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THE MAINTENANCE REPRESENTATION

Research and applications, mixing UAV and digital models

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Abstract: In Italy, a frequent approach to building maintenance is -for evident cost reasons- to operate following an occurred fault; from this point of view, the opportunity to design a database containing structured information on building's state of conservation is still a long way off. The paper focuses on an application to a real case study and leads to a methodological proposal for the construction of a spatialized model that shows the maintenance condition on an urban scale. The model is implemented in several steps, from a visual investigation (perception) and subsequent in-depth studies (surveys), to the definition of a spatialised synthetic data. After explaining the methodology, i.e. the definition of indicators, parameters and weights, the paper focuses on the specific case study to achieve a result as replicable as possible, highlighting any critical areas of the process.

Keywords: "maintenance, digital models, BIM, database construction, spatial representation, urban scale"

1. Introduction

Representation is continuously considered dependent on recipients of its contents. Currently, the building process actors access to an information management system and its representation linked to digital technologies constantly developing (Caldera et al. 2017). Nowadays, the methodology adopted for the digitalization of the AEC (Architecture, Engineering and Construction) sector is the Building Information Modeling (BIM): "a modeling technology and associated set of processes to produce, communicate and analyze building models" (Eastman et al. 2008). The BIM methodology represents an important paradigm shift in the construction sector and its process optimization, which has also been reflected from the legislative point of view in many countries. It is currently one of the technologies that, "entering into the project folds of that Lean manufacturing which is nothing more than industrial automation designed to improve working conditions and increase productivity in the sector", may certainly be able to perfect the entire construction sector (Garagnani 2018).

This paradigm' shift prompts to reflect critically: the drawings representation is evocative, attractive and involving; the model (digital and non-digital) provides information. The drawings representation has a meaning related to the culture and critical capabilities of the reader; the model acts as a container to represent, manage and analyze data, and finally to produce information (Moglia et al. 2019).

Venturi's topic "Complexity and Contradiction vs. Simplification or Picturesqueness in landscape" connects with the objective of this study that is the maintenance representation. Digital models and tools, that are capable of collecting a large amount of information at the time of the survey, lead us to suppose that a complex result in knowledge can be achieved in a simple way, underestimating the need to optimize the synthesis related to the definition of the result itself. Synthesis, in knowledge, in which the nested contradictions in reality have to find a solution through the process of optimization. Synthesis that then helps the survey to feed the project. Survey, design and co-design are the representative issues that intertwine with the Venturi's topic, “complexity and contradiction vs. simplification or picturesqueness in landscape”, and that invite us to reflect particularly on the project, both general and addressed to maintenance, which is related to reality and feasibility. The complexity of the project and its intrinsic unity urge us to reflect on the Venturi’s topic "The obligation Toward the Difficult Whole". In this study, maintenance is represented using the assessments of a group of experts, methodologically governed and made comparable, and therefore measurable. The "man centrality" becomes a hinge between digital models and instruments on the one hand and survey and design to the other.

So, how is it possible referring to the representation of maintenance? Should it be evocative and creative like a freehand drawing or should it be just to show information?

An initial consideration, aimed at framing the concepts of maintenance and representation, can start from and be guided in its development by the consultation of a language dictionary, in which etymology and meaning research are privileged. For these insights, the Dictionary of the Italian Language (Devoto & Oli, 1971) was used. Its preface states: "The dictionary is a source of clarification, of order. This is its charm".

The term maintenance is the "elementary notion of conservation", which in turn is "the idea of constancy, convenience, advantage, coherence". Moving from the general meaning to the context of the buildings, from the territory to the constructive element, it is possible to recognize the themes of: the time overcoming -with its action of decay-, the control of the resources use and that, particularly critical, of forms, materials and technologies permanence. Maintenance is "the set of necessary operations to preserve the convenient functionality and efficiency". Like any adjective, "convenient" also refers to the particular operating context, and convenience is not always just economic. Conservation, in addition to the meaning of "maintenance in a state of efficiency", opens to the one of "in a condition to be used", with an explicit concern for the future: conservation is "protection". To preserve is "to maintain something so that it does not undergo alterations": it is clear the reference to the theme of permanence introduced above. On this subject, it is also interesting to mention one of the meanings of conservation that is referred to "any cultural phenomenon hostile to new or imported elements".

The representation, however, is linked to the broad theme of communication: "expression by means of signs, figures, and images, as it requires commitment or artistic effectiveness, or the need to reduce in concrete and readable signs an abstract or concrete entity". In mathematics and in particular in geometry, the representation is "any correspondence that is established between two abstract entities, to simplify the study or compare its properties”. In philosophy, "every process for which a content of perceptions, imaginations, concepts is presented to the consciousness". Moreover, very interesting for its content of activity and action, "to keep the place and act on its behalf". To communicate is "to make something known", "to transmit something", "to link something with proper means".. Perception is "to take consciousness in the sphere of sensitive experience or intuition", then connected to representation (Fig. 1).

Fig.1Representation of perception at urban scale (source: Moglia, G. 2008)

1.1 *The model of the city: representation of reality or information needs?*

Powerful new technologies have emerged in recent years that greatly improve ability to collect, store, manage, analyse and utilize information regarding features of the Earth's surface and to combine these with other types of economic, social and environmental information (Caldera et al. 2017).

The model, from "reference scheme for the purposes of reproduction or imitation" becomes -ever more in the case of representation- a "mathematical expression of a certain phenomenon in relation to the most different sectors, which reproduces its essential characteristics". It should be noted that, according to Latino vulgare, *modellus* is the diminutive of *modulus*, module, "measure on which the compositional characteristics of a work of art are based; for the architecture, the relationship and the proportioning between the various parts". The reference to the "ideal medium type in the dimensions of the human body and its parts (also called *canon*)" is interesting for the module, too. And the canon underlines the meaning of "scheme to which one refers as the rule of an art" and, "in philosophy, criterion to be adopted for the conquest of truth" (Devoto & Oli 1971).

Representation therefore leads to the research of rules to govern the transmission of knowledge. Information is "what is accepted or communicated in the context of a practical or immediate utility and functionality" and, underlining the root of its lemma, it is, first, the "assignment of a naturally and scientifically valid form". The measure, that is "the ratio between a quantity and another homogeneous one assumed as a unit", is functional for the determination of quantity information.

Reality is investigated, and measured, in form, material, technology, with different methods and instruments and with precision defined by the discretization chosen for the purpose of the application. The information, with the measurement, is reported in the model, with reference to shape, material and technology, with modes that also use conventional units of measurement and schemes that highlight the laws of form, the behaviour of the material and the use of technology. In the model, information and measurement become documents, and are placed in time by implementing themselves. The model is a complex document of the knowledge obtained through the survey and becomes as a contract document between the parties: the large scale model is a summary of the reality description, and in its parts, on a small scale, it becomes its detailed one.

