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Towards a Healthy City: Urban and Architectural Strategies for Age-friendly Design

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ABSTRACT

The main challenges that today's metropolises have to face, in addition to an often-unregulated urban growth, concern the progressive aging of the world's population.

This article proposes an evaluation and support tool for age-friendly design based on integrating the certification system, combined with a predictive approach that characterizes Digital Twins.

The goal is to transform a city segment from a Smart to Healthy City, where technology will continuously improve the physical and social environments.

A model structured in this way and highlighting its physical discontinuities at the urban level allows simulating interventions to make them safer and respond on time to the deficiencies in the preventive assessment phase.

A virtual functionalized urban sector will be obtained, offering safe roadways and green spaces and adequate services to avoid the concentration of specific activities in the same areas (commerce, education, health services).

The innovative aspect of the research is the multidimensional approach, which allows you to combine the potential of digital models made in Building Information Modeling (BIM) environment with the Geographic Information System (GIS), further integrated with the Age-friendly system of evaluation and certification, which are an articulate and valid tool to support decision-making processes to design places on a human scale. This tool can also be helpful in the context of the health emergency we are experiencing due to the pandemic, which has placed an urgent need to rethink urban spaces to promote a greater sense of tranquillity, safety, and liveability. The purpose is to manage the flow of entry and exit from places of aggregation, imagining structures that can transform themselves when necessary and act as strategic support to health facilities. As a case study for the evaluation of the peculiarities of living spaces and social contexts, it was chosen the Balduina district, an urban area of Rome.

Keywords: *Healthy City, Age-friendly Built Environment, Building Information Modeling, Geographic Information System, Urban Digital Twins.*

INTRODUCTION

In the era of increasing ageing population, climate changes, urbanization, globalization, digitalization, new diseases, the public health challenges are quickly evolving, and strategic actions are necessary to create a healthy city (Azzopardi-Muscat et al, 2020). Each of these phenomena has important implications on the well-being and health of the population of each country and require that people be placed at the centre of any policy for sustainable development.

The First International Conference on Health Promotion, meeting in Ottawa on 21 November 1986, formulated the Ottawa Charter for Action on Health for All. The Ottawa Charter stated that "Health is created and lived by people within the settings of their everyday life; where they learn, work, play, and love." (WHO, 2021)

In 1988 the WHO Regional Office's for Europe's created the Healthy Cities project to bring Health for All (HFA) to the local level. The World Health Organisation (WHO) claimed that "*a Healthy City is not one that has achieved a particular health status. Rather, a Healthy City is conscious of health and striving to improve it. It continually creates and improves its physical and social environments and expands community resources that enable people to mutually support each other in performing all the functions of life and developing to their maximum potential*". (Tsouros, 2017) It means that health is an individual and collective condition, strongly influenced by the environmental context and the strategies implemented by local governments.

The 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, signed in 2015 by the governments of the 193 member countries of the United Nations, re- emphasized the importance of a health cities approach; in particular SDG 3 "ensure healthy lives and promote well-being for all at all ages", and SDG 11 "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations, 2015).

The current cities are defined by Capolongo et al "pivotal for the public health paradox" because on the one hand, they should offer services to promote health and well-being; but on the other hand they produce many risk factors such as pollution, heat island that affect the health status of inhabitants, especially the more fragile population such as the elderly (Capolongo et al, 2018). In fact, according to the Organisation for Economic Co-operation and Development (OECD) (OECD Publishing, 2015), cities are home to 43.2% of the elderly population.

Urban contexts are therefore the ideal place to address the issue of population ageing and Health for All in an integrated and interdisciplinary way. In particular, collaboration between public health and urban planning is essential to create healthier neighbourhoods, towns and cities (WHO, 1999).

The key role of designers and urban planners in making cities healthier for their inhabitants, from the building scale to the urban scale, is evident.

This paper proposes an evaluation and support tool for age-friendly planning, based on the integration of the age-friendly certification system, which coming from the bilateral Italy-Sweden project "PRACTICE" (Planning Rethinked Ageing Cities Through Innovative Cellular Environments), integrated with the methodologies of predictive approach that characterize the Digital Twins.

