SPHERE
BIM DIGITAL TWIN PLATFORM

BUILDING DIGITAL TWINS, SIMULATION TECHNICAL INSIGHT

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DISCLAIMER

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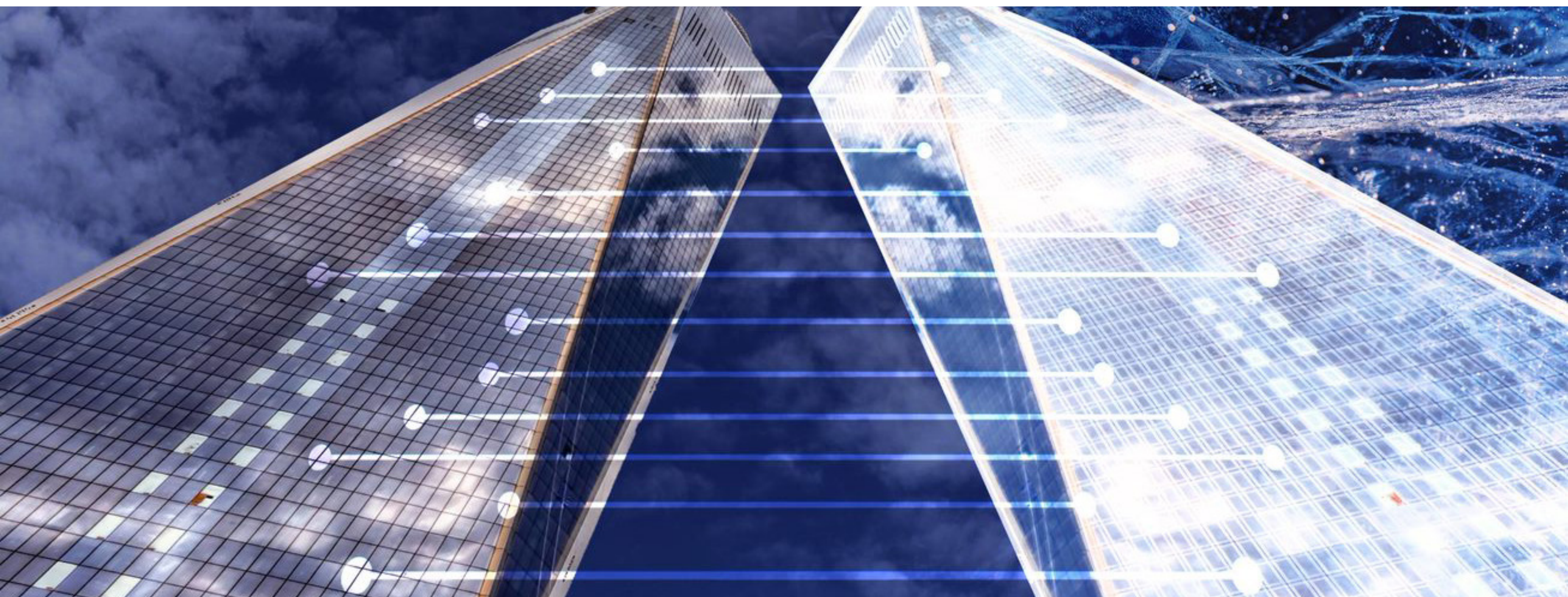
ABSTRACT

The concept of "Building Digital Twins" needs to be well defined to avoid another new diffuse and trendy topic. Definitions, new roles and standards are helpful to understand which type of twin we are talking about and how useful it may be for society.

Many concepts surround the idea of 'digitized and available' data through the web, but ontologies and data structures may demand critical decisions in early stages of development of those digital twins. Different data structures will requiere a correct representation to be able to be integrated somehow. That integration may become impossible if some decissions at the beginning of the digitization process are incorrect.

Mathematical simulation uses a non congruent or conciliable representation with BIM objects. Important decissions must be taken to ensure the coexistence and cooperation of both environments.



