Digital methods and tools in the construction process for efficient project management workflows: case histories

Sofia Agostinelli

CITERA - Interdepartmental Research Centre for Territory, Architecture, Heritage and Environment
Sapienza University of Rome

Buildings are becoming far more than walls, roofs and masonry: thanks to Artificial Intelligence (AI), building systems are becoming able to autonomously integrate the proliferation of data from IoT devices and occupant behavior to apply learning, optimize performance and improve environmental efficiency. As AI is integrated with building systems and Internet of Things (IoT) devices, it has the potential to improve occupant experience, increase operational efficiency and optimize space and asset utilization.

A vast array of information from digital devices provides insights about the operations, use and condition of everything from the building's infrastructure, physical environment, climate, water and energy usage, to an occupant's experience and satisfaction, then IoT and platforms embedded with Artificial Intelligence and machine learning make it possible to develop innovative new services for engaging with building occupants. These systems have the potential to radically reduce costs through automation and optimization of operations.

By taking advantage of powerful analytics and Artificial Intelligence for example, building owners can significantly cut energy consumption and achieve ambitious cost-saving targets. After equipment performance information is collected through sensors and meters, a library of benchmark data is applied, analytics are performed and potential operational improvements are identified.

Analytics can also be used to prevent energy waste by isolating inefficient energy use. Sensor-controlled systems can monitor dispensing and water use. Cognitive maintenance systems can help preserve the health of critical building equipment and assets by anticipating asset failure and guiding timely interventions and so on.

A comprehensive building optimization system leverages all aspects of building and facility management. These types of systems allow for monitoring the use of space, water and the usage and allocation of energy. Taking this monitoring one step further, building equipment data collected from IoT sensors that is tagged by location or asset type and associated with business rules can trigger algorithms to not only detect but also predict and respond to anomalies. These optimized ecosystems of building technologies identify opportunities for efficiency controls through predictive maintenance. They identify possible root causes, so actions can be prioritized, assigned, monetized and prevented, as recommendations that appear on dashboards or adjustments can be routed directly to the IoT device for action.

AI is able to capture data from day-to-day building operations to enable new levels of automation, which enables buildings to "think," engage and learn. These buildings can autonomously monitor and predict their own maintenance needs. Data transmitted from connected assets, such as boilers, pumps, chillers and elevators, is analyzed and enriched to identify anomalies, such as equipment operating outside of normal parameters. Potential failure modes are identified from tolerance and business rules, and devices are automatically instructed to take corrective action. The building memorizes the result of the intervention so it can improve the accuracy of detection and resolution of future incidents.

The integration of cognitive analytics, sensors and existing building systems can also significantly improve occupant experience. Envision going to work in a building that works for you. While you're there, IoT sensors are constantly monitoring your movement and the temperature. It turns lights on and off for you, adjusts the flow of water in restrooms and listens for your voice commands. Even breaths are monitored for carbon dioxide concentration in case an airflow adjustment is needed. And when the building detects that people have left their assigned workspaces, it turns on the lights in the parking garage, places the building systems into rest mode and checks tomorrow's weather.

This kind of approach to problem solving is related to simulation modelling, which aims at reproducing in a virtual environment the behavior of a non-linear dynamic system. It serves as a digital testbed where one can assess ex-ante different strategies over a simulated time-horizon.

The development of the Digital Twin therefore begins with an integrated Information Model, in the case of buildings this is the so-called BIM (Building Information Model), able to contain data and information useful to simulate the process, which in communication with data from sensors becomes a Digital Twin with learning capabilities, able to process the information received. Artificial Intelligence algorithms then allow the Digital Twin to develop predictive capabilities and finally to make and implement autonomous decisions based on the analysis performed.

The project aims to investigate, build and test methods and approaches that respond to the challenges proposed by the increasingly necessary digitization of industrial processes, as a true digital management, which combined with the growing potential of Artificial Intelligence and machine learning, allows to manage, optimize and automate the phases of construction processes, with particular regard to the management phase of processes related to the life cycle of the built environment.

As already mentioned, the key word is management: in particular it is explored a case history about the Digital Twin-based management of a portion of city, in the specific case of a residential area located in Rome and composed of 16 buildings. The goal is to build a digital process and ecosystem based on three-dimensional information models that are able to replicate physical objects, such as buildings, and especially manage and monitor their interactions with reality.

The Digital Twin of a residential system can therefore be a key tool for the storage, visualization, analysis and creation of data useful for the management of urban life and, considering the absolute centrality of data in the realization of digital processes, an important development consists in the integrated use of GIS and BIM, aimed at the information management and processing of information both at the scale of the building and at the geographical and territorial scale. BIM and GIS, although they share the essential concept of description of the real world through the combination of visual representations and information, are conceived and developed as belonging to different domains, and therefore have differences also and especially in the level of detail. BIM can be used to create, manage and share life-cycle data for vertical structures, such as buildings, while GIS can store, manage and analyze data describing the urban environment, distributed horizontally.

Therefore, Digital Twins of buildings reproduce their geometric, but above all, informative characteristics, and they appear as 3D models but they have the particularity of being configured and structured as real time three-dimensional databases, where data are contained within objects equipped with specific parameters and attributes that describe the characteristics of the components themselves, thus enclosing useful information for the definition and simulation of processes. The Digital Twin gradually becomes able to improve and enrich its knowledge and improves data, receiving inputs and signals from sensors constantly monitoring the buildings, developing self-learning and above all predictivity capabilities, through the integration with Artificial Intelligence algorithms.


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BIM & GIS for digital integrated design
SAPIENZA UNIVERSITY OF ROME
FACULTY OF ARCHITECTURE
Rome, August 31st – September 11th 2020
PROF. SOFIA AGOSTINELLI
SMART CITIES AND INDUSTRY 4.0
THROUGH DIGITAL TWINS AND CYBER-PHYSICAL SYSTEMS
07/09/2020
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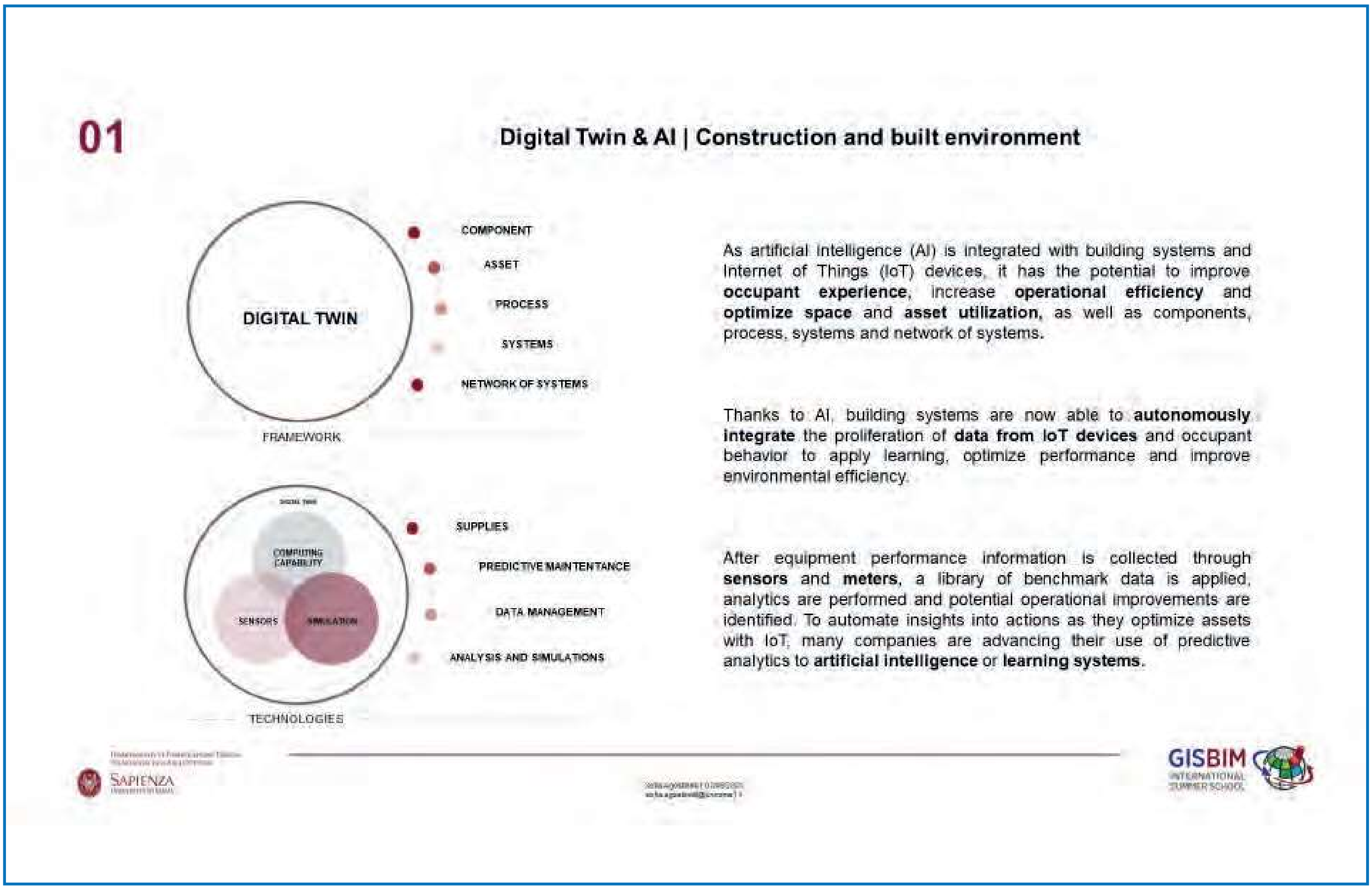
01
Digital Twin & AI | Construction and built environment
DIGITAL TWIN
COMPONENT
ASSET
PROCESS
SYSTEMS
NETWORK OF SYSTEMS
FRAMEWORK
COMPUTING CAPABILITY
SENSORS
SIMULATION
SUPPLIES
PREDICTIVE MAINTENTANCE
DATA MANAGEMENT
ANALYSIS AND SIMULATIONS
TECHNOLOGIES
As artificial intelligence (AI) is integrated with building systems and Internet of Things (IoT) devices, it has the potential to improve occupant experience, increase operational efficiency and optimize space and asset utilization, as well as components, process, systems and network of systems.
Thanks to AI, building systems are now able to autonomously integrate the proliferation of data from IoT devices and occupant behavior to apply learning, optimize performance and improve environmental efficiency.
After equipment performance information is collected through sensors and meters, a library of benchmark data is applied, analytics are performed and potential operational improvements are identified. To automate insights into actions as they optimize assets with IoT, many companies are advancing their use of predictive analytics to artificial intelligence or learning systems.
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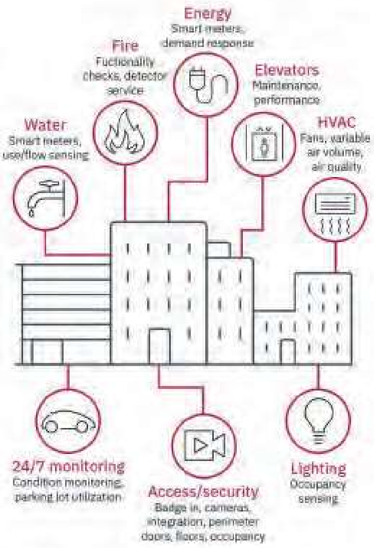
02

Digital Twin & AI | Framework and objectives



AI is able to capture **data from day-to-day building operations** to enable new levels of automation, which enables buildings to "**think,**" **engage and learn**. These buildings can autonomously monitor and predict their own maintenance needs.