The ultimate goal is to provide a multidimensional approach to the design of cities to define more appropriate solutions for the accessibility and usability of spaces allowing greater autonomy to the population with particular regard to the most fragile segments of the people, such as the elderly.

AGE-FRIENGLY CERTIFICATION FOR THE BUILT ENVIRONMENT

In 2007, the WHO drew up a guide, Global Age-friendly Cities: A Guide, based on a survey of 33 cities in all WHO regions. The WHO administered questionnaires to the over-65s in order to ascertain the advantages and difficulties they experience in the eight key areas of city life: housing, transportation, social participation, respect and social inclusion, civic participation and employment, communication and information, community support and health services, outdoor spaces and buildings (WHO, 2007).

Based on the WHO guidance, a multi-criteria analysis system was developed to assess the actual adequacy level of buildings, considering even its urban context. The proposed age-friendly certification is structured according to three hierarchical levels:

1. area, macro-themes relevant to the evaluation;
2. categories, particular aspects of the areas;
3. criteria, certification evaluation items given a score of -1 to 5.

In addition to the assessment area, category and criterion, each sheet also includes the following items:

- requirement, expresses the quality objective to be pursued;
- unit of measurement, referring to the quantitative performance indicator;
- normative references;
- performance scale to be used in the indicator normalisation phase in the range from -1 to +5;
- method and verification tools, to be used to characterise the indicator value;
- criterion weight, the degree of importance that is assigned to the criterion, compared to the whole assessment tool.

Each area, category and criterion was given a weight representing its relative importance to the entire certification. This weight was deduced from the analysis of the answers to the questionnaire administered to different experts categories, such as doctors, architects, engineers, psychologists and nurses.

All other scores are calculated using the weighting system:

- criteria scores contribute to category scores;
- category scores contribute to area scores;
- the sum of each area scores combines to form the overall score, classifying each building performance level: Bronze, Silver, Gold.

The age-friendly building certification is composed of 5 areas, 15 categories and 35 different criteria (fig. 1).

Age-friendly home should be able to satisfy the occupants needs that change during their live. The homes must include some key features that make them safer and more usable for people with chronic or temporary disabilities and the elderly.

The proposed certification applies to executive projects to allow verification of all evaluation criteria and to existing buildings. The age-friendly urban environment certification is composed of 4 areas, 12 categories and 24 different criteria (fig. 2). The quality in an urban context is rather important for all citizen, especially for older people.

The neighbourhood represents for the elderly citizen the reference territorial scale and therefore, proximity to public services, especially transport systems and health services, shops and other services, green areas, within a radius of 500 metres or 15 minutes on foot (the World Health Organisation considers these to be the optimal distances for the elderly person to be able to move around easily) becomes fundamental. The proposed certification assesses these aspects and the safety and comfort level.

Villa	Flat	AGE-FRIENDLY BUILDING CERTIFICATION	WEIGHT
		1. Access	**0,35**
		1.1 Building access	*0,5*
x	x	1.1.1 Horizontal pathway	0,35
x	x	1.1.2 Parking area	0,3
		1.1.3 Entrance door	0,35
		1.2 Ingresso dell'abitazione	*0,5*
x	x	1.2.1 Entrance door	0,3
		1.2.2 Stairs	0,15
x	x	1.2.3 Door threshold dimension	0,15
		1.2.4 Elevator	0,4
		2. Manoeuvring space	**0,25**
		2.1 Internal horizontal pathway	*0,2*
x	x	2.1.1 Corridors	0,3
x	x	2.1.2 Internal doors	0,4
x	x	2.1.3 Spaces in front of and behind doors	0,3
		2.2 Internal vertical pathway	*0,15*
x		2.2.1 Internal stairs	1
		2.3 Toilets	*0,2*
x	x	2.3.1 Dimensional and functional specifications	1
		2.4 Living area	*0,25*
x	x	2.4.1 Kitchen	0,4
x	x	2.4.2 Dining room	0,3
x	x	2.4.3 Living	0,3
		2.5 Sleeping area	*0,1*
x	x	2.5.1 Bedroom	1
		2.6 External spaces	*0,1*
x	x	2.6.1 Balconies and terraces	1
		3. Interior fittings	**0,2**
		3.1 Finishes	*0,5*
x	x	3.1.1 Taps	0,2
x	x	3.1.2 Floorings (kitche, bathroom)	0,2
x	x	3.1.3 Floorings	0,2
x	x	3.1.4 Handles	0,2
x	x	3.1.5 Windows	0,2
		3.2 System terminals	*0,45*
x	x	3.2.1 Cytophone/videophone	0,15
x	x	3.2.2 Bell	0,15
x	x	3.2.3 Switches	0,35
x	x	3.2.4 Plugs	0,35
		3.3 Fixed fornitures	*0,05*
x	x	3.3.1 Mailbox	1
		4. Installations	**0,1**
		4.1 HVAC system	*0,7*
x	x	4.1.1 Heating	0,7
x	x	4.1.2 Cooling	0,3
		4.2 Renewable energy	*0,3*
x	x	4.2.1 Photovoltaics	0,4
x	x	4.2.2 Solar collector	0,6
		5. Ambient assisted living	**0,1**
		5.1 Safety and security	*0,8*
x	x	5.1.1 Security, control and implementation systems	0,4
x	x	5.1.2 Alarm systems	0,4
x	x	5.1.3 Air quality	0,2
		5.2 Smart metering	*0,2*
x	x	5.2.1 Smart metering electricity/gas	1