KEYWORDS

- *Ontology management*
- *Building simulation*
- *Building energy use*
- *Energy efficiency*
- *Energy modeling*
- *Building life cycle*
- *Zero-net-energy buildings*
- *Comfort*
- *Heatlh*
- *Humans*
- *Occupation behaviour*

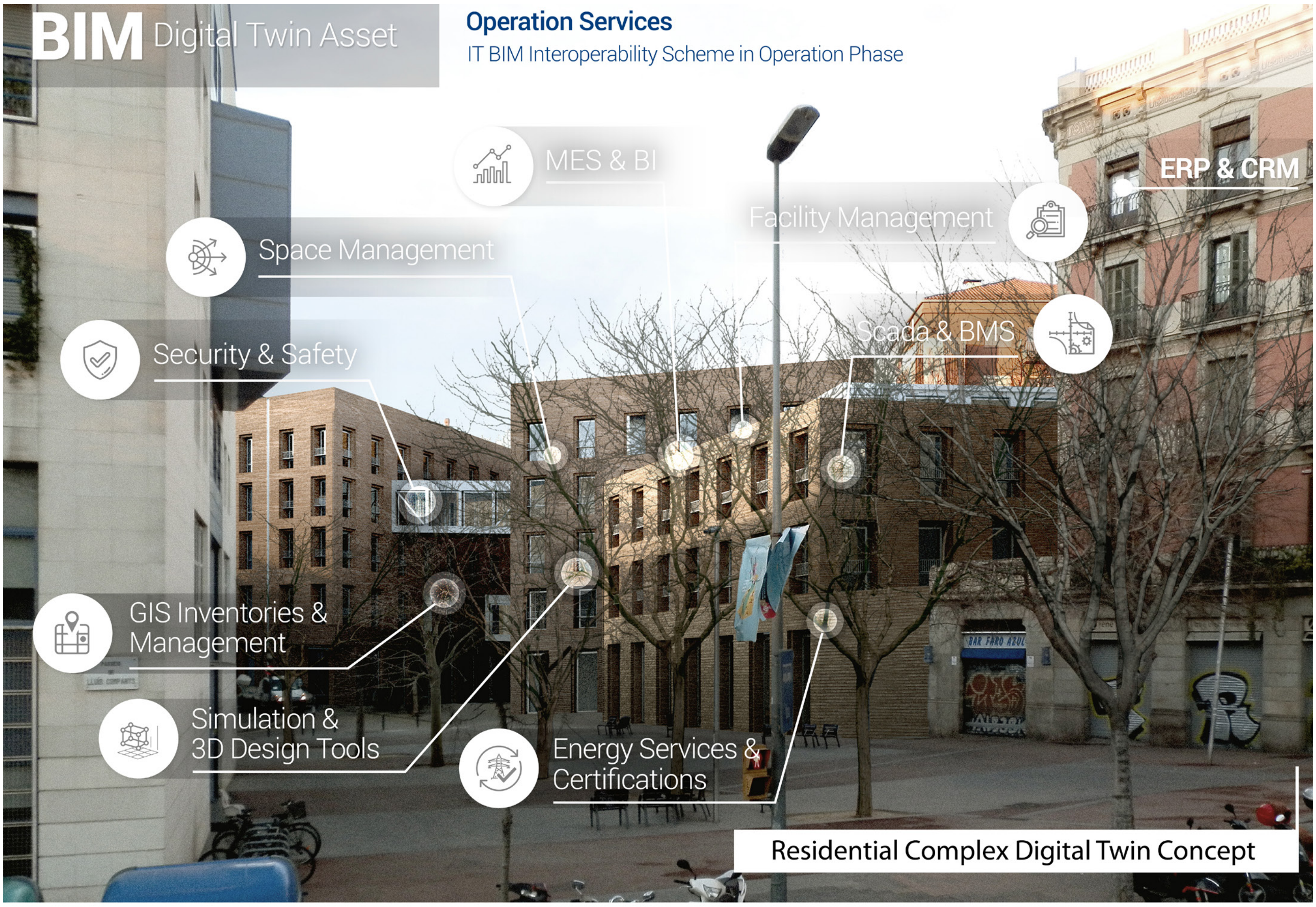


Figure 1: Residential Complex Digital Twin Concept (sketch by M. Borràs)

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INTRODUCTION. REDUCING INVESTMENT RISK

AECOO industry has faced the challenge of digital transformation excited with the OpenBIM wave and the graphic integration of many disciplines that were before isolated and not well managed. Graphical representation of ‘ideas’ (not reality) is an excellent way to explain and communicate, but as soon as reality enters to scene those geometric models are unconfortable and complex. Planes are not so flat and pipes not so straight. Point clouds are heavy and moving and checking against entities of the project an exhausting task. Everything starts to degrade and what was an ideal representation tool gets useless and non practical.