Building intelligence into buildings means:

Optimize building maintenance and improve responsiveness.
Use advanced algorithms to detect future operating faults before they occur. Expose faults with predictive analytics to determine case, impact and recommendation. Automate device responses.

What percentage of buildings operating costs is allocated to maintenance?

Integrate sensors, devices, data and external data sources.
Infuse weather data, micro-location forecasts and advanced analytics to make more informed energy decisions. Identify and reduce water waste, usage and costs by detecting leaks and other anomalies.

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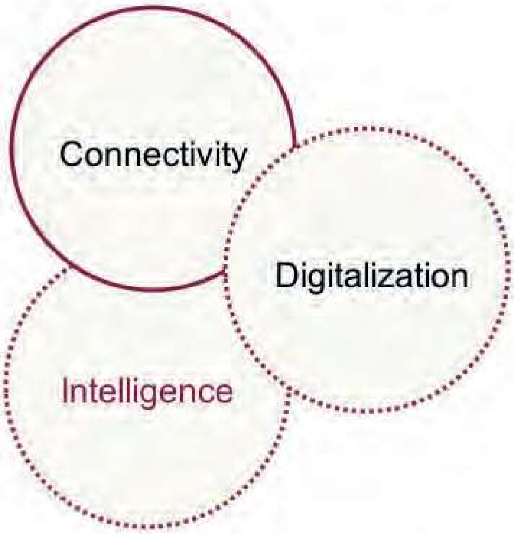
Big Data and Artificial Intelligence | Enabling technologies



Connectivity

Sensors

Sensors distributed throughout the processes and operations create signals that enable Digital Twin to capture operational and environmental data pertaining to the physical process in the real world.

Big data

Real-world operational and environmental data from the sensors are aggregated and combined with data from different sources.

IoT

sensors communicate the data to the digital world through integration technology (which includes edge, communication interfaces, and security) between the physical world and the digital world, and vice versa.

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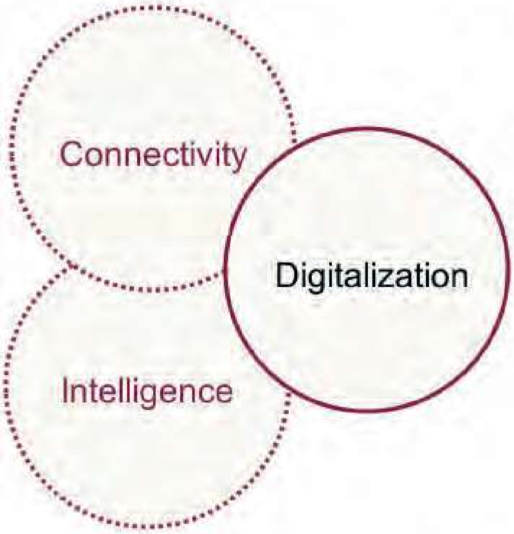
03 **Big Data and Artificial Intelligence | Enabling technologies**



Digitalization

Simulation modeling

the "digital" side of Digital Twin itself is an application that combines the components above into a near-real time digital model of the physical world and processes.

Data-driven modeling:

similar to simulation models, data-driven models (DDMs) provide the "digital" side of the Digital Twin. In contrast to Simulation models which consider explicit knowledge about the physical twin, DDMs borrow advance mathematical and statistical techniques to analyze the data that characterize a system to find relationships among inputs and outputs.

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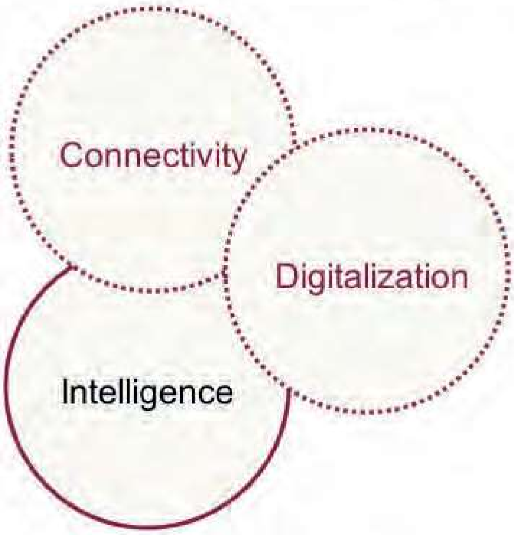

Intelligence

Artificial Intelligence (AI)

AI makes it possible for machines to learn from experience, adjust to new inputs and perform human-like tasks. AI can effectively perceive the environment, analyze the situation and identify the best decision to reach the predefined goal.

Analytics

Analytics techniques are used to analyze the data through algorithmic and visualization routines applied on the collected information by sensors in time.

Actuators

The AI behind the Digital Twin produces the action by using actuators, subject to human intervention, which triggers the physical process.
The necessary action usually regards the operative decision such as those needed in a dynamic control system;

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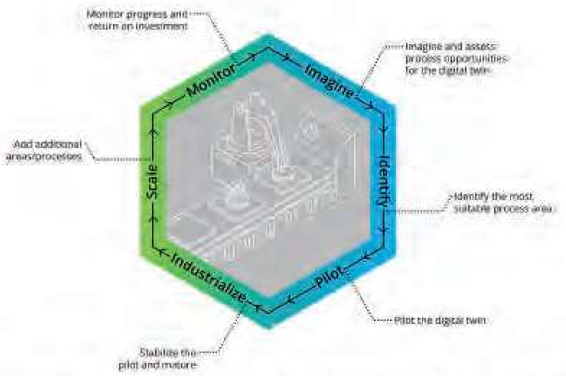

Source: Deloitte analysis.   Deloitte University Press | dupress.deloitte.com

Applications

Manufacturing

Digital Twin is poised to change the current face of manufacturing sector. Digital Twins have a significant impact on the way products are designed manufactured and maintained.

Automobile

Digital Twins can be used in the automobile sector for creating the virtual model of a connected vehicle. It captures the behavioral and operational data of the vehicle and helps in analyzing the overall vehicle performance as well as the connected features.

Retail

Appealing customer experience is key in the retail sector. Digital Twin implementation can play a key role in augmenting the retail customer experience by creating virtual twins for customers and modeling fashions for them on it.

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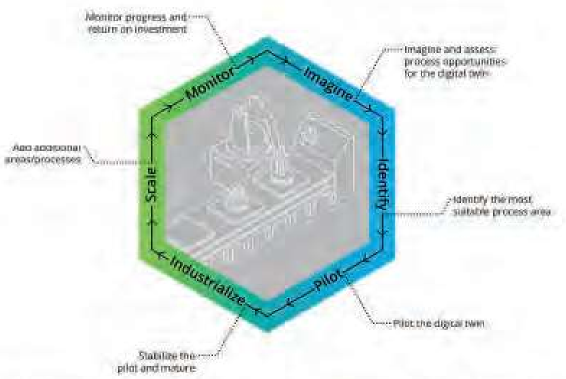

Source: Deloitte analysis.   Deloitte University Press | dupress.deloitte.com

Applications

Healthcare

Digital Twins along with data from IoT can play a key role in the health care sector from cost savings to patient monitoring, preventative intervention and providing personalized health care.

Smart Cities

The smart city planning and implementation with Digital Twins and IoT data helps enhancing economic development, efficient management of resources, reduction of ecological foot print and improving the overall quality of a citizen's life.

Industrial IoT

Industrial firms with Digital Twin implementation can now monitor, track and control industrial systems digitally. Apart from the operational data, the Digital Twins capture environmental data such as location, configuration, financial models etc. which helps in predicting the future operations and anomalies.

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04 Between Simulation models and Digital Twins | Opposite approaches

MORE THAN A DIGITAL MODEL

SIMULATION MODEL	DIGITAL TWIN
To-be	As-is
One-time built	Continuous evolutions
Offline	Online
Analysis	Actions
Logic based	Data intensiveness
Stand-alone	Connectivity
Single focus	Multiple focus

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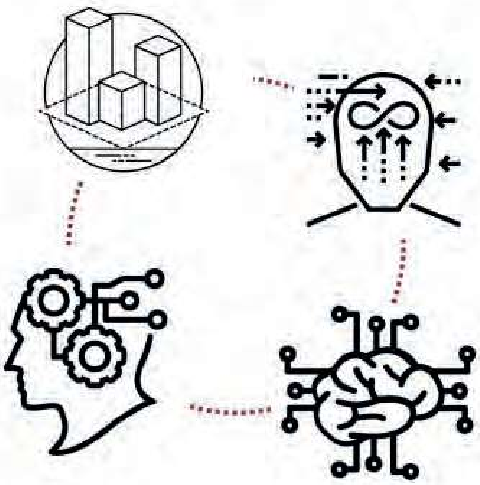
05 From information to automation | Construction workflow



Information model
3D federated information models

Learning
Digital models with learning capabilities, which process and transmit information detected by sensors

Intelligence
Integrated models with algorithms able to develop predictive analysis systems

Automation
models able to make autonomous decisions and implement the resulting actions

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Between BIM and GIS | Towards interoperability

Building the buildings Intelligence:
developing model in the urban context

1. Optimize the supply chain
2. Implement predictive maintenance systems
3. Manage and monitor the entire life cycle of urban assets serving decision makers, users and citizens