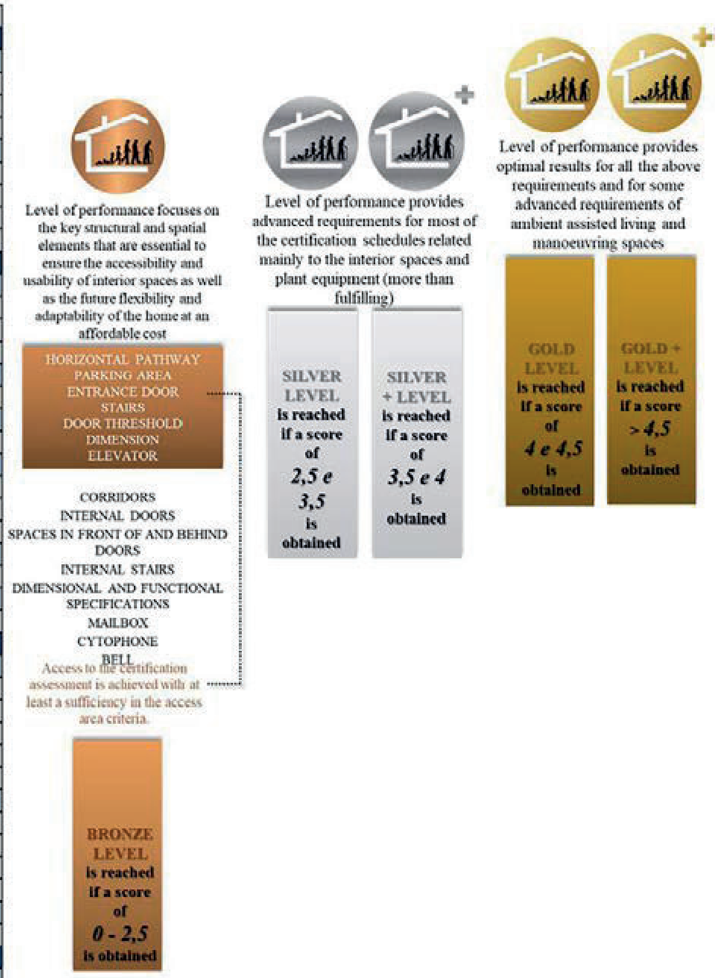

Figure 1: Index of age-friendly building certification assessment sheets.