We may think that a similar case can happen when we add a functional model to the projected geometry and associated data. Functional representation of a ‘space’ may look a priory an impossible objective as it involves fluids, gases mixtures, solar radiation, convection currents, contaminants and humans. But mathematical simulation offers a phantastic simplification methodology of that space, which may be adapted or not to the BIM representation. So we reproduce once again the incompatible data representation we found when we compared our ‘ideal’ project with reality measurements: BIM entities are not simulation components, and data structures used in each case are different.

When planning ambitious digital twin platforms incorporating functionalities as real time simulation the rigth initial representation must be studied, and the corresponding simulation components as well. BIM models must be carefully checked and entities of MEP installations well studied. Naming of networks and systems are necessary, and the integration with spaces, doors and windows will be needed in its functional representation. If we want to be able to integrate different representations we need to prepare data structures in a very specific way, and geometry may be helping or not. Fascination about geometry and viewers has produced in the past terrible results. Lessons we should learn in building construction.

SIMULATION IN THE CORE OF THE BUILDING DIGITAL TWIN PARADIGM

In the same way that a drawing can represent an imposible design, a 3D model may be a well defined geometric representation but an imposible funcional model. We can have a wonderful 3D model of a space with no heating, or tiny equipment connected to a huge network, or networks which are not driving fluids in the right way. 3D geometric models are a great step ahead to communicate designs and to avoid interferences, but the real and important disruption in design methodology comes with functionality. So mathematical simulation can add that level of perfection to our 'plain' geometric designs.

Simulation components are small 'programs' with the same aspect than a subroutine: name of the component, connections (or ports), variables definition and equations. It may be represented in the simulation envirotment by a symbol or graphic and some connectors (ports). When we copy and connect that graphic symbol we are connecting mathematically all the equations of that component.

We can decide which level of detail one component may have. We can decide to represent with a great detail level the fluids inside a room or just to consider a node where all conditions of that space are concentrated. This level of representation is critical as we may have just a few equations for each component or a great number of equations and convergence problems. We may want to have generic components with some parameters or ready-to-use components which responds to manufacturers models (we can call these components SIMBOTS). In any case when we decide which representation level is the best, that component is representing one or several geometric BIM objects in our 3D model. So there is no one-to-one relationship in general, but we can have several BIM components represented by only one simulation component. This would be the case of a branch in a network with several straight pipes and bends which I represent in my simulation by only one single component.

In the same we have to consider the time observation factor. Usually we are going to be working with intervals of 10 min time with sensors. So to represent phenomena which occurs in 1 min has no sense. For example a small pressure variation in the air flow during some seconds or a pressure drop in water pipes in less than one minute.

We have to consider that building models may have simple components but a lot of them, so complexity in each component is something we must control since the beginning. Converge must be carefully studied to avoid problems associated with fluids or equipment with too detailed equations.

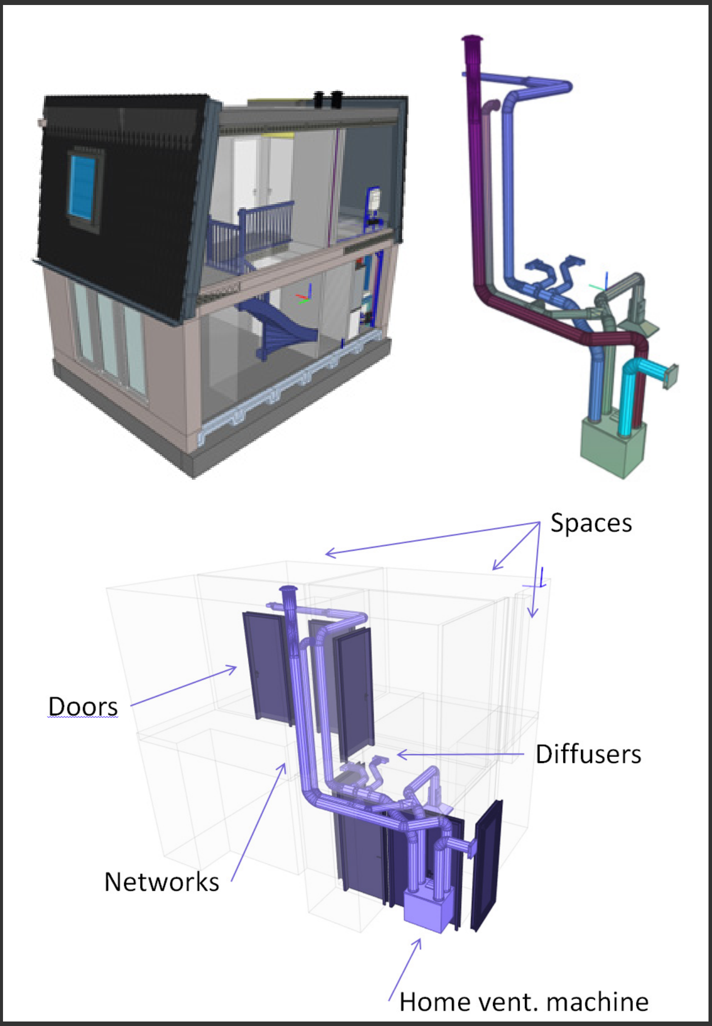
And simulation is an economic task we must consider as well. If creating simulation models is as expensive as creating a project from scratch no project is going to implement a functional simulation. It is important to have good libraries, SIMBOTS and resources before attacking the simulation. In this way simulation of a building is a task of hours, not days or weeks.