So the models are the necessary core for the collection, processing, management and preservation of information coming from the external environment, through human or instrumental interfaces, and destined to return there, finalized according to a declared project, designed and developed. Representation makes these information perceptible, living in a complex plurality of interfaces intended for different senses, human or not, symbolic or iconic, graphic or alphanumeric, static or dynamic, obvious or hidden, always characterized by the possibility of updating to potentially available languages.

1.2 *Maintenance representation: suggestions from a literature review*

The representation can address a communication problem of the need or opportunity for maintenance of an element, using a symbolic or iconic interface accompanied by legends. Complex analogue models -in the past and now-, and complex digital models as digital twins (Grieves & Vickers 2017; Schleich et al. 2017) - now and in the future- are the source of the data to communicate singular aspects using the interfaces as attention filter. In this intentionally general statement, the element must be associated with a dimension class and a working sector.

The need for an element's maintenance in a mechanical or computer system can be associated with probabilistic predictive parameters that foresee its collapse, or directly linked to the element's collapse. The representation, in these cases, takes place by means of perceptible warnings through different human senses, or directly through the evidence of the ceased functioning of the element or the system. The necessity becomes an opportunity when a dangerous condition is prevented, before the predictive parameters of collapse are reached. The maintenance need of an element in a building or urban or territorial system, on the other hand, cannot be associated, currently in many cases, with probabilistic predictive parameters of collapse, which can be communicated with warnings. However, this need can be associated with scenarios, that are perceptible and assessable by trained people likewise happens in prevention or in risk & safety management sectors, evaluating individual or collective, operational or life situations. Also in the buildings or urban or territorial systems, maintenance becomes an opportunity to implement prevention, in general, and to maintain the safety of people and things.

Regarding the activity of representing (or mapping) maintenance (or buildings' deterioration), the literature provides many case studies, and witnesses many attempts to derive standardized procedures and workflows.

Mostly the object of such applied research turns out to be an historically relevant building, while the various methodologies under examination mainly fall onto the concept of ‘integrated survey’, which results in the involvement of different techniques and operational tools for the assessment of buildings’ degradation level. By surveying the main databases of scientific content, we found, for example, evidence of the integration of techniques such as traditional-visual based representation, photogrammetric one and material analysis (Nannei et al. 2019); thematic mapping of materials decay by 3D modelling (Maliverni et al. 2019); geo-referencing methods, such as UAVs implementation (Russo et al. 2019); risk analysis methodologies as decision making tools (Noya et al. 2016; Khalil et al. 2016).

The main limitations, in the development of an integrated survey technique, lies essentially in its ability of resulting flexible, detailed and of sufficient expeditious realization (Mirabella Roberti et al. 2019).

What the mentioned examples have in common, is mainly the fact that in most cases their focus is the building, aiming at preserve its functionality. This research, instead, wants to shift the attention to the citizen, who, simply by moving in a built environment that also includes the buildings and the infrastructures, becomes its user, and therefore a potential victim in case of sudden collapse of its parts along the public streets. This papers then aims at shifting from the building scale to the urban and territorial one, in the activity of mapping buildings’ and infrastructures’ deterioration, by applying the same techniques but with a lower level of detail, in order to maximize the extent of information mapped and provide a valuable support for targeted public policies’ development.

In supporting public intervention policies, there is a need to combine the objectivity of the survey with the subjectivity of the surveyor and the finalization of the survey to the centrality of the project. The hierarchy of urgency of maintenance interventions helps to the choice in the use of public resources. From many parameters, the unity of the project must be achieved, likewise "The obligation Toward the Difficult Whole", Venturi's topic.

A similar change of perspective replicates in the shift from single building’s maintenance plan (Caldera et al. 2019-1) to territorial vulnerability index (Brunetta & Salata 2019). In accordance with the last mentioned authors, increasing the scale could imply the creation of a priority list to support preventive conservation policies. The paradigm change will be summarized in the present contribution by the transition from 'mapping buildings deterioration' to 'mapping urban maintenance'. This definition does not seem to fit into a strand of existing literature on the topics of building maintenance, and because of this a simplified network representation of the most used and mutually linked keywords is afterwards proposed in order to provide a useful framework to the reader (Fig. 2).

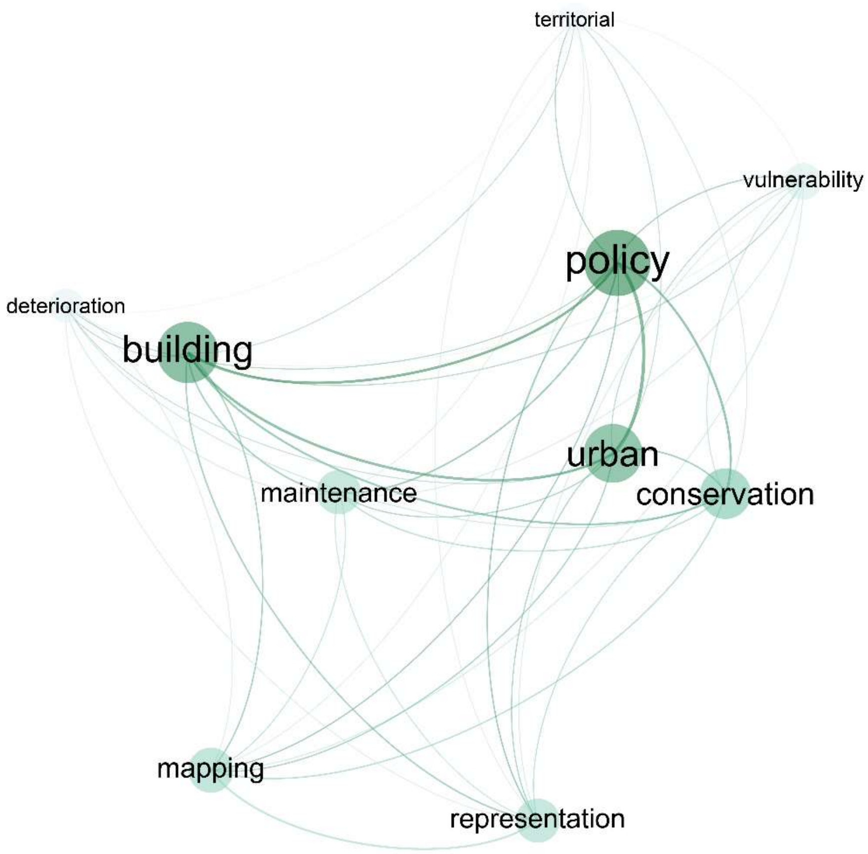

Fig.2 Keywords' state of art – network visualization

The network visualization was developed with the support of the Java based software Gephi, which allowed an efficient data processing and visualization of the results of the enquiries that were developed on Scopus database. In particular, these surveys were intended to find out the mutual existing links, in the published scientific literature, among the most important keywords connected with the subject dealt with here. Therefore, there are two main information we can extract from it: (i) each keyword's diffusion within the total amount of the considered publications, revealed by the node's size and (ii) each pair's level of relation, shown by the thickness of the connecting edge. As it can be deduced from the figure, the keywords 'territorial' and 'deterioration' turn out to be outsiders in this network, being less diffused than the others and weakly connected with them in the actual state of art. The paper's aim then is to analyse how, instead, they can be linked with the topic of 'representation/mapping', surely by leveraging on the existing literature concerning urban and territorial resilience (the latest strand of the spatial measurement of urban and territorial vulnerability).