AGE-FRIENDLY URBAN ENVIRONMENT CERTIFICATION	WEIGHT
1. Green and open-air spaces	**0,30**
1.1 Pavements	***0,20***
1.1.1 Road pavements	0,55
1.1.2 Parking area	0,45
1.2 Pedestrian areas	***0,30***
1.2.1 Pedestrian crossings	0,35
1.2.2 Sidewalk	0,55
1.2.3 Bike paths	0,10
1.3 Outdoor facilities	***0,50***
1.3.1 Public toilet	0,25
1.3.2 Benches and urban furniture	0,60
1.3.3 Urban decorum	0,15
2. Transports	**0,20**
2.1 Public transport	***0,70***
2.1.1 Transport accessibility	0,35
2.1.2 Location of public transportation stops	0,35
2.1.3 Quality of public transportation stops	0,10
2.1.4 Frequency	0,20
2.2 Private transport	***0,30***
2.2.1 Parking area	1,00
3. Safety and comfort	**0,15**
3.1 Outdoor pollution	***0,30***
3.1.1 Noise pollution	0,30
3.1.2 Atmospheric pollution	0,70
3.2 Urban safety	***0,30***
3.2.1 Safety system	1,00
3.3 Public lighting	***0,40***
3.3.1 Urban lighting	1,00
4. Services	**0,35**
4.1 Health services	***0,40***
4.1.1 Hospitals/first aid	0,45
4.1.2 Clinics	0,55
4.2 Cult places	***0,10***
4.2.1 Churches	1,00
4.3 Basic needs shop	***0,20***
4.3.1 Pharmacies	0,60
4.3.2 Supermarkets	0,40
4.4 Leisure and recreation	***0,30***
4.4.1 Parks and/or public gardens	0,50
4.4.2 Recreational clubs	0,50

Figure 2: Index of age-friendly urban environment certification assessment sheets.

DIGITAL TWIN – A NEW STRATEGY FOR HEALTHY CITY BUILDING

The urban context can have positive or negative effects on people's health and this highlights the need to enable research methodologies and monitoring of accurate data that today allow urban planners and architects a role as mediators and facilitators (Giofrè et al., 2017).

That is why the efficient and appropriate management of cities is very important given their rapid development in terms of size, population and consumption of resources.

With increasing urbanisation, it is crucial to focus on how technological innovation can help safeguard people's health and provide a sustainable future.

In this context, Digital Twin (DT) can be considered a new strategy for today's healthy city construction.

The Digital Twin is the virtual copy of a real physical object/system, through which studies, cost- benefit analyses of alternative solutions and various simulations can be carried out (Jones et al., 2020). Developed by NASA engineers as part of space programmes in the 1960s, DT thanks to the availability of numerous new Information Communication Technologies - ICT including Big Data, Cloud, Internet of Things, sensors, is now considered one of the main strategic technological trends of the coming years (Deren et al., 2021).

The following table gives some examples of Digital Twin potential applications in various sectors.

Table 1: Examples of Digital Twin possible and potential applications. (Source: Tao et al. 2019).

Domains	Possible/potential applications
Aerospace	Assembly line monitoring (Yin et al.,2019)
Agriculture and breeding	Animals health monitoring (Neethirajan et al, 2021)
Automotive	Car performance test in different conditions (Rajesh et al, 2019)
City management	Heating, ventilation and air conditioning system monitoring Intervention design selection support Real-time mobility monitoring Simulation traffic to optimize (Rudskoy et al., 2020)
Construction	Real time progress monitoring (Sacks et al., 2020) Safety workers monitoring Resource allocation and waste tracking optimization
Electric power generation	Carry out energy consumption scenarios and simulations with great precision and to adapt the electricity supply to them (Agostinelli et al, 2021) Help improve operations and maintenance over the useful life of physical installation Power grid planning optimization
Environmental protection	Resources management optimization Environmental health monitoring
Healthcare	Diagnosis and treatment decision support Patient realtime monitoring Personalized medicine Simulate the patient health status (Braun, 2020) Staff scheduling
Security and emergency	Catastrophic event prevention (Ford et al. 2020) Disaster management

Through advances in geospatial technologies, the Digital Twin is applicable to three-dimensional digital modelling at both building and urban scales.

The integration of the digital model with the Geographic Information System - GIS and ICT allows the data collection and their integration in real time, the processing of advanced analysis and the automation of future predictions (Zhu et al., 2018).

Data-driven urbanism, urban planning based on data collected more or less automatically, can enable more efficient city management.

An urban Digital Twin is the most accurate and complex possible reproduction of an urban environment, a part of a city or all of it (Castelli et al., 2019).

The aim is to collect and systematise as much data about the city as possible in order to have as complete a view as possible of the urban organism functioning at a given time.

Although study on the urban Digital Twin is still in its infancy, the potential applications are innumerable.