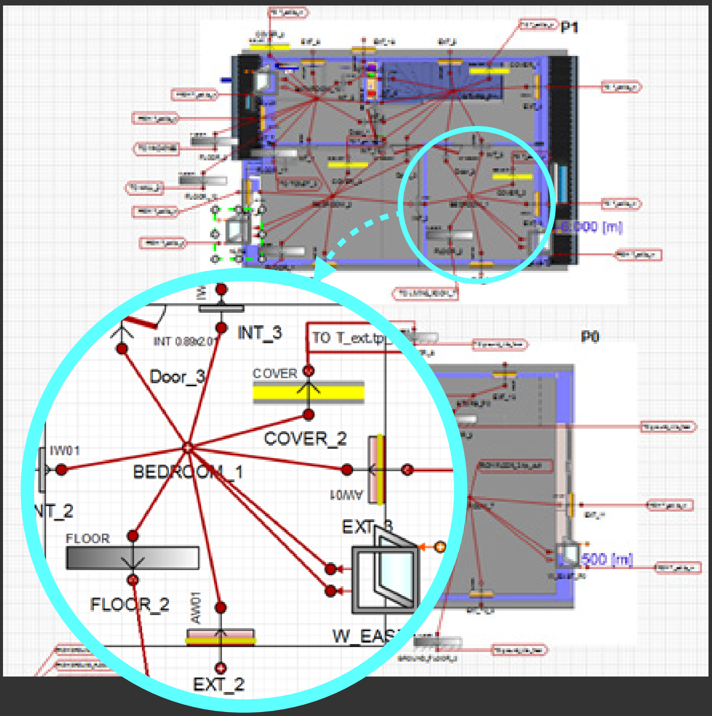
Simulation is a task which may be affecting design, comissioning and explotation of the building. That means that the value we get from models can be useful in all the life cycle of the building. That is a great value. Simulation can be at one point compiled and inserted in a building management system, improving monitoring but detecting malfunction as well. It can be translating complex magnitudes into economic values in real time, helping the end user and supporting decissions to improve energy efficiency and comfort.

EXHIBIT I. EXAMPLE OF A SIMBOT

SPHERE demo pilot at municipality of Heerhugowaard, in the province of North Holland of the Netherlands (NeroZero houses). The ventilation system has been simulated using a SIMBOT of the ventilation machine and human models. They are both integrated with the thermal model of the house.

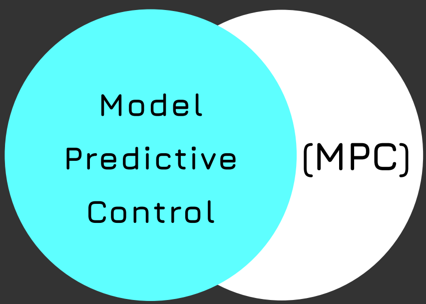
The simulation model is later integrated in a real time system in order to assist the intelligent control of the house.





FEATURES ENABLED BY SIMULATION BASED BUILDING DIGITAL TWINS

EXHIBIT II. WHAT IS A MPC?



Model predictive control is an advanced method of process control that is used to control a process while satisfying a set of constraints. It has been in use in the process industries in chemical plants and oil refineries since the 1980s.