2. Materials and method

The perception of the maintenance need in a building (or urban, or territorial) system, when not associated with explicit warnings, occurs through the recognition of signals from the element or elements of the system, recognizable and assessable by an expert. These must be detected (the survey is knowledge) and returned to be processed and to be conserved. The relative techniques, analogical or digital, qualitative or quantitative, offer the possibility to select information and results, in order to finalize them to specific objectives.

To represent maintenance on an urban scale, moving from a City Model (CM) that contains dimensional information (shape, height, volume, impacts, ...) to one that shows the Buildings Conservation (BC), it is necessary to follow the logical path of Fig. 3: from the city to the buildings (from 1 to 2), to return again to the city, representing maintenance information (4) and, at the same time, implementing existing city model (1).

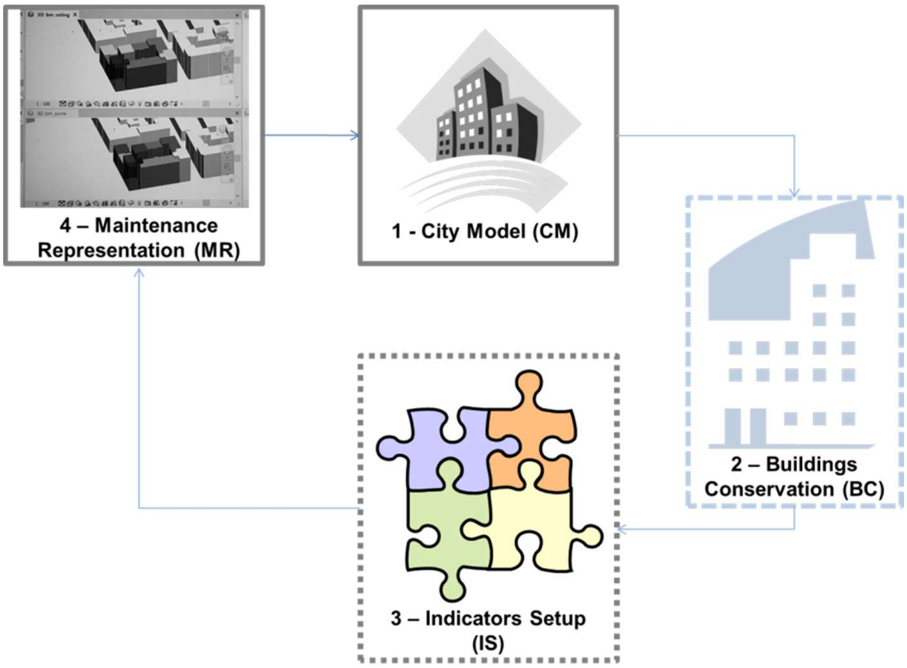

Fig.3 logical framework of method construction

The initial model (1) can be two-dimensional, if created - for example - using a GIS software, or three-dimensional, if processed - for example - through a BIM software. In any case, for the final representation on the urban scale (4) it is necessary to analyze (and evaluate) some elements on the building scale (2 and 3). Phases (1) and (4) can be created quite "automatically": the model can derive from an algorithm able to collect information and to generate objects derived from it through a Visual Programming Language (VPL) and maintenance can refer to the contents of specific sector studies (ISTAT 2015). If the purpose is - as in this case - the safety of the external space, phases (2) and (3) are needed and also difficult to be articulated in a short time, being in fact made up of the phases shown in Fig. 4.

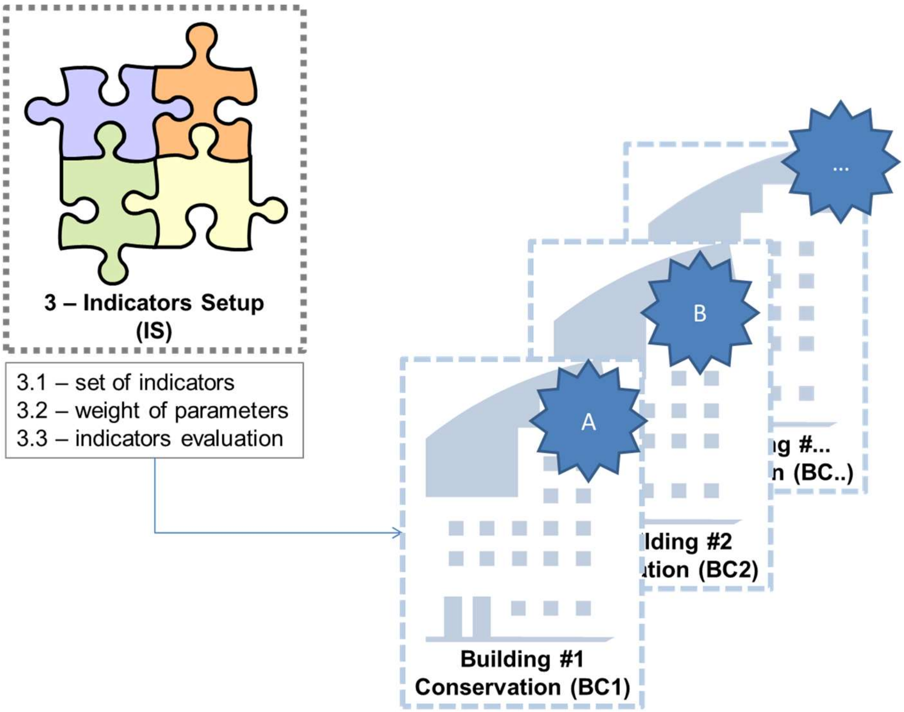

Fig.4 Detail of steps 2 and 3 of the method

The indicators (step 3.1), which allow to move from the urban to the building scale, must be searched in literature and/or through a stakeholder analysis. Since not all the indicators have the same relevance in relation to the final objective (information collection, security & safety, investment planning, ...), the weight of the indicators (step 3.2) will be determined through a hierarchical analysis that involves stakeholders again.

Subsequently, an external expert has to test the evaluation method (ease and accuracy of analysis of the indicators) and to apply it (step 3.3) to the chosen urban portion. Indicators and stakeholders are chosen in order to broaden the analysis to the whole city. In the following pages the three phases are described in detail.