For exemple, the prototype of an urban Digital Twin for the 30,000-people town of Herrenberg in Germany has been developed to urban mobility and wind simulation, to support urban planners, urban designers and the general stakeholder (Dembsk et al., 2020).

The Digital Twin of the City of Zurich has been developed to support the city administration and to visualize construction projects and make them available to a selected group of people (Schrotter et al., 2020).

The open DT of the Docklands area in Dublin (Ireland) has been developed for urban planning of green space and skylines, allowing users to interact and report feedback on planned changes (White et al., 2021).

Ahn et al. use Digital Twin City (DTC) model to evaluate objects/areas potentially having a negative impact on older people mobility, to simulate possible solutions and to identify less-demanding paths (Ahn et al., 2020).

As the aim of planning is to improve the quality of life and urban space, the Digital Twin also aims to foreshadow possible scenarios as a result of the choices made and projects implemented. The idea is developed in the field of urban intelligence, adding the urban component to the smart city computerised approach, defined by the Massachusetts Institute of Technology the Senseable city (MIT). The word "Sense-able" includes the human component and has a double meaning: sensitive city and city capable of feeling.

In senseable cities, technology is not the ultimate goal but the tool to building highly computerised cities while at the same time questioning the human side of the city, going beyond the predominantly technological approach of the smart city (Belingardi, 2020).

METHODOLOGY: FROM 3D MODEL TO DIGITAL TWIN

The first methodological approach for the realization of the assessment tool is based on 3D modeling created through the use of BIM software such as Allplan Architecture, Autodesk Revit, Bentley Systems AECOsim Building, Designer Graphisoft ArchiCAD. The second step is the integration of age-friendly certification to evaluate the built environment through a graphical programming interface, such as Autodesk Dynamo, allowing customisation of the building information workflow.

The third methodological step is the integration BIM model with GIS technology, to perform simulations of real situations and then to simulate possible new scenarios, visualizing in real time their impact, for example, for the improvement of mobility to reduce pollution.

The fourth methodological step is to create an Urban Digital Twin through the installation of the IoT sensors, to monitor the actual behaviour of the entire built environment.

The following is a case study for a better understanding of the proposed methodological approach.

CASE STUDY: BALDUINA DISTRICT IN ROME, ITALY

The methodology described has been applied and verified in a quiet residential neighbourhood in the northwest of Rome, in the XIV Municipio (Fig. 3). The Municipio of our interest has increased between 2011 and 2019 by 5,563 units. The composition by age classes of the population, referring respectively to 2010, 2016, 2019, shows a particular evolution. Citizens aged between 35 and 44 years, those most present in the municipal territory, record a significant decrease from 17% to 14.7%. Instead, there is an increase of the 45-54 age group. There has been an increase even in over 75s in the municipal area in nine years, from 10.6% in 2010 to 11.7% in 2019 (Municipio Roma XIV, 2018).

Figure 3: Satellite view of the neighbourhood area examined (red) and the building examined (orange).

STEP 1 – 3D MODELING OF THE BUILDING

The building and the individual flats were reproduced out with Autodesk Revit 2020 software (fig. 4) to design the improvements and insert them into the GIS platform.

The modeling was based on an on-site visit that allowed us to obtain information about the building's geometry and the location of the assets. Specific information on the stratigraphy and materials used was decided to model walls, floors, ceilings, and generic roofs with the sole purpose of delimiting the rooms. The modeling of doors, windows, and furniture was also carried out to create a representatively coherent model. In this case, model information, separated into environment components (walls, floors, roofs) and model components (stairs, windows, doors, furniture), are at different levels of detail (LOD).

While the building blocks are of LOD 300, the elements are represented with the correct size, position, and orientation and interface correctly with the other elements of the model; the model components are of a higher level of detail than their predecessor, as they include manufacturing, assembly and installation information (LOD 400).

Figure 4: BIM model view of the case study building and architectural plan.

This diversification of the LOD is due to the proper application of age-friendly certification, which requires specific information such as door height, handle type, and faucet type. Once the building model was completed, the space of the flat under consideration was defined. The definition of the spaces is fundamental as it has allowed us to know the position of the various components.