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06

Between BIM and GIS | Towards interoperability

BIM
1. Attributes and properties of components
2. Consistencies and quantity
3. Parameters and design features

GIS
1. Large-scale data
2. Territorial planning
3. Management of assets and urban areas

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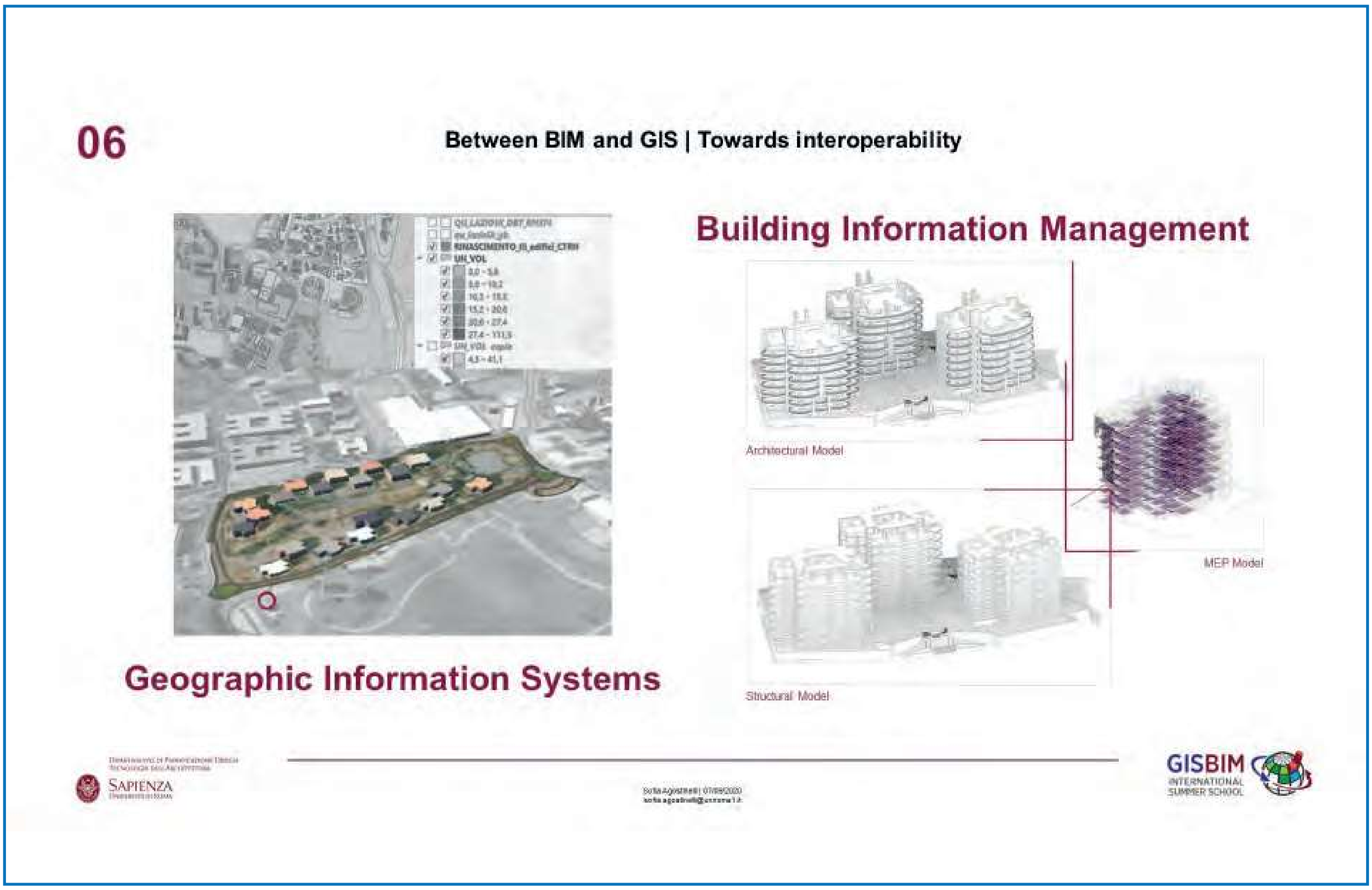
06
Between BIM and GIS | Towards interoperability
Building Information Management
Architectural Model
MEP Model
Structural Model
Geographic Information Systems
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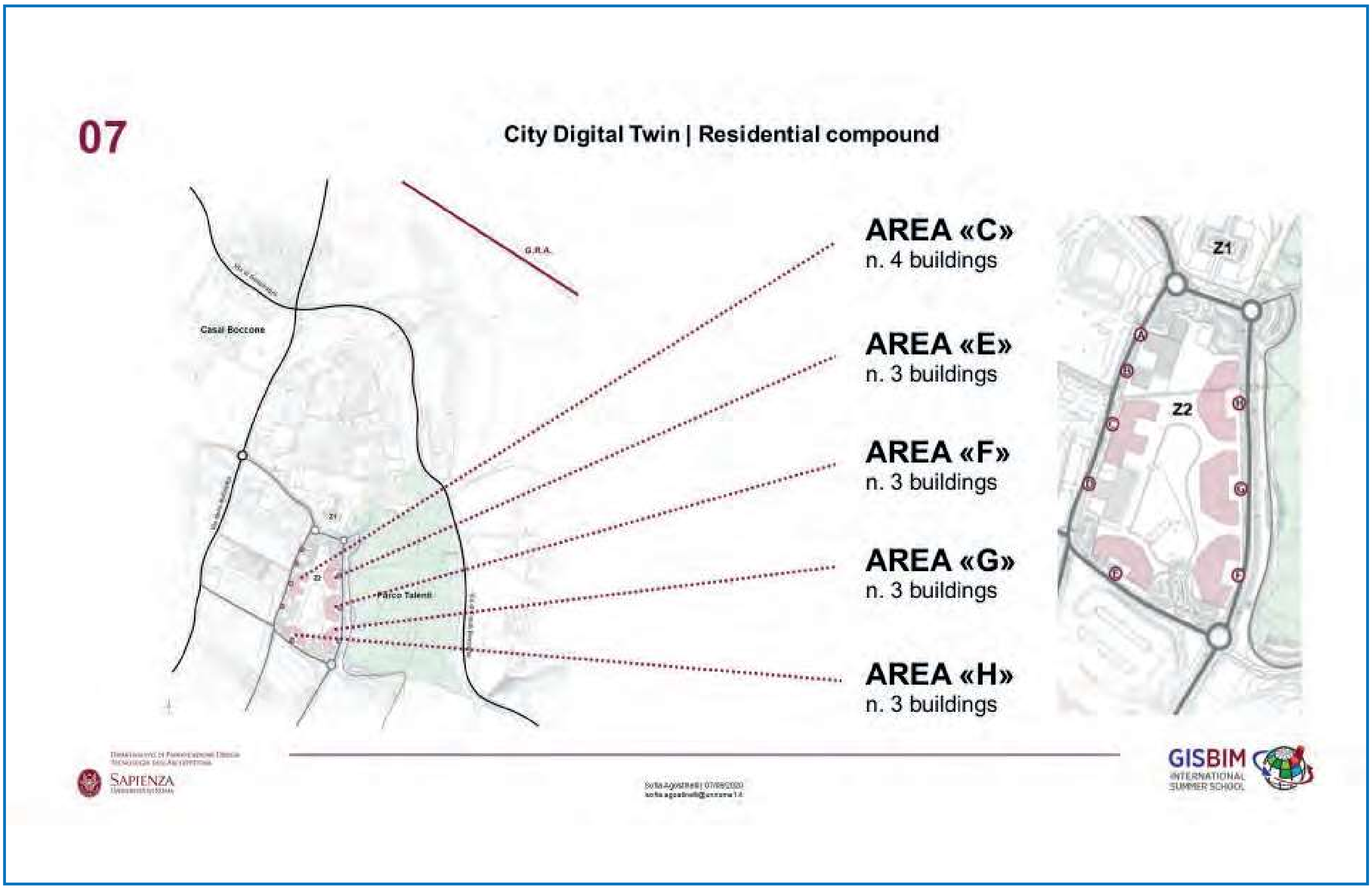
07
City Digital Twin | Residential compound
G.R.A.
Casal Boccone
Parco Talenti
AREA «C»
n. 4 buildings
AREA «E»
n. 3 buildings
AREA «F»
n. 3 buildings
AREA «G»
n. 3 buildings
AREA «H»
n. 3 buildings
Z1
Z2
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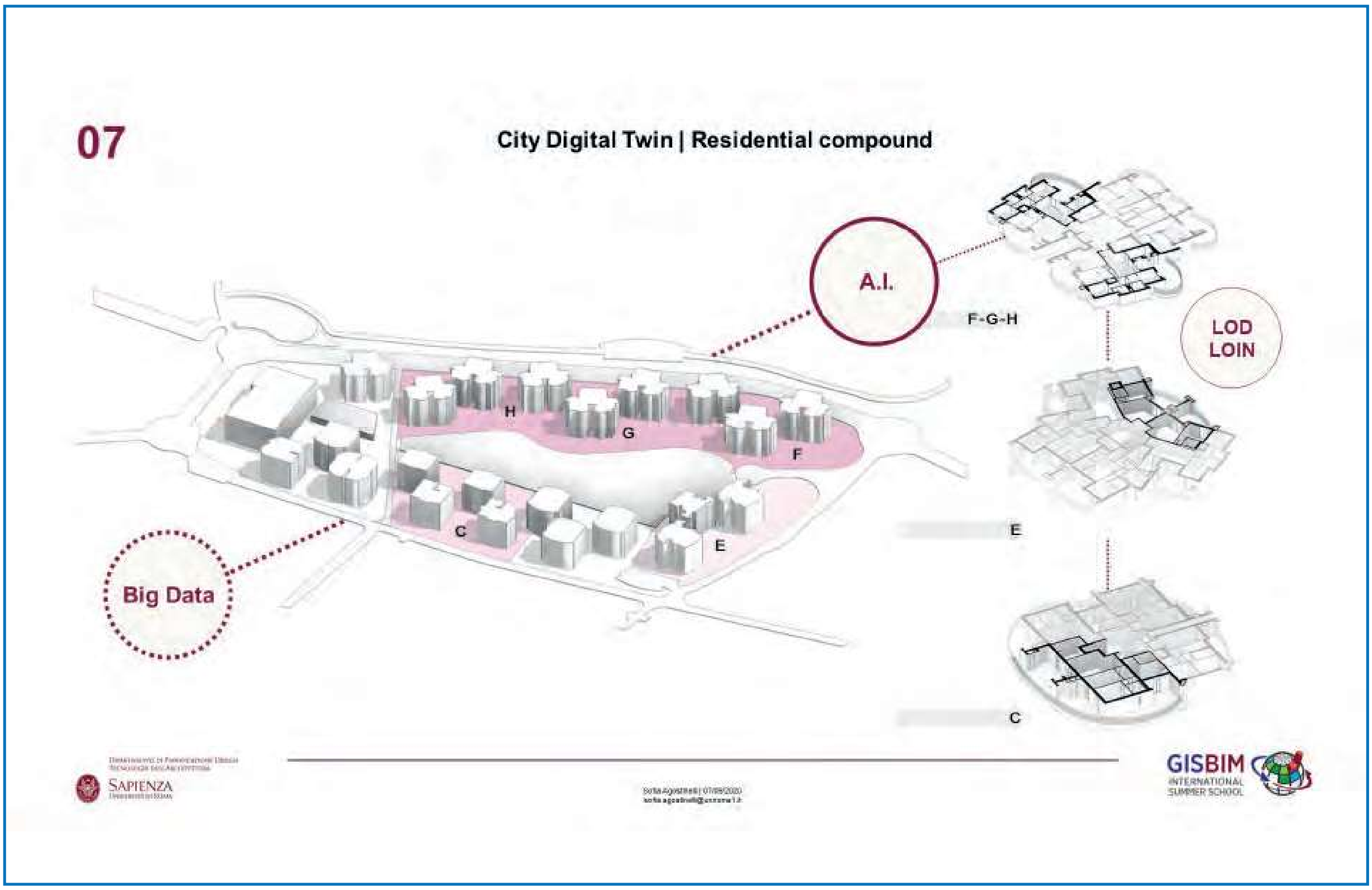
07
City Digital Twin | Residential compound
A.I.
F-G-H
LOD
LOIN
H
G
F
C
E
E
C
Big Data
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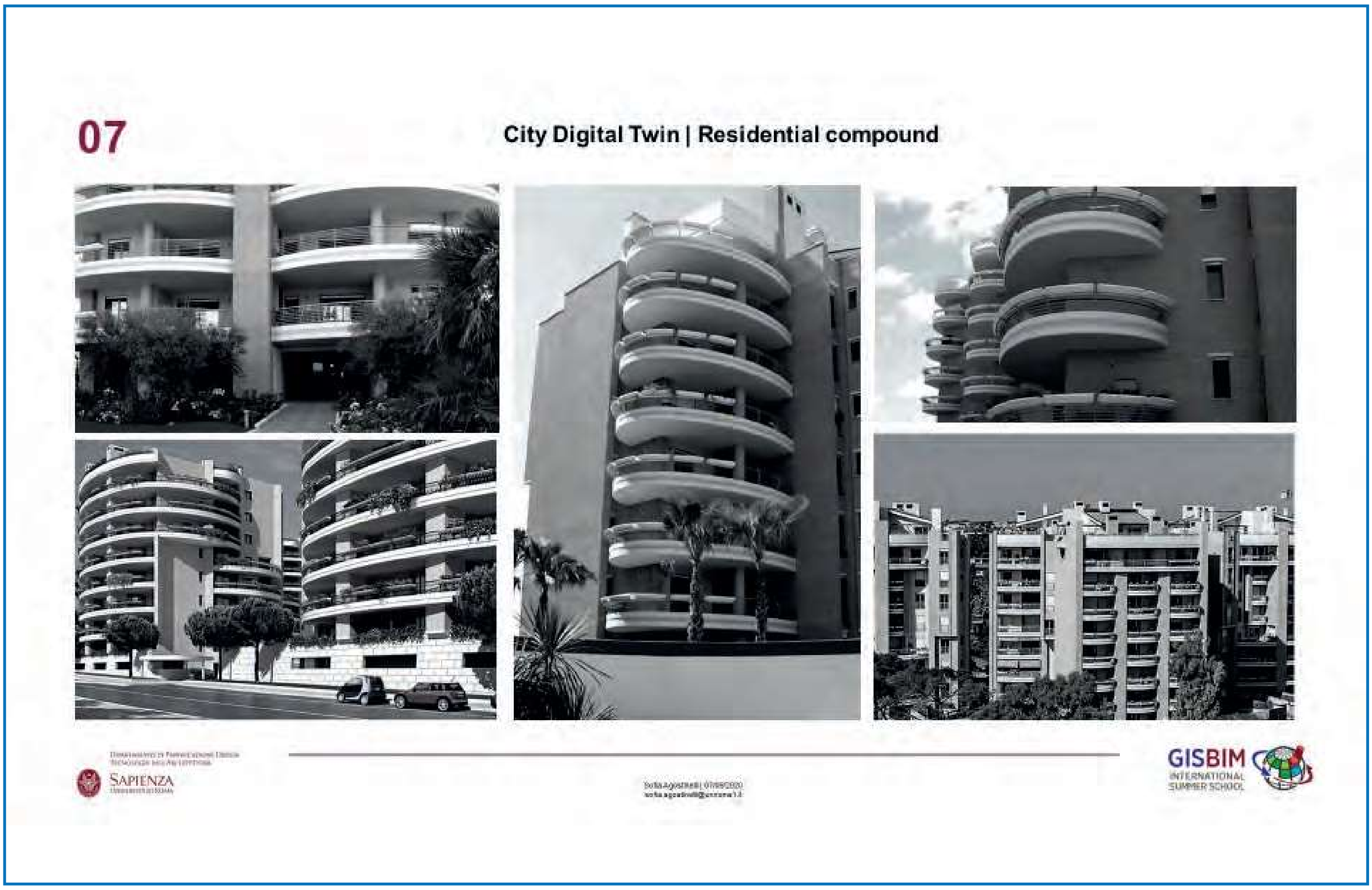
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City Digital Twin | Residential compound
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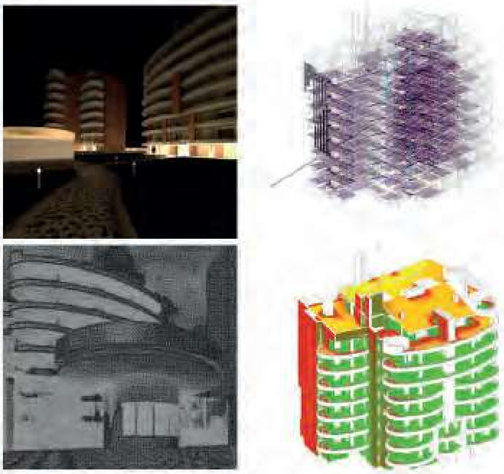
09