To analyse a generic portion of the Building Fabric (BF), it's possible to proceed by steps, from expeditious investigations up to specific surveys: preliminary, starting from the analysis of the databases of censuses that are carried out by the National Statistical Office (NSO: known as "ISTAT" in Italy), in order to have some overall data of the BF, useful for its classification. The Italian NSO draw up these studies almost every ten years, collecting many data related to different parameters (for instance the number of buildings per typologies – residential, productive, commercial, office/tertiary, tourism/reception, services and other; the number of residential buildings in load-bearing masonry; etc.). These ones are picked up for all the Italian Municipality, but they are not always the same for each census because sometimes they are modified or new ones are added. Therefore, it is possible to define the temporal trend only for the recurrent parameters. It will not be possible to derive a historical series for a parameter that is been collected only in a single census but it will be useful as a quantitative data of an explicit time. So, it is possible to obtain a preliminary description of the BF by the analysis of parameters census and, in case of shortcomings, it will be possible to create new indicators as implementation.

The knowledge of "how much vulnerable is the BF" is extremely important for the prevention of human and economic losses (Brunetta & Salata 2019); so, indicators that describe and represent the built up are needed. Their function is to define a specific trait of the BF, in order to characterize and make it easy to monitor over time. To get this goal, the analysis starts from the buildings, where many features have to be outlined and represented, for instance: the structural, the energy, the plants, and the maintenance and property management ones (Lai & Man 2016).

The analysis' level of detail and the management available resources, as times and costs, depend on the chosen scale of investigation. Therefore, during the construction of the indicators, it is important not to lose sight of it. To give a clear overview of the results of each indicators it is possible to create territorial thematic maps of the BF. However, to draw up them, it is necessary to define the minimum portion of territory (not at building's scale) under which no more details can be represented. Once is defined the minimum dimensions of the cell, for example 200 x 200 meters each, it will be necessary to carry out some tests to verify the goodness of each indicator and, if necessary, to correct the criticalities. As said before, it is necessary first to define the vulnerability of each building in order to estimate the one of the whole BF. Therefore, the indicators coming from the various subjects must be appropriately weighed and condensed into a single synthetic indicator (Khalil et al. 2016). That one will also represent, parallel to the degree of the vulnerability, the safety degree that is guaranteed by each building to the users. By this analysis will be easy to identify the critical cells that need further investigations. The latter are those ones that have a very high value of the synthetic indicator. That is, those ones that include buildings that are in a very bad state, on which more assessments have to be carried out.

2.1 *Indicators setting*

The aim of this research is to define indicators able to describe and represent the maintenance state of the buildings, which are elements/components of the BF.

Each building, whether public or private, is in a certain state of conservation due to the different management methods carried out by the owners and / or tenants. Each property has got technological elements with different service lives; so it requires constant maintenance (Bardelli et al. 2009, Lee & Scott 2009, Levitt 2000). It is possible to notice that the state of conservation of a building mirrors its maintenance state (MS). Indeed, the first one depends on whether the maintenance operations have been carried out or not.

Just as for a mechanical element, the knowledge of the condition of its components is useful, since it depends on them the proper functioning of the whole, the same is for the BF and its buildings. Therefore, this global view is useful to identify the most degraded and potentially dangerous areas. Indeed, poorly maintained buildings are likely to be potentially more dangerous to the society than other buildings in good condition.

On that, it was decided to represent the MS of each building both in a generic way (GMS: General Maintenance State) and according to the safety (SMS: Safety related to Maintenance State) that it is able to provide, at the time of the detection, to its different kind of users. The direct users are those who have access to a building, while the indirect users are those who can stay or pass near a building on public soil.

Therefore, two Indicators have been created: the first represents the general maintenance state(I-GMS), while the second represents the maintenance state in relation to the safety that each building is able to provide to the society (I-SMS). So, for each building, it is possible to calculate two synthetic values, between 0 - 100, one for the I-GMS and the other for the I-SMS. In both cases, those synthetic values are then grouped into classes, which describe the state of the building; specifically, seven classes for the I-SMS and four for the I-GMS were defined (Tab. 1 and 2).

I-SMS		
#	**CONDITION**	**VALUE**
1	Bad	= 100
2	Poor	100 < x < 80
3	Sufficient	80 ≤ x < 60
4	Weak	60 ≤ x < 40
5	Middling	40 ≤ x < 20
6	Good	20 ≤ x < 0
7	Excellent	= 0

Table 1 Classes and belonging ranges of I-SMS indicator

I-GMS		
#	**CONDITIONS**	**VALUE**
I	Dangerous	100 ≤ x < 80
II	Possibly dangerous	80 ≤ x < 40
III	Not dangerous	40 ≤ x < 20
IV	Optimal	20 ≤ x < 0

Table 2 Classes and belonging ranges of I-GMS indicator

To define the indicators, nine evaluation parameters were identified (UNI 11182:2006): they concern different types of damage that can be found on a building (Tab.3) and they are the same for both indicators (I-GMS and I-SMS), but –as better explained in the following pages- with different weights in the final value attribution (Tab.4 and 5).

#	PARAMETERS	DESCRIPTION
1	*Deformation*	Shape variation
2	*Degradation*	Macroscopic discontinuity of the surface material and/or discontinuity of a technological element (e.g. absence of a downpipe portion, absence of an eaves portion).
3	*Dilapidated elements*	Presence of elements in unstable balance. They can be building elements that make up the original structure of the building (e.g. eaves, banisters, ...) or added elements (TV antennas, external curtains, flowerpots, ...).
4	*Unfinished works*	Incomplete installation of technological elements
5	*Fracturing or cracking*	Continuity solution of the material that involves the displacement of the parts.
6	*Rising damp*	Limit of water migration that declares itself with efflorescence and/or material losses. It is generally matched by variations in colour saturation in the area below.
7	*Vegetable organisms*	Spread presence of micro and/or macro organisms (algae, fungi, lichens, mosses, superior plants) and/or presence of herbaceous, shrubby or arboreal individuals.
8	*Discolouration*	Alteration that shows itself by the variation of one or more parameters, which define the colour: hue, clarity, saturation. It can declares itself with many morphologies depending on the conditions.
9	*Stain*	Localized chromatic variation of the surface.

Table 3 Inspection parameters shared by the two indicators I-GMS and I-SMS

The attribution of a specific value to the indicator requires its decomposition into contributions/components/parameters and can take place through multiple techniques with the aim of addressing and evaluating both qualitative and quantitative aspects. The methods (which in most cases belong to the multi-criteria analysis method) can be compensatory, even partially or not compensatory, according to the principle that an extreme positive feature balances out the penalizing ones.

