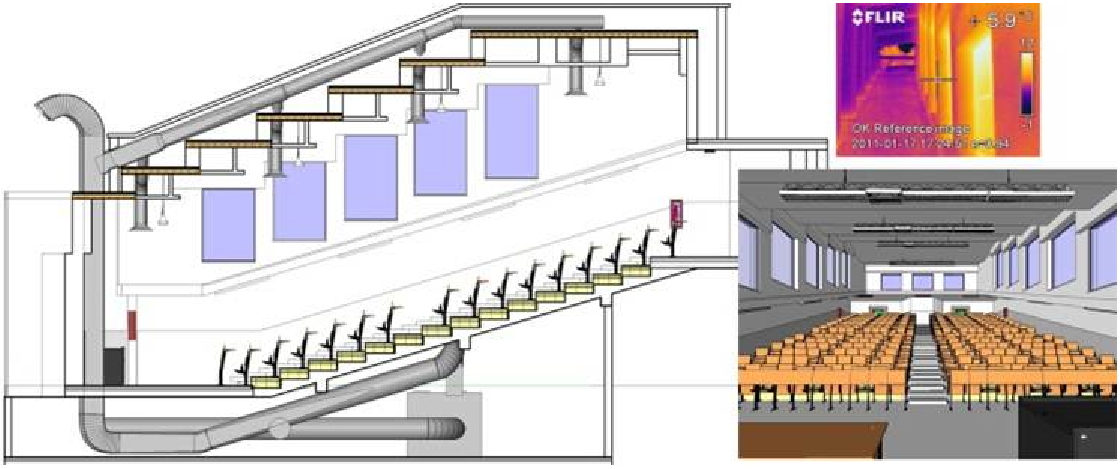

Figure 9 The Main campus preliminary model was started integrating HVAC and lighting systems model (classroom 1). Data sources were completely different and they have been interpreted and integrated into a 3D parametric model realized

Valentino Castle is only in the test phase. The reason for this is that the 3D parametric modelling of a historical building like this is very complex and significant simplification must be achieved through standardization, requiring more time to obtain acceptable results. Test number 4 is just at the beginning because the interoperability between an architectural software and specialized ones (for HVAC and lighting) is not always simple and a lot of tests are needed to verify which data are correctly transferred. In addition to this, it is indispensable to understand why some specific data are not interoperable. For this reason a specific database (using Access) has been set-up in order to collect all data and error that currently stop the process. Its interrogation will allow the comprehension of the problem as soon as it is enriched with a significant number of tests. The architectural and the HVAC and lighting systems model (test 5) of two very different rooms (one in the Main campus and the other one in the Valentino Castle) was set-up. A future development will be the improvement of the modelling procedure to allow the design of new systems (for instance heating and cooling) and their dynamic energetic simulation. Finally, the use of the AR for the FM activity (test 6) is just in a conceptual phase and a fast improvement is expected as a result of collaborative work between researchers specialized in BIM and ICT.

Figure 10 The Salone d'Onore in the Valentino Castle architectural model was realized with 3DStudioMax (by Brian Barbini and Stefano Gagliardotto) and the systems will be modelled with Revit MEP and then amplified with open source software for Augmented Reality

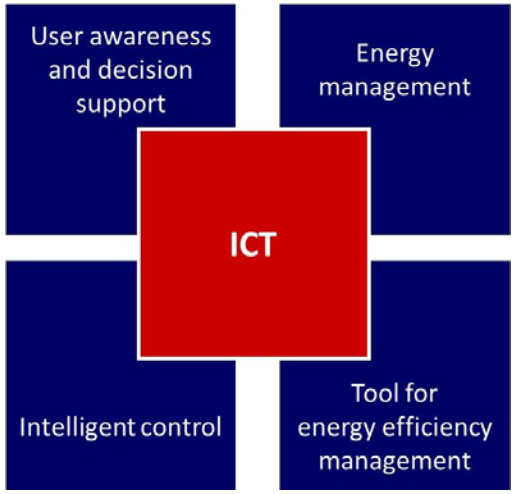

Figure 11 The concept of the Politecnico di Torino BIM-based FM system

With SEEMPubS an integrated BIM-based energy management process will provide Politecnico with a comprehensive view of its entire energy portfolio across all facilities, with data that can be linked to specific assets at each facility and delivered to energy managers in every site. Moreover, site data can be aggregated to provide an organization with the information needed to create a comprehensive energy management strategy.

Obviously, the key benefits of a building information model are: the production of an accurate geometrical representation of all components of a building in an integrated data environment, and the interoperability between applications.

At present, results of the iterative approach among the different tests underline that the definition of a single complete 3D parametric model is absolutely not easy in mix existing and historical buildings like the Politecnico di Torino campus as shown in Figure 11 (on the left). Moreover, results of this preliminary research activity point out that some challenges occur in the professional adoption of BIM. These include: convincing people to explore a new paradigm; overcoming people's discomfort with familiar software tools; reduced productivity during training and transition; developing components libraries and details; establishing new standards; and expending the financial investment to shift from existing software platforms.

In spite of this, BIM, interoperability and integration will significantly impact the Architect and Engineer activities and collaboration as shown in Figure 11 (on the right) thanks to the optimization of the process. Therefore, changes in the profession will be inevitable as well as in education because the level of expertise required to intelligently design with BIM is significant.