Predictive management systems | Objectives and further developments



1. **Energy Management**
self-managed oriented energy smart grid for consumption and production optimization

2. **Security Management**
integrated digital system for unmanned security management (independent from human component)

3. **Facility Management**
reduction of operating costs and malfunctions through predictive maintenance systems

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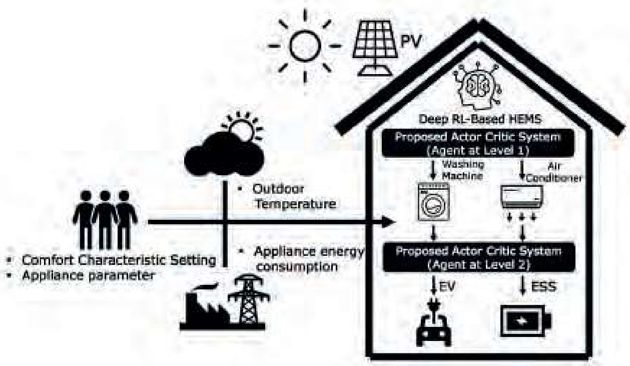
09

Machine learning | Energy Management



Dataset is passed to a machine learning algorithm that is literally "trained", making it possible to predict or accurately estimate the future energy consumption of devices or loads.

By processing energy consumption data, for example, the historical data of energy consumed by a building from 1996 to 2015, it is possible for a model to reveal **trends** and **patterns**, but also, to predict **future energy consumption patterns** with 3 major benefits:

- Economic: companies and individuals can translate energy into cost, and therefore estimate their energy bill, and make decisions based on this.
- Practical: By not only knowing how much energy we will consume, but understanding how and why we will, we can change our habits without affecting our productivity or the quality of our lives.
- Technical: Better managing energy data unlocks new possibilities in the collection and analysis of this data, as well as in generating more accurate predictions.