To this first group (compensatory) belongs the method used in this paper, the so-called weighted summation. It consists in the attribution of partial scores to the considered parameters, from which the indicator score is obtained by a simple sum. The method that has been widely imposed in many fields for its simplicity, if compared to other theoretical procedures, consists of an additive function of utility in which the elements are conceptually divided into different criteria (parameters) that characterize and represent it. The final score (S_i) represented by the product between the value (V_i) attributed to the individual parameter (V_{i1}, V_{i2}, V_{i3}, …) and its weight (W_1, W_2, W_3, …), is calculated according to the formula (Von Winterfeldt & Fischer 1975):

$$S_i = V_{i1}\, x\, W_1 + V_{i2}\, x\, W_2 + \cdots + V_{in}\, x\, W_n = \sum_{j=1}^{n} V_{ij}\, x\, W_j$$

2.2 Hierarchical weight assignment

Therefore, only theoretically the decision-maker is unique and can express preferences independently. So, to be more close to the reality, the final parameters weights correspond to the average of the priorities expressed by a panel of experts. They are: a member of a professional association (user#1), a building manager (user#2), a municipality engineer (user#3), a building firm rep (user#4), a user (owner or tenant) of a private property (user#5). Each one was asked to compare in pairs the 9 parameters (Fig. 5) indicating the hierarchical relationship between the individual pairs of the considered criteria. The operation was carried out by filling in, by the interviewed stakeholder, a comparison matrix, assuming that the rule of weight assignment could change according to the purpose for which the indicator was designed (monitoring of maintenance or safety). In the comparison in pairs, the expert has to express himself indicating each time:

(1) if the two parameters are EQUALS

(3) if parameter A is MODERATELY MORE important than B

(5) if parameter A is MORE important than B

(7) if parameter A is MUCH MORE important than B

(9) if parameter A is ABSOLUTELY MORE important than parameter B

A \ B	parameter#1	parameter#2	parameter#3	⋮	⋮	⋮	⋮	⋮	⋮	⋮	parameter#n
parameter#1	1										
parameter#2		1									
parameter#3			1								
…				1							
…					1						
…						1					
…							1				
…								1			
…									1		
…										1	
parameter#n											1

Fig.5 Comparison matrix for weight assignment

The calculation is carried out by comparing the parameter A (per row) with the B ones (per column), filling the empty cells (comparisons in pairs, Figure 5) below the main diagonal (which values are always equal to 1, and represent the result of the comparison of two equal criteria). The grey portion of the matrix is automatically completed according to an inverse reciprocity criterion. Let's compare for example the "deformation" (A) respect to the "degradation" (B); if we can say that for one of the stakeholders A is more important than B attributing to A a score equal to 5, it will be also true that the inverse relationship (B with respect to A) will be represented by the inverse of the value previously attributed (i.e. 1/5). This evaluation logic clearly takes up from Thomas Saaty's theory of hierarchical analysis, better known as AHP -Analytic Hierarchy Process (Saaty 1988 e 1990).

2.*3 Indicators evaluation*

As the chosen survey scale is the urban one, the aim is to get an overall view of the MS of the BF rather than a detailed view of each building. Therefore, for the census of the MS of the buildings, it was decided to evaluate only the elevations of the buildings facing the public road system. Moreover, the value obtained in this way, was considered representative for the whole building.

On the base of the selected parameters, the evaluator has to define the extension of each damage, as percentage value in relation to the building facade area. For this operation on site surveys are not requested, because the idea is to use photos coming from Google Street View.

By applying to the calculated value of each parameter its own weight, it is possible to obtain the two representative synthetic values of every building, one for GMS and the other for the SMS. Finally, these values fall respectively in one of those classes, afore described, of the I-GMS and of the I-SMS.

Finally, the results of the previous operations have to be represented on a digital platform, for instance a BIM model, in order to make them easy to be consulted and quarried. The digital model will make it easy to identify the most critical areas of the BF. On these ones, more in-depth analyses are needed. Therefore, it is necessary to increase the scale of the survey aiming at reaching a major degree of detail. For instance, the drones could be used for new and more accurate inspections (Caldera et al. 2019-2), and secondly, for each building, an analysis on the existing documents could be carried out (Dejaco et al. 2017).

Where the I-GMS and I-SMS will be confirmed by the new more deepen evaluations, the scale of investigation should be further increased by carrying out on-the-spot survey operations. The latter will cover the architectural, the plant engineering and structural components and will be aimed at defining, with a high degree of accuracy, the level of safety that a given building is able to provide to its users on one hand, and on the other hand its vulnerability to external events of various kinds.

This model will also allow institutional bodies, where necessary, to impose maintenance and security operations to the owners. In the end, that model, if constantly updated, will allow the building monitoring through the elimination of the uncertainty degree that currently exists with regard to the maintenance state of buildings that make up our cities.

2.*4 Model implementation*

Transforming an existing district in a smart district requires to know complex phenomena, which are typical for a city, and the capability to manage large amount of data.

In the last years, several researches have been developed towards the smart city concepts, highlighting the value of using digital and telecommunication technologies for the benefit of its inhabitants and business. Moreover, the idea of smart city goes beyond the use of ICTs highlighting the meaning of a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population. ICTs are becoming a key factor to connect citizen with public administration, developing digital graphical interfaces able to represent data useful to arise smart city topics (European Commission 2018).

In this context, the creation of graphical databases such as at urban (GIS) and building (BIM) level allow to fill in and extract data to achieve the expected objectives. Although BIM contains any/all information about the construction, the development of a detailed 3D parametric model requires a considerable effort depending on the established Level of Detail (LOD). On the other hand, a GIS dataset collects information on the urban and district scale useful for the development of analyses of macro systems for the evaluation of several policies such as energy saving, state of maintenance, through a simplified 2D/3D model.

Obviously, parametric models created in different data domains have different characteristics because they refer to different kind of information. For example, GIS is adopted at urban scale while BIM at building scale and for both of them it is requested the ability to exploit geometric and alphanumeric information in a different way.

In the last years, several researches have investigated the creation of a city model, connecting BIM with GIS domains through interoperability that facilitates data sharing between the two datasets. Currently, Visual Programming Language (VPL) is discovered by researchers to find a process able to automate the creation of BIM model starting from GIS model. The main idea behind this kind of language is based on using graphical artifacts as opposed to the use of a textual programming language. In VPL tools, logic programs are built using graphs rich of elements called nodes (Monteiro 2016). Through the processing of scripts created with VPL language, it is therefore possible to automate the generation of a BIM model from the GIS dataset, developing a Virtual City Model (VCM) (Moglia et al. 2018).

The VCM is characterized by a proper Level of Graphical detail (LOG) and Level of Information (LOI). It is based on principles and techniques of Unified Building Model (UBM) (El-Mekawy et al. 2012) and District Information Model (DIM) (Del Giudice et al. 2017), defining users' needs.

VCM repository can be used by public and private authorities to create urban policies expressed in actions such as planning scenarios and digital innovation. In particular, the requirements (e.g. energy management, seismic prevention) are defined by the components of urban space and are governed by public administrations.