In buildings MPC techniques will help to consider inertial thermal effects of the mass of buildings for example. These means to switch on or off the heating depending how exterior temperature will be in two hours. Nowadays we can use good wheather forecasting through internet and this simple information could save a tremendous amount of energy.

To implement these techniques we need a mathematical model of the building and different algorithms can be used.

Real-time optimization and control

Building control systems are critical to ensuring efficient operations and occupant comfort. To support building control, simulations is being coupled in real time with building energy monitoring and control systems and sensors, where it is used to predict thermal loads in buildings and provide guidance on energy- and comfort-optimal control strategies. Typically, real-time building operation data (equipment and systems), predictive weather data, and occupant data are fed to energy models that simulate and evaluate various control strategies across a future time horizon, identifying the control strategy with the best predicted energy and comfort outcomes. This type of model predictive control (MPC) is extremely appropriated for power system balancing models and building controls. Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification. The main advantage of MPC is the fact that it allows the current operation time-slot to be optimized while simultaneously accounting for future time-slots.

Human building interaction for occupant-centric building design and operation modelling.

Building occupants interact with indoor environments and control systems through their presence in a space and the adaptive actions they take to maintain personal environmental satisfaction. These human-building interactions (HBIs) affect both energy use and occupant comfort outcomes and are therefore central to building design and operation. Occupants' behavioral interactions with buildings are of a wide variety, including the passive exchange of heat with space, opening and closing doors and windows; adjustment of thermostat settings, light settings, blinds and shades, or clothing levels; use of personal heating and cooling devices; and consumption of warm or cold drinks. Each interaction may be motivated by a number of factors ranging from the physical environment and availability of control options to occupants' personal preferences and environmental attitudes, social interactions, and broader cultural context. Modeling capabilities human behaivour constributes effectitvily to enhance both design-stage simulations (enabling the ability to represent expected occupant behaviors and their effects on simulated energy flows can support design strategies that are robust to these behaviors) and to improve controls system software (enabling a more efficient building operation) by introducing building occupants model supporting model-predictive control (MPC) approaches optimizing both the energy performance while improving the occupant comfort.

Enhanced model calibration

Discrepancies between simulated energy use from building energy models and actual measured data undermine confidence in model predictions and curtails adoption of building energy performance tools during design, commissioning, operation, so energy models must be improved to closely represent the actual performance of modeled buildings, for example through model calibration, using enhanced simulation and "tuning" various inputs to the program so that observed energy use matches closely with that predicted by the simulation software. Calibration can significantly improve the validity of and confidence in energy models while being used to: assess various performance optimization measures during the operational stage , implement continuous commissioning or fault detection measures to identify equipment malfunction or support decision making in existing building retrofits, assessing the benefits and uncertainties associated with each life cycle stage.

Advanced facility management

SIL based approaches enhances the new appraaces on automated facility management, as can fault detection and diagnosis algorithm (FDD). A new set of automated building performance assessment tools of based on real time simulation, is expected to be delivered by on-going projects, allowing comparison of actual and expected building performance in real time using Digital Twin and advanced simulation approaches, in which Digital model determines and reports the expected performance of a building in real time, adquiring relevant inputs from a protocol based interface and sent to simulation platform as well as a database for archiving.

Model based energy efficient retrofitting

Detailed energy models created using SIL approaches can be used to explore and evaluate energy efficiency measures for energy retrofit projects. Usually, the base case model is calibrated using monthly utility bill data before being used to simulate and analyze energy efficiency measures, while new approaches enable easy-to-use energy retrofitting analysis and improves energy management. In non residential buildings, the focus is energy benchmarking and different analysis levels, considering the project targets, data availability, and user experience, while on the residential side the target is to empower homeowners and renters to save money by reducing energy use in their homes.

Virtual commissioning

Most buildings do not perform as well in practice as intended by design, as their energy performance levels deteriorate over time. Reasons for this deterioration in performance include faulty construction, malfunctioning equipment, incorrectly configured control systems and inappropriate operating procedures. To address the problem , simulation under Digital twin approaches can address this problem by comparing the predictions of an energy simulation model of the building to the measured performance and analyze significant differences to infer the presence and location of faults, a topic that is discussed further in the next section. Model-based retro-commissioning refers to this use of building energy models to help identify and evaluate operation problems in buildings as part of a retro- commissioning process. Calibrated energy models can be a good tool in assisting the measurement and verification (M&V) of a retro-commissioning project.