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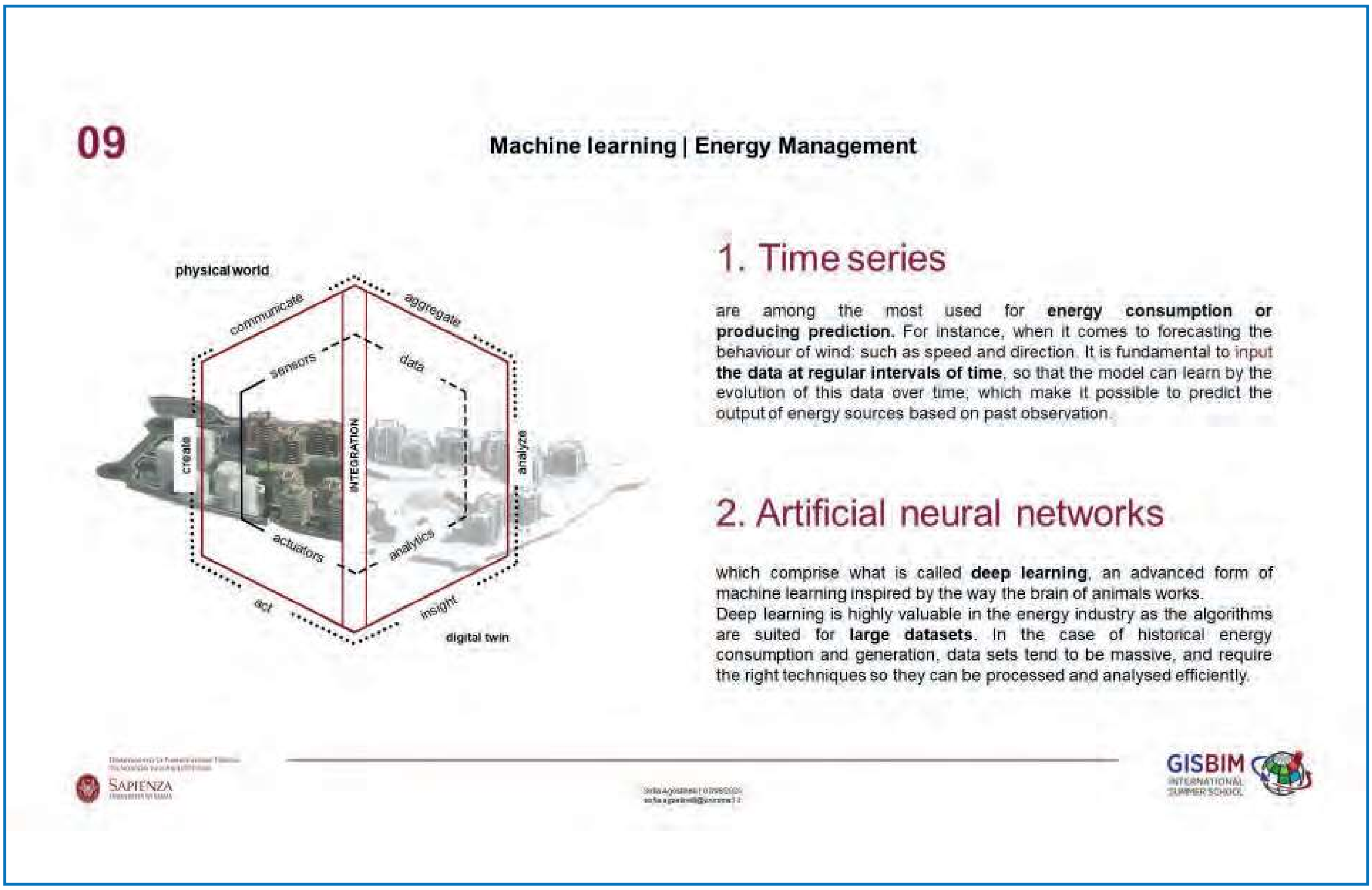
09
Machine learning | Energy Management
physical world
communicate
aggregate
sensors
data
create
INTEGRATION
analyze
actuators
analytics
act
insight
digital twin
1. Time series
are among the most used for **energy consumption or producing prediction.** For instance, when it comes to forecasting the behaviour of wind: such as speed and direction. It is fundamental to input **the data at regular intervals of time**, so that the model can learn by the evolution of this data over time; which make it possible to predict the output of energy sources based on past observation.
2. Artificial neural networks
which comprise what is called **deep learning**, an advanced form of machine learning inspired by the way the brain of animals works.
Deep learning is highly valuable in the energy industry as the algorithms are suited for **large datasets**. In the case of historical energy consumption and generation, data sets tend to be massive, and require the right techniques so they can be processed and analysed efficiently.
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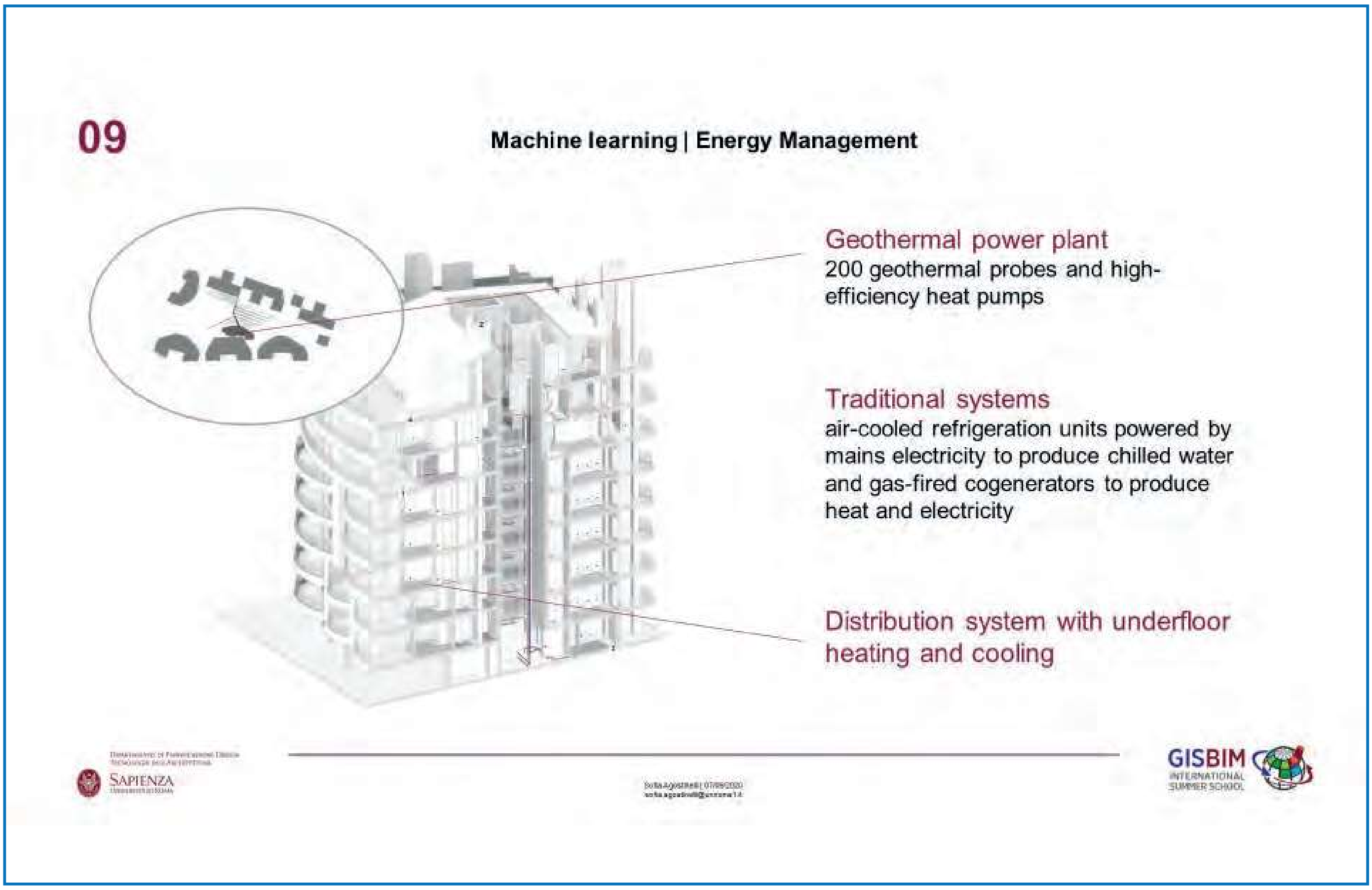
09
Machine learning | Energy Management
Geothermal power plant
200 geothermal probes and high-efficiency heat pumps
Traditional systems
air-cooled refrigeration units powered by mains electricity to produce chilled water and gas-fired cogenerators to produce heat and electricity
Distribution system with underfloor heating and cooling
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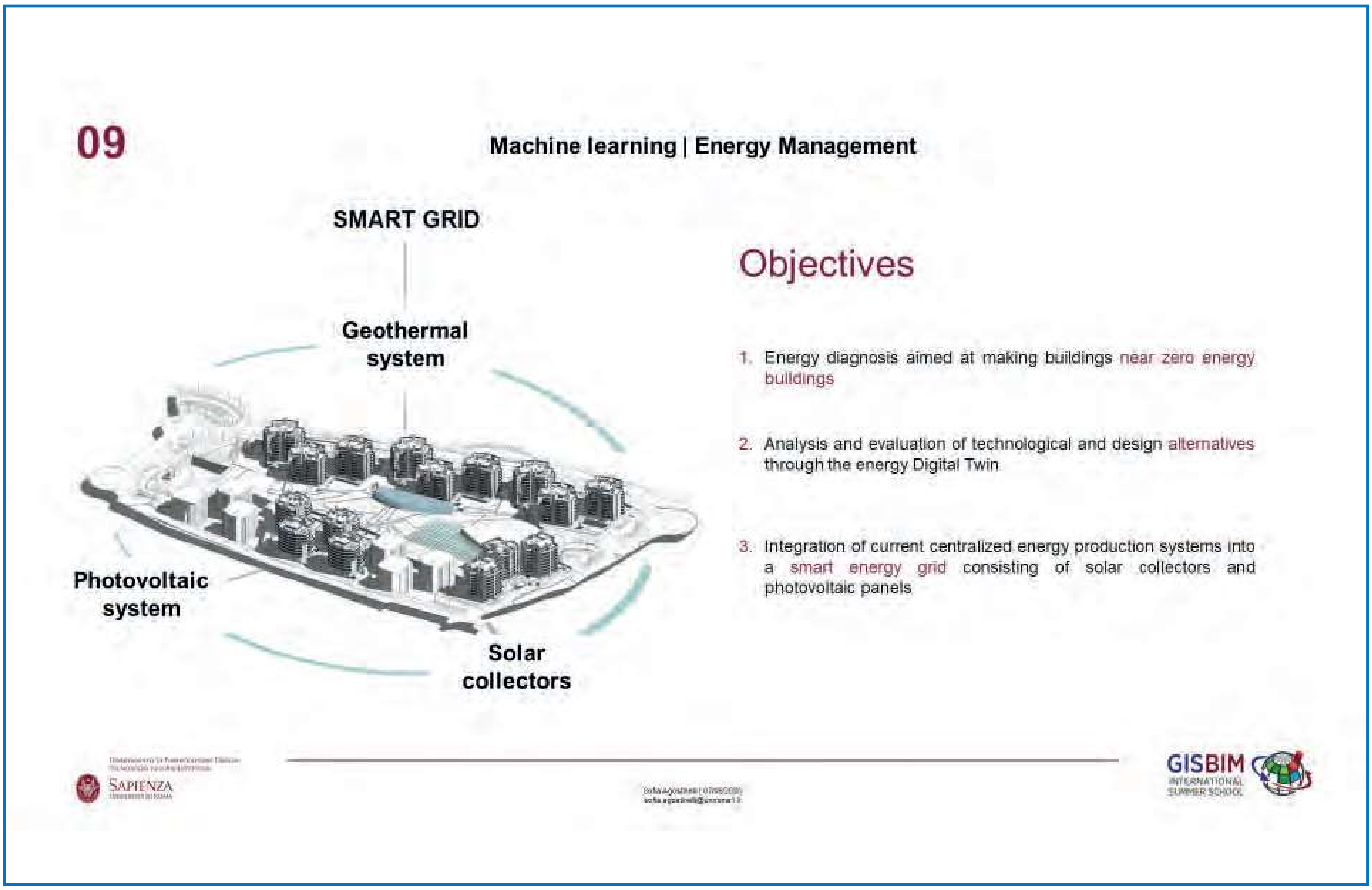
09
Machine learning | Energy Management
SMART GRID
Geothermal system
Photovoltaic system
Solar collectors
Objectives
1. Energy diagnosis aimed at making buildings near zero energy buildings
2. Analysis and evaluation of technological and design alternatives through the energy Digital Twin
3. Integration of current centralized energy production systems into a smart energy grid consisting of solar collectors and photovoltaic panels
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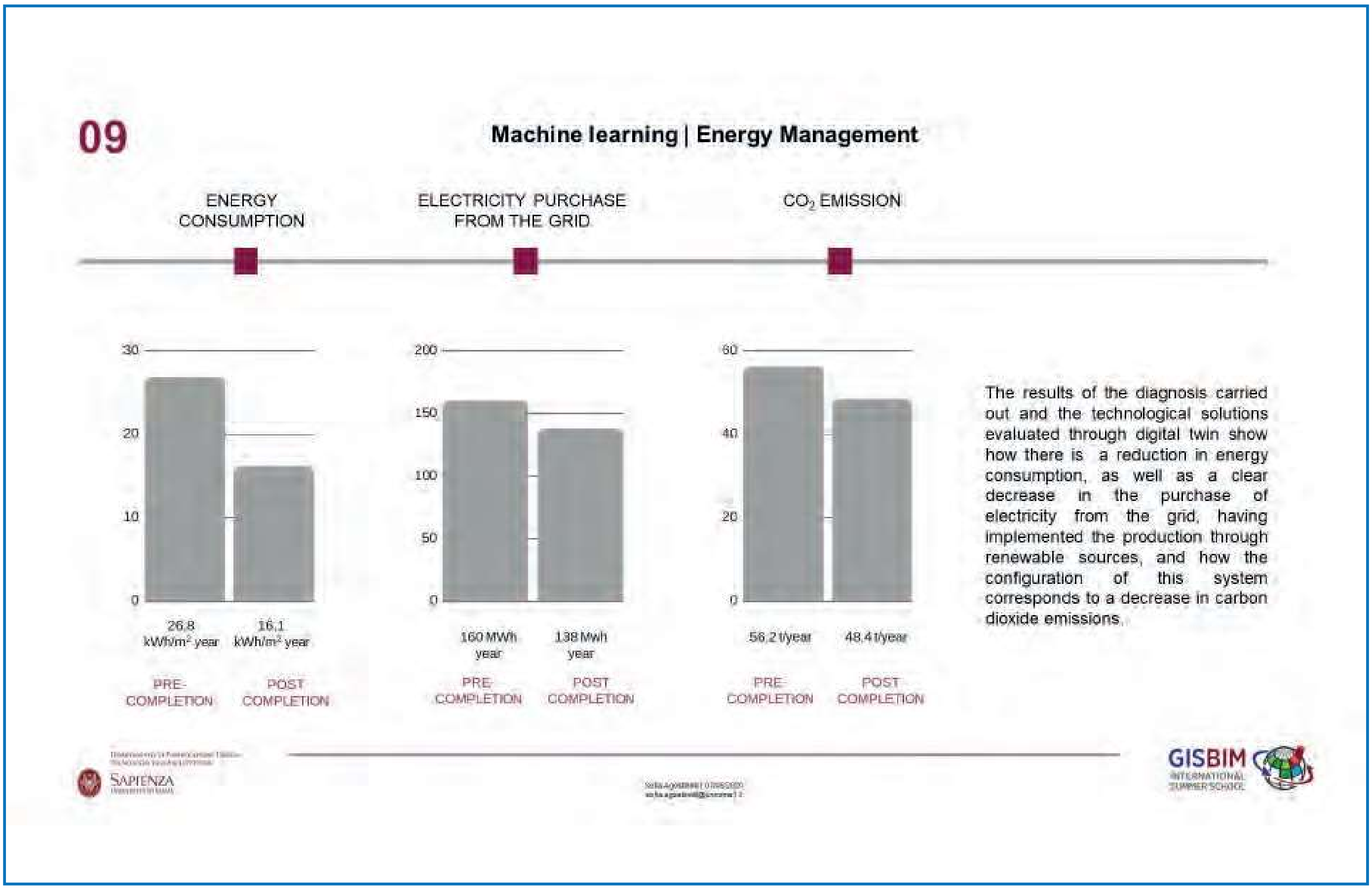
09
Machine learning | Energy Management
ENERGY CONSUMPTION
ELECTRICITY PURCHASE FROM THE GRID
CO2 EMISSION
30
20
10
0
26.8 kWh/m2 year
16.1 kWh/m2 year
PRE-COMPLETION
POST COMPLETION
200
150
100
50
0
160 MWh year
138 Mwh year
PRE-COMPLETION
POST COMPLETION
60
40
20
0
56.2 t/year
48.4 t/year
PRE-COMPLETION
POST COMPLETION
The results of the diagnosis carried out and the technological solutions evaluated through digital twin show how there is a reduction in energy consumption, as well as a clear decrease in the purchase of electricity from the grid, having implemented the production through renewable sources, and how the configuration of this system corresponds to a decrease in carbon dioxide emissions.
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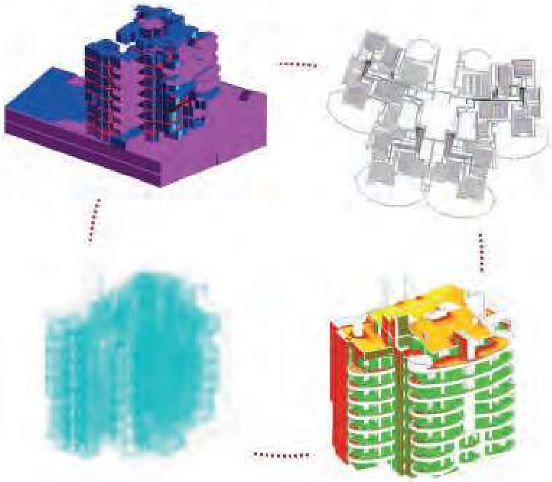
10