3. Application and results

3.1 The selected case study

Once the indicators have been defined, a test was carried out on a portion of BF in order to highlight its strengths and its criticalities. The investigated area consists in a 7 blocks district of the city of Turin called "Crocetta" (Fig. 6). These ones stand out both for its number of buildings and for the buildings' construction features like ages, intended uses and properties.

Fig.6 Extract of the Turin city map with identification of the "Crocetta" district (in red) and the case study (in yellow) [source: Google maps]

This contribution has selected, as case study, the district analyzed within the District Information Modeling and Management for Energy Reduction (DIMMER) European Project that aimed at develop an advanced 3D modeling (Fig. 7), as basic element for visualization and interaction technologies able to optimize the use of the data at building and urban level to manage and to promote energy efficient behaviors. The development of a 3D model able to collect several data started from the cadastral Microzone, characterized with economic parameters (Italian Cadastral and Land Registry web site and Italian Revenue Agency web site) (Moglia et al. 2018) and now new parameters describing the BC were added, aiming at validate the logical process of the assessment for the analysis and modeling methods proposed.

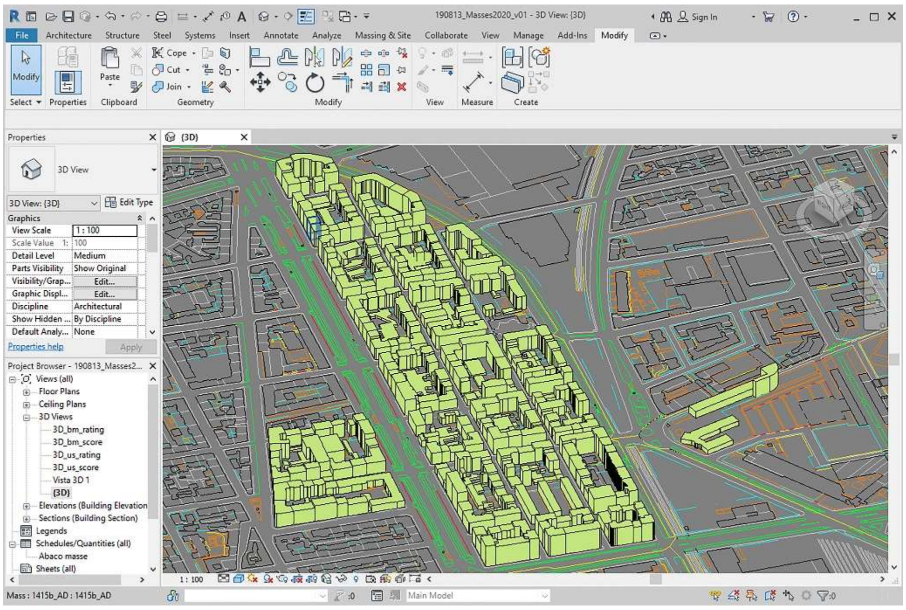

Fig.7 Case study 3D model

3.2 Parameters hierarchy for indicator creation

To define -for both indicators- final weight of parameters, a panel of experts were selected:

- user#1, a member of a professional association. Graduated, with more than 10-year experience in design on the existing building;
- user#2, a building manager. High school graduate, with 20-year experience in building asset management;
- user#3, a municipality engineer. Graduate, with a management function in a city public office and five years' experience in the projects verification;
- user#4, a building firm rep. High school graduate, with over 20-year experience in public and private contracts;
- user#5, an owner/tenant. A non-expert, living alone in a city apartment for more than 5 years.

As previously explained, each one was asked -during 5 individual interviews- to compare in pairs the defined parameters, aiming at evaluating “the General Maintenance State of a building” and “the Safety related to Maintenance State”. All experts ran into the same problem: expressing preference over the GMS; so it was decided, by mutual agreement, to consider the 9 parameters equally important in the state of maintenance description (and related indicator), thus defining the weights of Tab. 4.

I-GMS

Parameters	*Weights*
1	11.11%
2	11.11%
3	11.11%
4	11.11%
5	11.11%
6	11.11%
7	11.11%
8	11.11%
9	11.11%

Table 4 I-GMS indicator parameter weights

However, the final parameters weights for the indicator I-SMS derive as an average (Fig. 13) of the stakeholders' individual preferences (Fig. 8-12) and are those contained in Table 5.

user#1	Deformation	Degradation	Dilapidated elements	Unfinished works	Fracturing or cracking	Rising damp	Vegetable organisms	Discolouration	Stain
Deformation	1.00	3.00	0.20	9.00	0.20	3.00	5.00	5.00	3.00
Degradation	0.33	1.00	0.14	7.00	0.33	1.00	3.00	3.00	5.00
Dilapidated elements	5.00	7.00	1.00	9.00	3.00	3.00	7.00	7.00	5.00
Unfinished works	0.11	0.14	0.11	1.00	0.14	0.20	0.33	0.33	0.33
Fracturing or cracking	5.00	3.00	0.33	7.00	1.00	3.00	7.00	7.00	5.00
Rising damp	0.33	1.00	0.33	5.00	0.33	1.00	5.00	5.00	3.00
Vegetable organisms	0.20	0.33	0.14	3.00	0.14	0.20	1.00	1.00	1.00
Discolouration	0.20	0.33	0.14	3.00	0.14	0.20	1.00	1.00	0.33
Stain	0.33	0.20	0.20	3.00	0.20	0.33	1.00	3.00	1.00

Fig.8 User#1 evaluation matrix

user#2	Deformation	Degradation	Dilapidated elements	Unfinished works	Fracturing or cracking	Rising damp	Vegetable organisms	Discolouration	Stain
Deformation	1.00	3.00	0.11	1.00	0.20	5.00	5.00	0.33	0.33
Degradation	0.33	1.00	0.11	1.00	0.14	1.00	1.00	0.33	0.33
Dilapidated elements	9.00	9.00	1.00	9.00	5.00	9.00	9.00	7.00	7.00
Unfinished works	1.00	1.00	0.11	1.00	0.14	1.00	1.00	0.33	0.33
Fracturing or cracking	5.00	7.00	0.20	7.00	1.00	9.00	9.00	0.33	0.33
Rising damp	0.20	1.00	0.11	1.00	0.11	1.00	1.00	0.33	0.33
Vegetable organisms	0.20	1.00	0.11	1.00	0.11	1.00	1.00	0.33	0.33
Discolouration	3.00	3.00	0.14	3.00	3.00	3.00	3.00	1.00	1.00
Stain	3.00	3.00	0.14	3.00	3.00	3.00	3.00	1.00	1.00