Modelling grid adaptability

Building's adaptability to grid will play a central role from both market and regulation perspective under the new EPDB proposals enabled by the SRI framework[1], so enabling enhanced grid-responsive buildings, regarding those that can adjust electricity demand and on-site energy generation based on the dynamic needs of the grid will be crucial to play an specific role under the new framework. The ways and means of such grid- responsiveness are found in increased deployment of IoT devices and equipment and human-in-the-loop feedback control strategies. The resulting flexibility in building electricity demands help to avert system stress, enhancing the reliability of the entire power grid. The design and operation of grid-responsive buildings is challenging because energy cost may be valued differently depending on fast-changing grid conditions. Use of various types of energy and electricity storage is key to serving critical loads in such buildings, which must also be able to operate in partial services modes both in time and space. Rapidly coordinating demand and supply from groups of buildings is necessary for smooth grid operation and security. Viewed from the perspective of SIL approaches and development, a key challenge is coupling traditional building energy simulation with simulation of renewable energy generation and the utility grid, where the temporal and spatial fidelity of such models can be dramatically different.

Energy-positive buildings and zero-net-emission buildings

As buildings become more grid-responsive, the potential for energy-positive and carbon-neutral buildings is also emerging. Such buildings employ advanced technologies, ant its energy modelling interactively poses a particular challenge for enhaced simulation approaches. In these advanced cases, accurately representing both the technologies and behavioral opportunities may be beyond the native modeling capabilities of current simulation approaches. Accordingly, SIL embedded in Digital Twin provides flexibility and expanded modeling capabilities – for example using PaaS business models and coupling different simulation platforms or custom code, using an Energy Management System new control models and/or overwrites existing algorithms.

1 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12364-Establishment-of-a-smart-readiness-indicator-for-buildings_en

Advanced facility management

Topic	Impact area
• SIL tackling the Building performance gap	Verification of building performance goals and ratings/certifications.
• Human-building interactions	Integration of models of environmentally adaptive occupant behavior, which has significant impacts on health, comfort and building energy performance
• Energy model calibration • Modeling operation, controls and retrofits • Modeling operational faults in buildings	Support operational improvements and energy efficiency improvements/retrofits in existing buildings
• Zero-net-energy (ZNE) and grid-responsive buildings	NZEB design of buildings and representation of building energy load dynamics needed to deploy building efficiency as a grid resource
• Large scale energy modeling	City-scale building energy efficiency measures needed to achieve energy/ environmental goals
• Evaluating the energy-saving potential of building technologies at national or regional scales • Modeling energy efficient	Government decision making on building efficiency research, technology development and assessment
• Integrated modeling and simulation	BPS supports decision making across the entire building life cycle

FUTURE RESEARCH DIRECTION AND PERSPECTIVES

Around functional simulation and advanced control of buildings we may find several aspects which potentially will bring developments in the short or medium time period. They are not developments about the digital twin concept but contributors which add value and projection to the concept as a whole.

One of these developments will be the **microgrid concept** applied to buildings and local energy communities, considering small generation of PV installations or other devices to migrate the actual electricity centralized business in a broad transactions system, inside the building and inside smart cities.

Another important development will have **human models and occupancy interaction** with the building as fulcrum, using wearable's and smart sensors to receive the human presence and status and to implement an advance control of the building, not only thinking on energy savings but considering health and comfort implications.

Advanced simulation immersed in real time monitoring systems will be key tools for **performance contracts** in the "Deep Renovation Wave" nowadays in the EU. Simulation provide calculated additional key performance indicators in real time, with a dynamic baseline which may be used as a reference between the stakeholders.

Monitoring and registering statistics gives the opportunity to **enrich the digital logbooks** of a building. This information must be managed and stored, and challenges regarding privacy will be solved in order to have property, security and control over those data collected.

An advance control does not mean more sensors, but **less and more trustable instrumentation**. Simulation will help with the maintenance of smart systems providing an automatic way to detect failures and malfunctioning.

Simulation is **a way to connect all phases of the building**, beginning with conceptual design, helping in commissioning and assisting the complete life cycle of the building. This could change the **"project concept"** itself, adding more functional content in contractual processes.

Finally advanced control applied to building will make explicit many privacy threats but solutions as well. **New privacy management tools** will be implemented in order to comply with regulations but making possible **data transactions and public reporting** in controlled conditions.