Conventional CAD platforms were more of less a replacement for the drafting table and pen, which made the training focus on the aspects of using the application rather than rethinking the workflow. It is completely different in the case of BIM as training should consider the change in the process along with the new application interface and functionalities. For this reason an Architect or an Engineer with no previous CAD training would be easier to comprehend the concept of BIM.

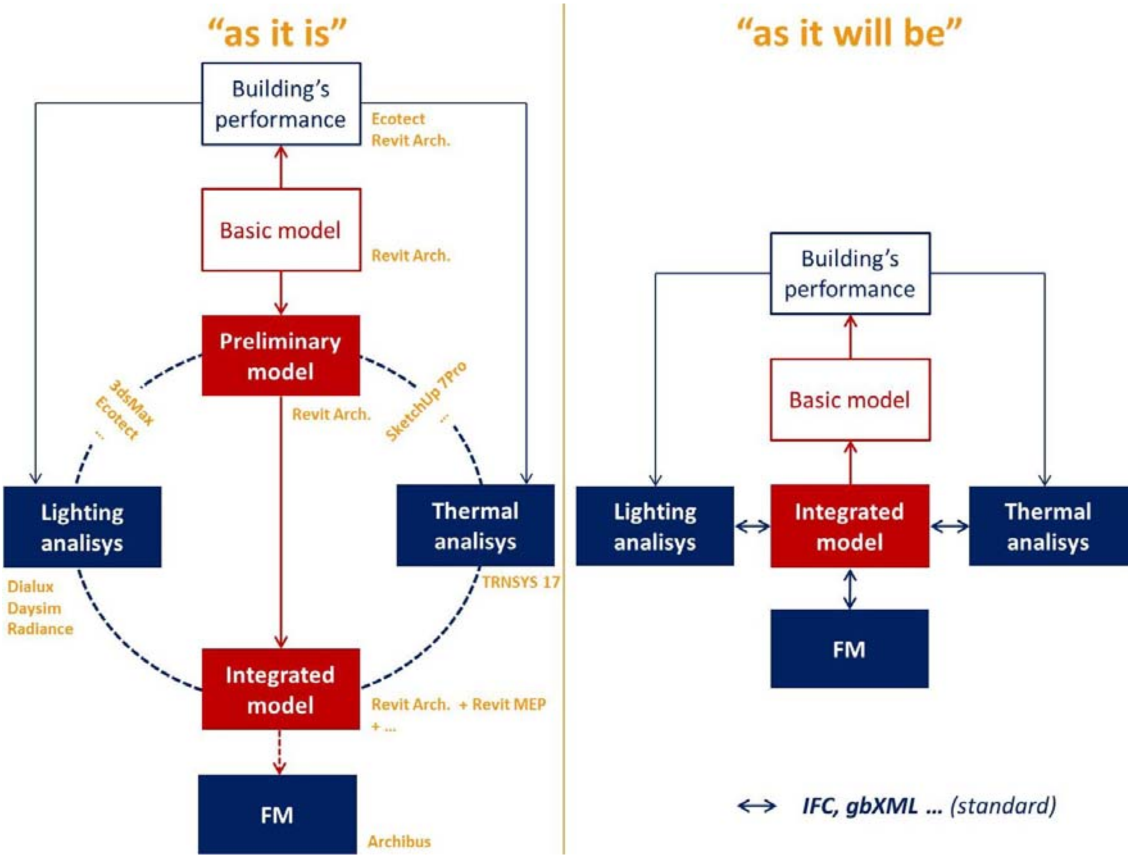

Figure 12 The BIM and the interoperability diagram "as it is" and "as it will be"

As previously described, this project is perfectly in line with the EeB PPP because it will zoom in all specific aspects such as use of materials, energy management and internal building layout within an interoperable building information model and process based on the GOLD concept (*globally optimised, locally designed*). The application and the comparison on a large-scale spectrum of styles from historical to contemporary involve great and detailed investigations that could be extended to a significant number of buildings in Europe.

4 Conslusions

This paper has presented a method to manage the evolution of FM for energy efficiency from unknown and heterogeneous data (architectural, HVAC and lighting systems) to a smart and interoperable process based on BIM. This method is articulated in four parts, each one filling a particular task:

- Define the basic model and verify the building's performance
- Define the preliminary model and test the interoperability
- Define the integrated model and test its applicability to existing and historical buildings in FM defining standard for all data used
- Take into account the human aspect in all previous listed tasks.

Our methodology demonstrates that in a fully coordinated BIM environment, all parties will be integrated and working on the same building information model. This cultural epochal change needs first of all new education methodologies in which students are proactive participating as creators of an open, temporary and - if possible - international work. This approach targets new skills.
Our results show that building information models have great potential for expanding architectural practice through their various embedded analysis tools. In fact, as energy efficiency becomes fundamental to many practices, the ability of BIM to embed energy modelling within the program or to export data to similar analysis programs becomes an advantage over traditional 2D or 3D software programs.
Particularly, this research underlines that there is a necessity to overcome the interoperability issues among computer-aided design, engineering and software systems. There is no question that the information technology required for these processes is complex and difficult to implement. Much more work must be done to enable the technology to be fully applied on a day-by-day basis, and the industry is still far from having an interoperable, federated system that can enable fully integrated parametric building and system modelling.
Future work should consider that in many cases, digital exchange and integration of design models, equipment specifications, sensor and control information, management plan and related information has been and is being impeded by the absence of consistent vocabularies, identifiers and encoding formats for data exchange and for information generated and used by users throughout the life cycle of facilities.

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