STEP 2 – AGE-FRIENDLY CERTIFICATION FOR THE BUILT ENVIRONMENT

The building and urban scale certification described above has been integrated within the parametric BIM software to allow designers and planners to obtain an automatic evaluation of the criteria. This integration was achieved through the Dynamo tool; this is an open-source visual programming environment that allows automation procedures to be created by manipulating and linking graphic entities (nodes) to achieve the desired result.

The figure 5 shows a age-friendly certification sheet of the building scale that has been inserted in the environment BIM through Dynamo. This formula queries the model through criteria and evaluation elements of the certification to which is assigned a score from -1 to 5 (negative, sufficient, good, excellent), finally obtaining an sheet evaluation. This procedure, applied to each category, allows obtaining an overall assessment of the building.

This tool makes it possible to create algorithms to automatically identify critical points at the building and urban scale by reading the parameters contained in both the BIM model and the GIS. While BIM focuses on the building itself,often disconnected from its context, GIS specializes in the geospatial information that defines its exterior. The integrated use of these technologies can bring benefits in both fields. Data from a GIS can facilitate BIM applications such as site selection and material layout. At the same time, BIM models can help generate detailed models in a GIS and lead to more effective project management.

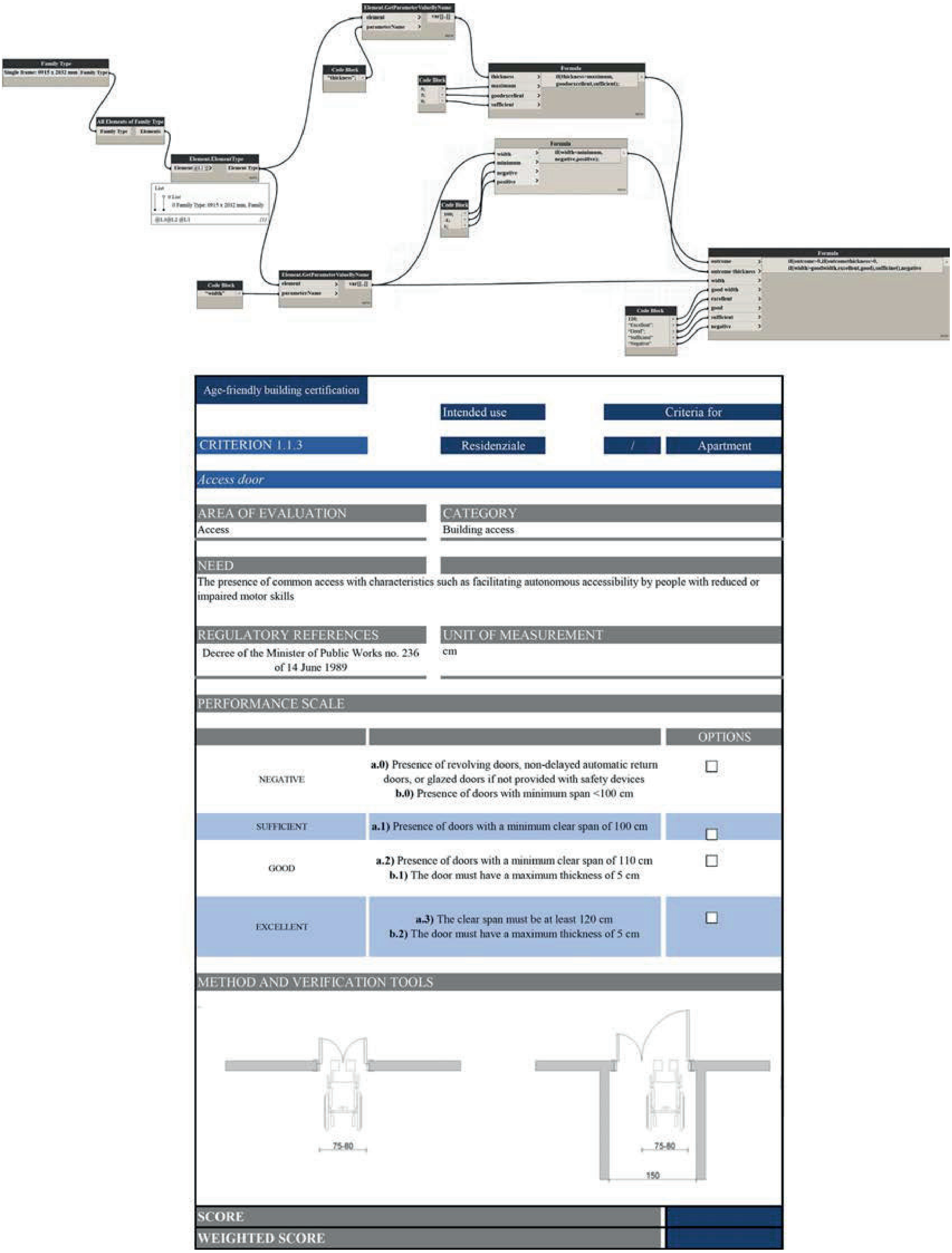

Figure 5: Example of the algorithm for criterion 1.1.3 of age-friendly building certification with reference sheet.

STEP 3 –BIM-GIS INTEGRATION

Once the building has been created in a larger context, it can be imported into an InfraWorks model for analise, planning and managing roads and other infrastructure in the surrounding area. Revit geometry is positioned geographically and imported into the InfraWorks model.