BEM & Energy Analysis | Case study



BEMs for energy audits

1. Definition of general data about buildings (location, climate etc.)
2. Identification of materials, structures, windows and doors
3. Definition of exposures
4. Definition of buildings units and zones
5. Inclusion of thermal bridges
6. Winter Dispersion Calculation
7. Calculation of Thermal Loads

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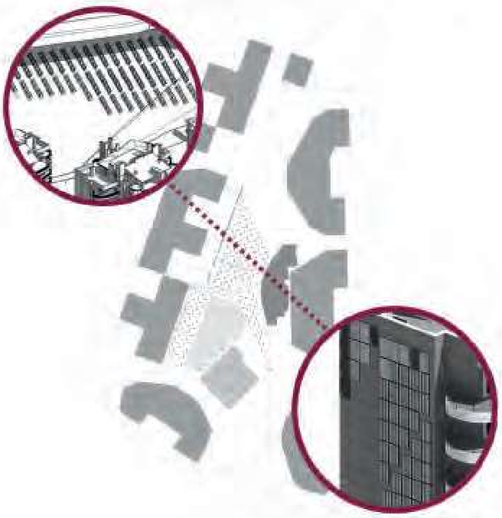
11

Smart grid management through AI | Case study



Objectives

1. Use the potential of machine learning to create a virtuous automated system for the management of both the **production** and **consumption** of electricity and heat in the whole compound.

2. Algorithms for calculating the maximum energy that can be produced by the three systems (geothermal, solar thermal and solar photovoltaic), which predict the consumption of buildings based on historical data transmitted by sensors and integrated with the daily calculation of thermal loads made by digital twin