Fig.9 User#2 evaluation matrix

user#3	Deformation	Degradation	Dilapidated elements	Unfinished works	Fracturing or cracking	Rising damp	Vegetable organisms	Discolouration	Stain
Deformation	1.00	1.00	0.33	9.00	1.00	9.00	9.00	9.00	9.00
Degradation	1.00	1.00	0.33	9.00	1.00	9.00	9.00	9.00	9.00
Dilapidated elements	3.00	3.00	1.00	9.00	3.00	9.00	9.00	9.00	9.00
Unfinished works	0.11	0.11	0.11	1.00	0.14	1.00	1.00	1.00	1.00
Fracturing or cracking	1.00	1.00	0.33	7.00	1.00	5.00	5.00	5.00	5.00
Rising damp	0.11	0.11	0.11	1.00	0.20	1.00	1.00	1.00	1.00
Vegetable organisms	0.11	0.11	0.11	1.00	0.20	1.00	1.00	1.00	1.00
Discolouration	0.11	0.11	0.11	1.00	0.20	1.00	1.00	1.00	0.33
Stain	0.11	0.11	0.11	1.00	0.20	1.00	1.00	3.00	1.00

Fig.10 User#3 evaluation matrix

user#4	Deformation	Degradation	Dilapidated elements	Unfinished works	Fracturing or cracking	Rising damp	Vegetable organisms	Discolouration	Stain
Deformation	1.00	1.00	0.33	7.00	1.00	7.00	7.00	3.00	3.00
Degradation	1.00	1.00	0.33	7.00	1.00	7.00	7.00	5.00	5.00
Dilapidated elements	3.00	3.00	1.00	9.00	3.00	9.00	9.00	5.00	5.00
Unfinished works	0.14	0.14	0.11	1.00	0.20	1.00	1.00	1.00	0.20
Fracturing or cracking	1.00	1.00	0.33	5.00	1.00	5.00	5.00	3.00	3.00
Rising damp	0.14	0.14	0.11	1.00	0.20	1.00	1.00	0.33	0.33
Vegetable organisms	0.14	0.14	0.11	1.00	0.20	1.00	1.00	0.33	0.33
Discolouration	0.33	0.20	0.20	1.00	0.33	3.00	3.00	1.00	1.00
Stain	0.33	0.20	0.20	5.00	0.33	3.00	3.00	1.00	1.00

Fig.11 User#4 evaluation matrix

user#5	Deformation	Degradation	Dilapidated elements	Unfinished works	Fracturing or cracking	Rising damp	Vegetable organisms	Discolouration	Stain
Deformation	1.00	5.00	0.14	5.00	0.20	5.00	5.00	5.00	5.00
Degradation	0.20	1.00	0.11	1.00	0.14	1.00	1.00	1.00	1.00
Dilapidated elements	7.00	9.00	1.00	9.00	5.00	9.00	9.00	9.00	9.00
Unfinished works	0.20	1.00	0.11	1.00	0.14	5.00	5.00	5.00	5.00
Fracturing or cracking	5.00	7.00	0.20	7.00	1.00	9.00	9.00	9.00	9.00
Rising damp	0.20	1.00	0.11	0.20	0.11	1.00	1.00	1.00	1.00
Vegetable organisms	0.20	1.00	0.11	0.20	0.11	1.00	1.00	1.00	1.00
Discolouration	0.20	1.00	0.11	0.20	0.11	1.00	1.00	1.00	1.00
Stain	0.20	1.00	0.11	0.20	0.11	1.00	1.00	1.00	1.00

Fig.12 User#5 evaluation matrix

Average	Deformation	Degradation	Dilapidated elements	Unfinished works	Fracturing or cracking	Rising damp	Vegetable organisms	Discolouration	Stain
Deformation	1.00	2.60	0.22	6.20	0.52	5.80	6.20	4.47	4.07
Degradation	0.57	1.00	0.21	5.00	0.52	3.80	4.20	3.67	4.07
Dilapidated elements	5.40	6.20	1.00	9.00	3.80	7.80	8.60	7.40	7.00
Unfinished works	0.31	0.48	0.11	1.00	0.15	1.64	1.67	1.53	1.37
Fracturing or cracking	3.40	3.80	0.28	6.60	1.00	6.20	7.00	4.87	4.47
Rising damp	0.20	0.65	0.16	1.64	0.19	1.00	1.80	1.53	1.13
Vegetable organisms	0.17	0.52	0.12	1.24	0.15	0.84	1.00	0.73	0.73
Discolouration	0.77	0.93	0.14	1.64	0.76	1.64	1.80	1.00	0.73
Stain	0.80	0.90	0.15	2.44	0.77	1.67	1.80	1.80	1.00

Fig.13 Final matrix containing average stakeholders' evaluations

I-SMS	
Parameters	*Weights*
1	0.030660327102%
2	0.001842335565%
3	99.404677776437%
4	0.000000369908%
5	0.562784085101%
6	0.000000489641%
7	0.000000022231%
8	0.000006794314%
9	0.000027799702%

Table 5 I-SMS indicator parameter weights

3.3 Results

The work outline, which aims at defining the different state of maintenance of the buildings, is as follows:

1. Assignment of an identification code to each block (Fig. 14)
2. Assignment of an identification code to each building (Fig. 15)
3. Visual analysis by "Street View" tool that is provided by Google Maps
4. Assignment of a score to each parameter for the inspected building
5. Calculation of two synthetic values (I-GMS and I-SMS) for each building and their allocation in the rating classes
6. Model implementation, to build settings configuration and four new data attributes
7. Specific script creation, useful to generate automatically the digital model starting from thedata inserted
8. Data input and results control.