In InfraWorks, after loading the REVIT file in the "Create New Layer" section, the geo-localized project can be accessed directly and displayed in the list of building data sources.

Infraworks has therefore made it possible to locate the objects in space, linked to specific alphanumeric attributes saved in the relational database (Archive), and to manage them as "information layers" that identify their spatial relations. The models, visually realistic and complete in every detail, are built using all available GIS data: environmental and anthropogenic data, orthophotos, terrain models and survey data (fig. 6).

Therefore, the model obtained implemented within a GIS system, placed side by side with other models of adjacent buildings or in any case of the study area, allowed further analysis and documentation of the assets and the surrounding environment as a whole.

Figure 6: Axonometric view of the volumetric model generated with Autodesk Infraworks 2021.

STEP 4 – DIGITAL TWIN CREATION THROUGH IOT BUILDING SENSORS CONNECTION

The home is the privileged place where, more than in any other, it is possible to measure the criticalities, demands and developmental aspirations of active ageing. Technology can support ageing in place especially for older people living alone. The installation of IoT devices inside the building allows to improve the quality of life, psycho-physical health and autonomy of the elderly tenant at the same time it generates Big Data. The Digital Twin continuously updates itself with the data collected and shows in real time the areas in which it is important to improve safety, autonomy and user comfort. The installation of sensors and cameras at urban scale makes it possible to collect Big Data (fig. 7). The DT collects real data from installed IoT devices, which can be processed using analytical techniques and simulations based on algorithms.