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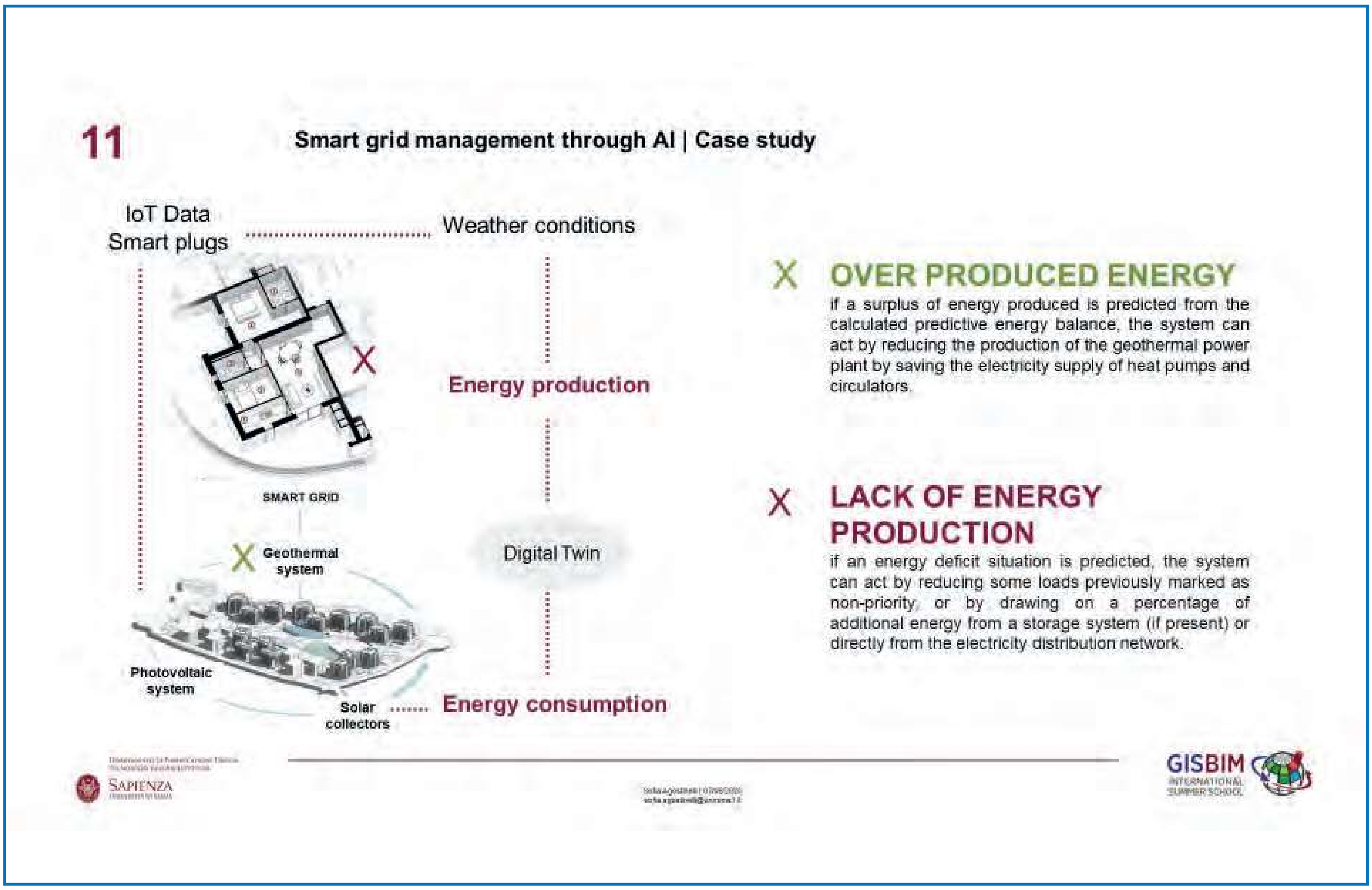
11
Smart grid management through AI | Case study
IoT Data
Smart plugs
Weather conditions
Energy production
SMART GRID
Geothermal system
Digital Twin
Photovoltaic system
Solar collectors
Energy consumption
X OVER PRODUCED ENERGY
if a surplus of energy produced is predicted from the calculated predictive energy balance, the system can act by reducing the production of the geothermal power plant by saving the electricity supply of heat pumps and circulators.
X LACK OF ENERGY PRODUCTION
if an energy deficit situation is predicted, the system can act by reducing some loads previously marked as non-priority, or by drawing on a percentage of additional energy from a storage system (if present) or directly from the electricity distribution network.
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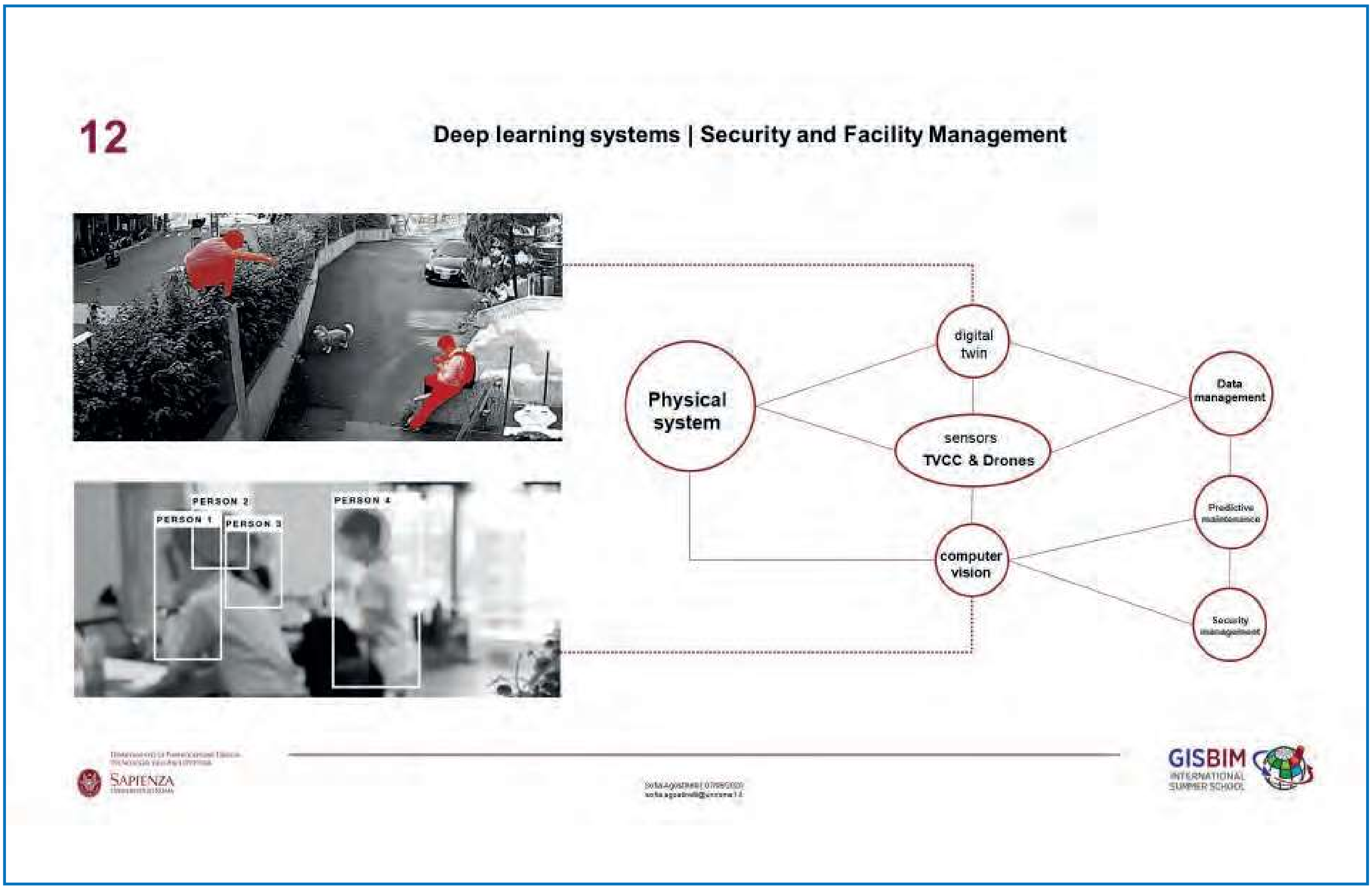
12
Deep learning systems | Security and Facility Management
PERSON 1
PERSON 2
PERSON 3
PERSON 4
Physical system
digital twin
sensors
TVCC & Drones
computer vision
Data management
Predictive maintenance
Security management
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13

TVCC & lighting systems | Security and Facility Management

The era of **Big Data** and **computing power** has brought artificial intelligence closer to video security systems, creating intelligent detection algorithms based on Deep Learning to analyze hundreds of **real-world detection cases**. The result is the possibility to apply a filter in **VCA** (video content analysis) detections that allows to distinguish human beings and vehicles from other targets that can generate false alarms.

The ability of these devices consists in the detection in detail and in a fully automated way of suspicious attitudes or actions that can be postponed to theft or assault. The Artificial Intelligence systems are therefore able to activate themselves in an instantaneous and preventive way, reporting what is happening through alerts, activation of alarms, visual signals, call to the police, notification to the security manager etc. according to the type of scene identified.

The potentialities of such advanced security systems also reside in the possibility to create a profile of the protagonists of unclear actions, so that they can be identified at a later time, even if they wear different clothes or have their head covered.

This system needs to be implemented with a **TVCC network** with the integration of a **lighting system** that allow cameras to detect actions and recognize details.

TVCC system
Closed Circuit Television

Lighting system

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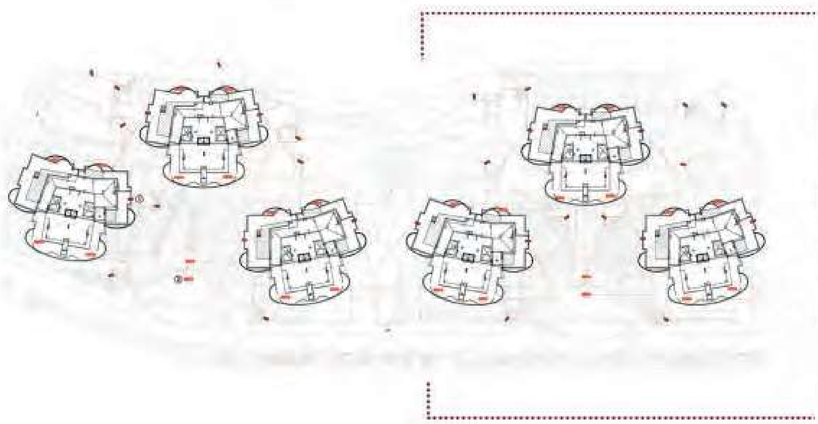
TVCC & lighting systems | Security and Facility Management



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Risk analysis | Security Management

The digital security management of the sector then goes through the careful phase of **risk modeling**, i.e. the configuration within the model of different categories of areas to be monitored and differentiated basing on possible intercepted emergencies.

Each area has therefore been assigned a set of possible risks connected and evaluated basing on the **structural nature** of the area (interior, perimeter, public areas, etc.) and the **lighting levels**.

The analysis of the risk factors identified leads to a summary picture that highlights the critical areas and identifies in detail the **monitoring parameters** of the individual areas that make up the residential compound.

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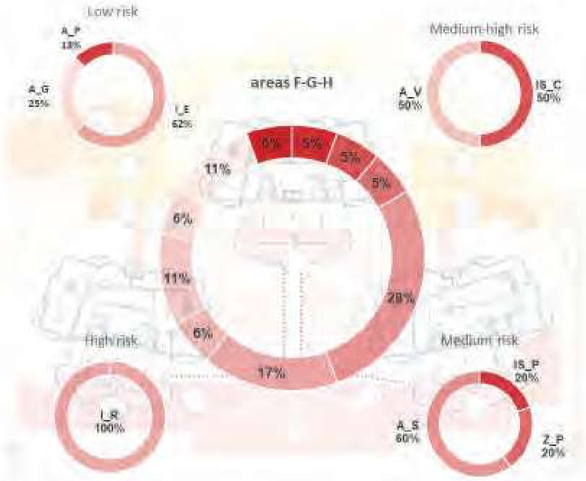
Risk analysis | Security Management



Through digital twin, therefore, a **risk database** is created within a **three-dimensional information model** that contains a volumetric recognition of the areas subjected to video surveillance.

Each area is analyzed and evaluated according to the hazard and the associated risks with reference to current security conditions, which can be implemented through **analysis** and **simulation** of **different design solutions**, evaluated through digital twin, up to define an **image recognition system** integrating cameras and related lighting system necessary to ensure high levels of security.