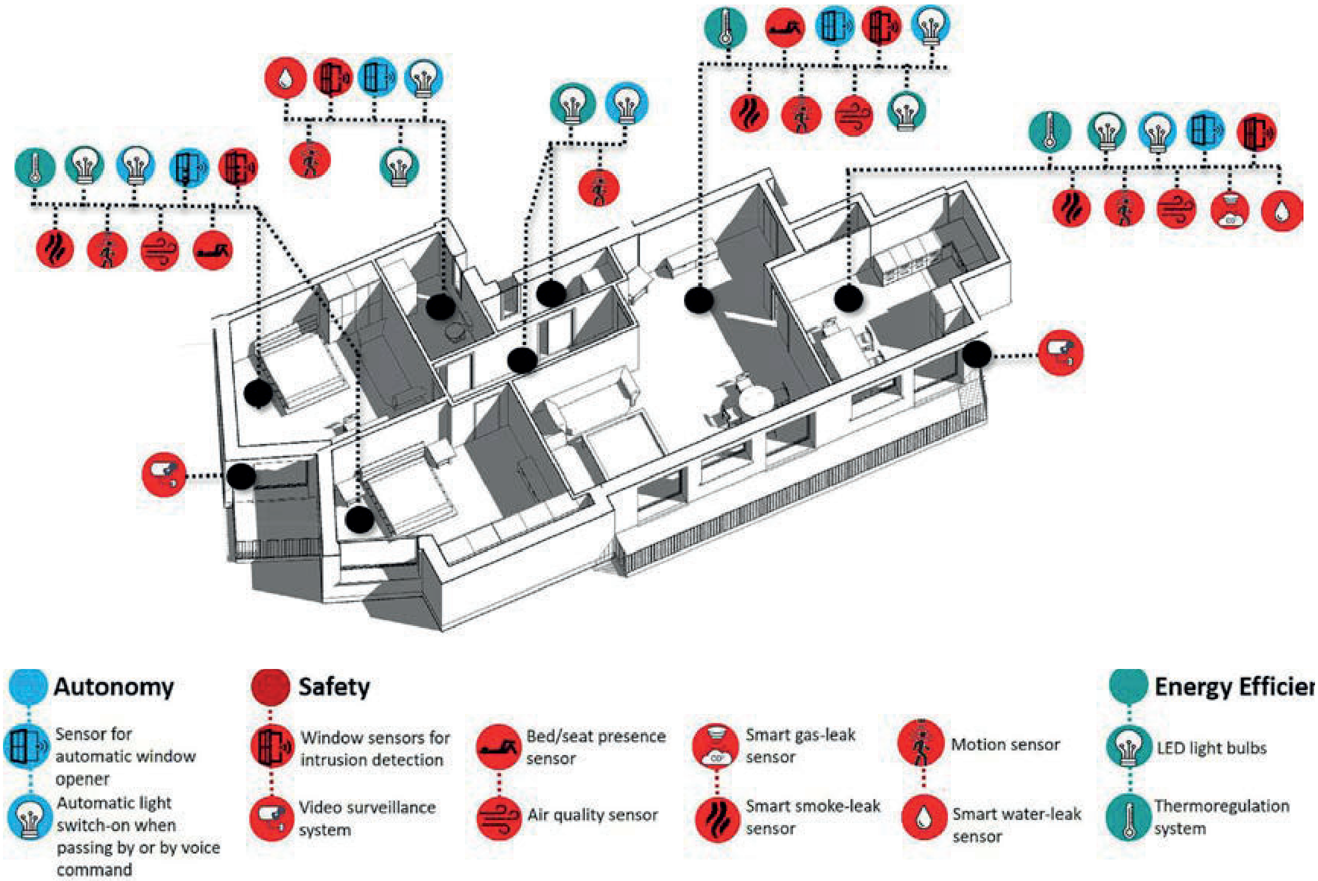

Figure 7: Smart home Digital Twin and IoT sensors.

RESULTS AND CONCLUSIONS

Aging population, climate change, particular diseases engender new challenges for the city and to face those complex issues an integrated and multidisciplinary approach is required.

The first and the second step of the case study analysis, after a detailed and careful analysis applied directly to a typical apartment of the building, assessed that it is certified with a Bronze level with a score of 0.70 on 5; this certification tool highlighted the difficulties regarding especially to accessibility and usability of interior spaces. The third step evaluating the building in the urban environment, such as urban design, road safety, noise pollution, and services offered, lead to a certification score of 0.63 on 5 - Bronze. This result is mainly due to the inadequacy of urban facilities and the almost total absence of cycle and pedestrian routes.

The case study essentially evaluates the effectiveness of the algorithm that automatically

generates the certification results by extracting the data to fill in the sheets directly from the digital model. Therefore, the results produced were compared to those coming from the direct compilation made by the technicians who performed the inspections.

The fourth step makes it possible, through the installation of special sensors, to make certification dynamic. This makes it possible, for example, to update the building's energy consumption assessments and, at the same time, to record any changes in the building and urban scale through the installed cameras.

The same sensors are essential in creating a Digital Twin, that requires the construction of a comprehensive spatial information infrastructure to simulate urban and architectural strategies for age-friendly design and, not only that.

To optimize the potential of the Urban Digital Twin, research efforts should focus on improving data processing efficiency and the inclusion of the city's socio-economic components.

In conclusion, the integrated use of technologies with a certification already proposed by the PRACTICE project but developed directly within a digital information system, ensuring a complete and dynamic view of the entire project and in turn combined with the digital twin strategy, can be an objective tool, thus promoting a building and planning more attentive to the needs of all types of users.

The tool proposed in this paper is a starting point for an open discussion with all stakeholders involved in this topic. This tool could significantly improve the design, visualization, and simulation workflow in developing cities oriented to all citizens' expectations in terms of safety, accessibility, comfort, and active life.

The city modeling makes it possible to improve visualizations of the urban environment and appropriately manage priorities for interventions to build healthy cities.

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