The result of the analysis of the risk database is therefore the definition of a **risk level** for each area, evaluated through a matrix that identifies the **nature of the area**, its current safety level in terms of **levels of lighting**, and assigns a rank useful for the **digital monitoring** of the entire area.

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15 **Artificial Intelligence for O&M | Facility Management**

Objectives

1. Reconfiguration of the maintenance approaches (currently limited to plant operation and fault intervention), by implementing intelligent systems for **predictive maintenance**, based on sensors and historical data.
2. Monitoring with digital systems for the reduction of maintenance interventions with the aim of ensuring overall **cost savings.**
3. Implementation of the information model with the technical data of the individual interventions (costs, duration, frequency) for the configuration and **digital management** of the maintenance program

15 **Artificial Intelligence for O&M | Facility Management**

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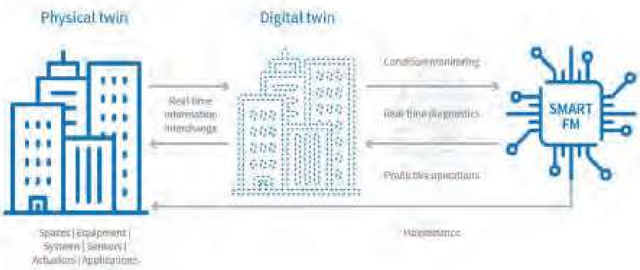

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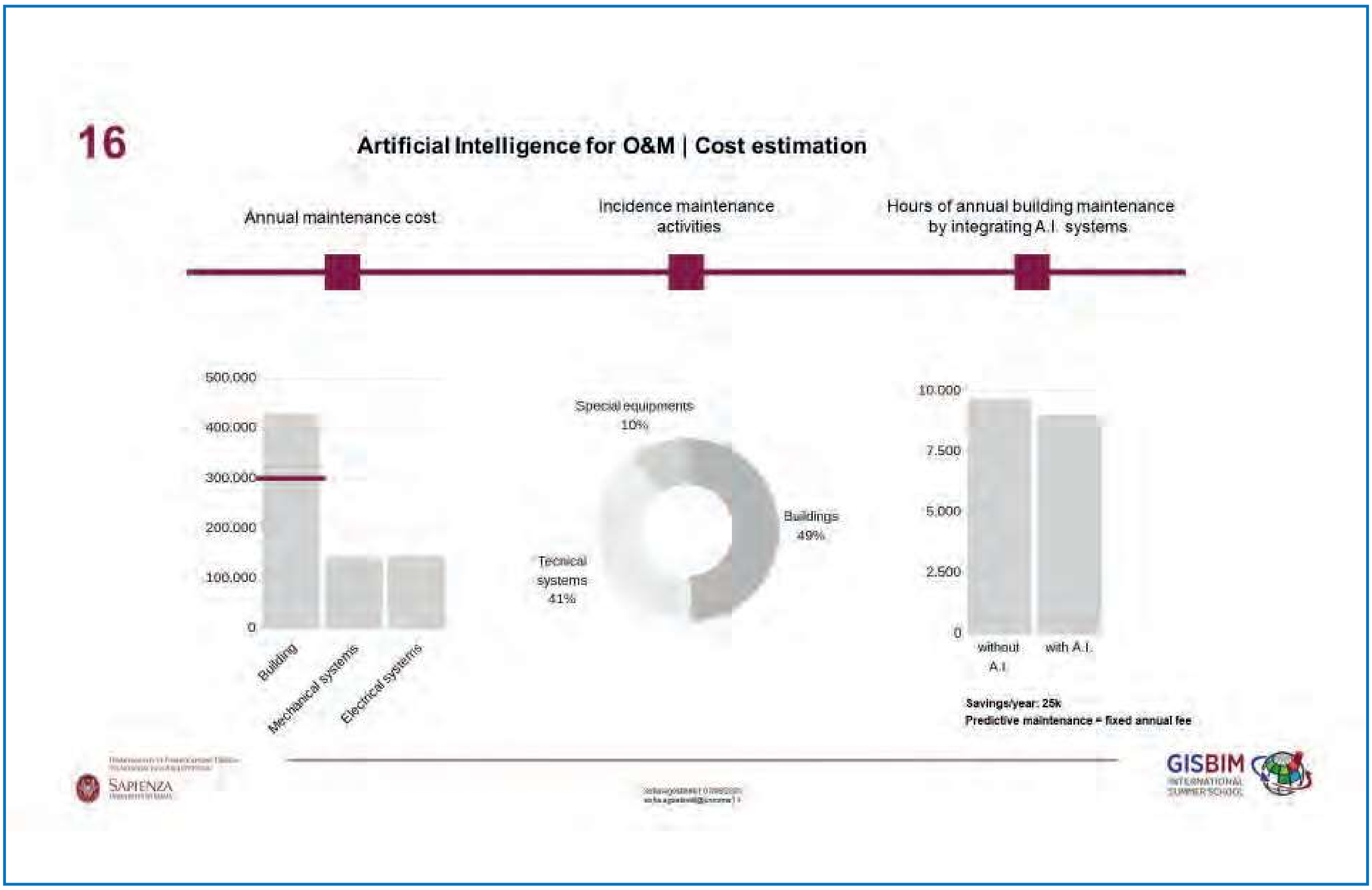
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Artificial Intelligence for O&M | Cost estimation
Annual maintenance cost
Incidence maintenance activities
Hours of annual building maintenance by integrating A.I. systems
500.000
400.000
300.000
200.000
100.000
0
Building
Mechanical systems
Electrical systems
Special equipments 10%
Buildings 49%
Tecnical systems 41%
10.000
7.500
5.000
2.500
0
without A.I.
with A.I.
Savings/year: 25k
Predictive maintenance = fixed annual fee
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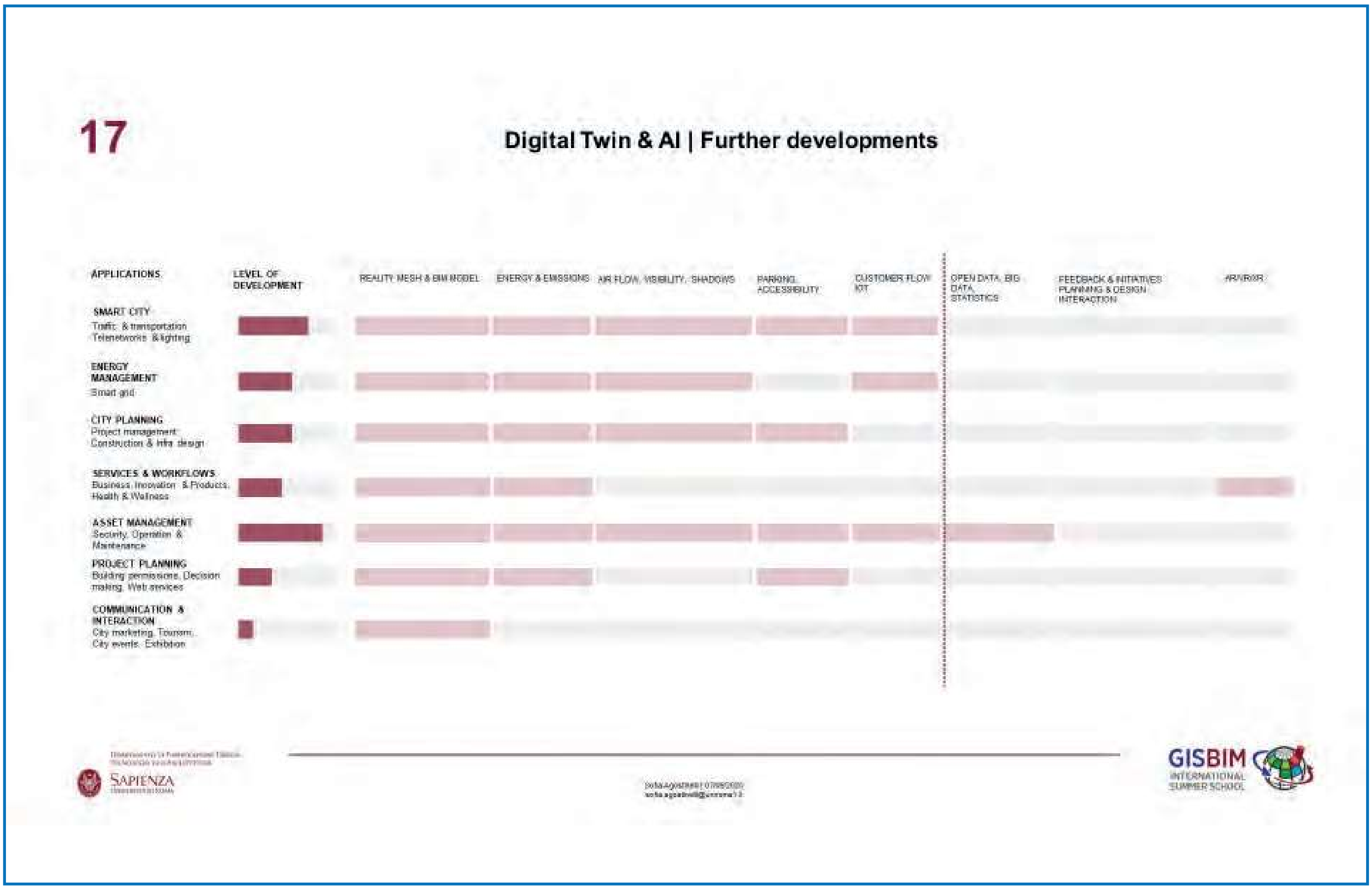
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Digital Twin & AI | Further developments
APPLICATIONS
LEVEL OF DEVELOPMENT
REALITY MESH & BIM MODEL
ENERGY & EMISSIONS
AIR FLOW, VISIBILITY, SHADOWS
PARKING, ACCESSIBILITY
CUSTOMER FLOW IOT
OPEN DATA, BIG DATA, STATISTICS
FEEDBACK & INITIATIVES PLANNING & DESIGN INTERACTION
AR/VR/XR
SMART CITY
Traffic & transportation Telenetworks & lighting
ENERGY MANAGEMENT
Smart grid
CITY PLANNING
Project management Construction & Infra design
SERVICES & WORKFLOWS
Business, Innovation & Products, Health & Wellness
ASSET MANAGEMENT
Security, Operation & Maintenance
PROJECT PLANNING
Building permissions, Decision making, Web services
COMMUNICATION & INTERACTION
City marketing, Tourism, City events, Exhibition
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