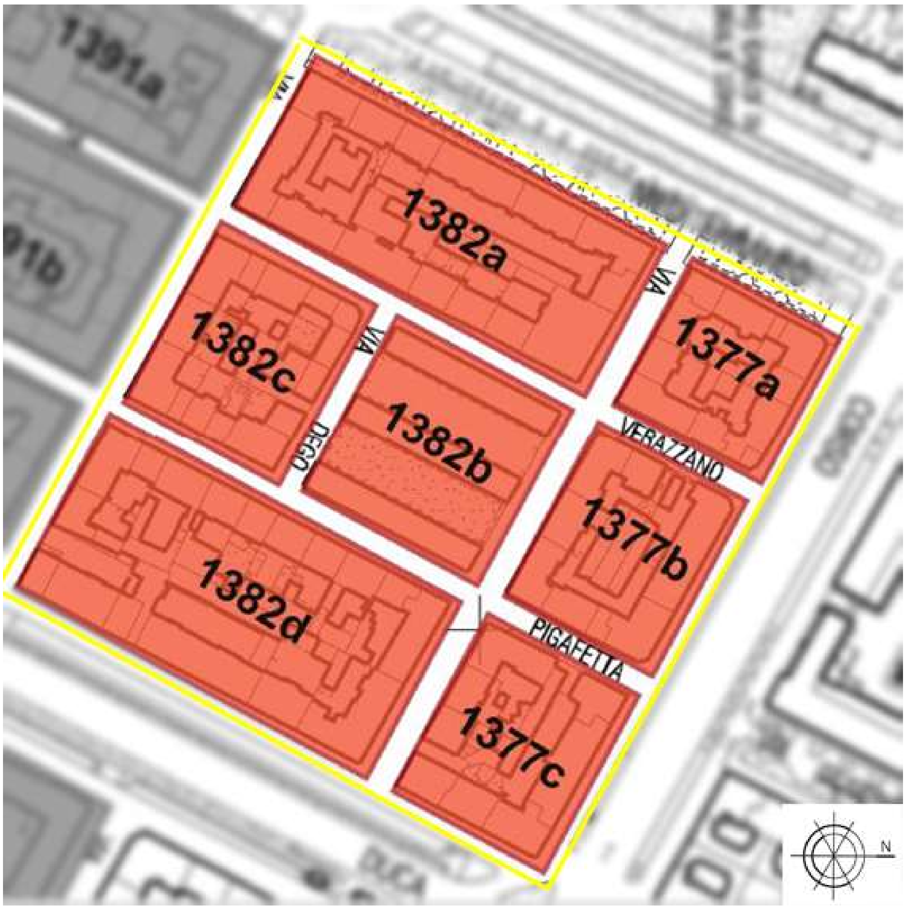

Fig.14 Blocks identification codes [source: authors]

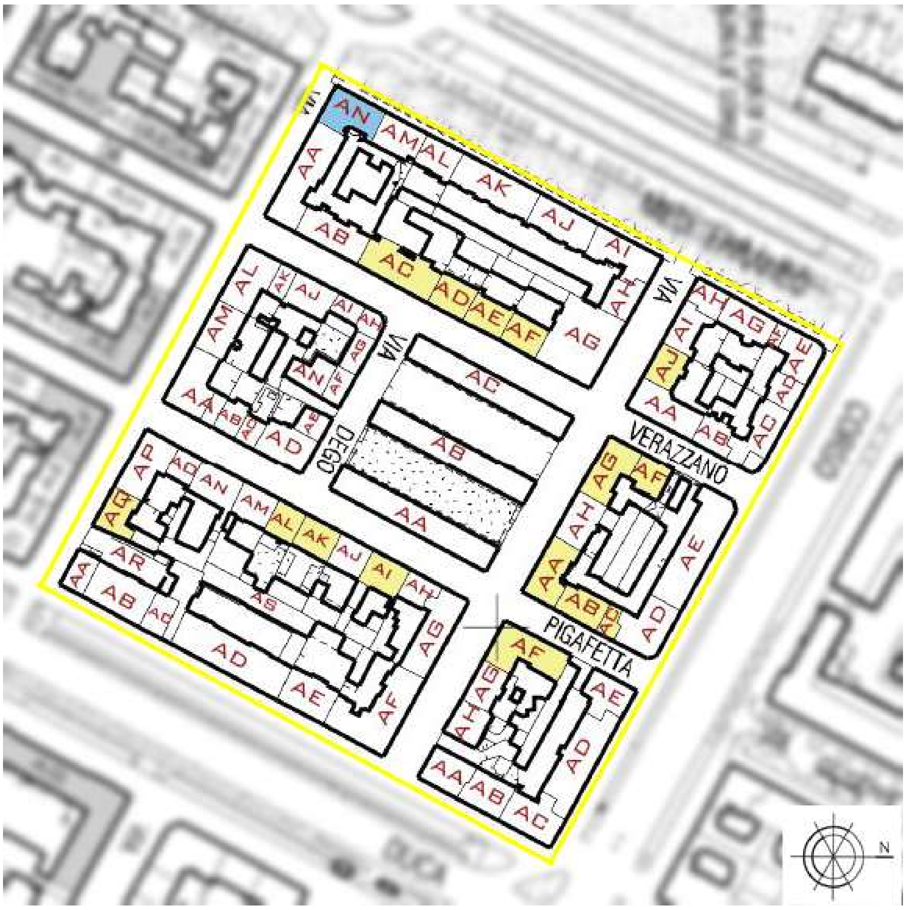

Fig.15 Building identification codes [source: authors]

The visual analysis that must be done for each building consists in the observation of all the elevations that overlooks the public streets. That operation uses as mean for the inspection the Google's "Street View" tool.

The evaluator has to give scores to the parameters showed before, consisting in a numerical value between 0-100 that correspond to the percentage of inspected elevation surface area (m^2), that is affected by a specific damage included in one of the nine parameters.

For each building, only the principal elevations (facing the streets) will be evaluated, since these are the only ones completely available with Street View tool. For every construction, it is possible to have up to four elevations (North, South, East, and West), depending on whether they overlook the road or not. Therefore, you will get four different scores for each parameter, but -aiming at representing a building in a single way- it is necessary to have a unique value for all of them. So the worst must be chosen.

Every building synthetic score will be defined by multiplying parameters value by the corresponding weights and, in the end, adding them up (Tab.6 and 7). The two obtained results, one for each indicator (I-GMS and I-SMS), will fall respectively in one of the classes before explained.

BLOCK IDENTIFICATION CODE		
BUILDING IDENTIFICATION CODE		
Parameters	**Weights**	**Value**
1	0.030660327102%	..
2	0.001842335565%	..
3	99.404677776437%	..
4	0.000000369908%	..
5	0.562784085101%	..
6	0.000000489641%	..
7	0.000000022231%	..

8	0.000006794314%	..
9	0.000027799702%	..
"bm_score"		**Final Score**

Table 6 – Calculation table of the synthetic score for the I-SMS indicator

BLOCK IDENTIFICATION CODE		
BUILDING IDENTIFICATION CODE		
Parameters	**Weights**	**Value**
1	11.11%	..
2	11.11%	..
3	11.11%	..
4	11.11%	..
5	11.11%	..
6	11.11%	..
7	11.11%	..
8	11.11%	..
9	11.11%	..
"us_score"		**Final Score**

Table 7 Calculation table of the synthetic score for the I-GMS indicator

To represent this data, dealing with the research goal, the use of a BIM software was needed. In the digital model, the buildings' scores of the two indicators I-SMS and I-GMS, calculated before, were reported through the creation of two attributes that are respectively "us_score" (urban safety) and "bm_score" (building maintenance). The same operation was done for the representation of the classes in which each building falls. Indeed, for both the indicator I-SMS and I-GMS, other two attributes called respectively us_rating and bm_rating were created.

Autodesk Revit was used as a BIM authoring platform to generate the informative model. Each building of the selected district is represented by a schematic volume rich of quantitative and qualitative features and information selected to finalize knowledge of the urban district. Shared parameters are nested in masses with an identified LOD with each building that is part of the cadastral micro zone. This mass is characterized by a choice of graphic and alphanumeric information related to the individuality of each building. The following figure (Fig. 16) highlights relationship between parameters chosen and coded, and characterizing the related views.

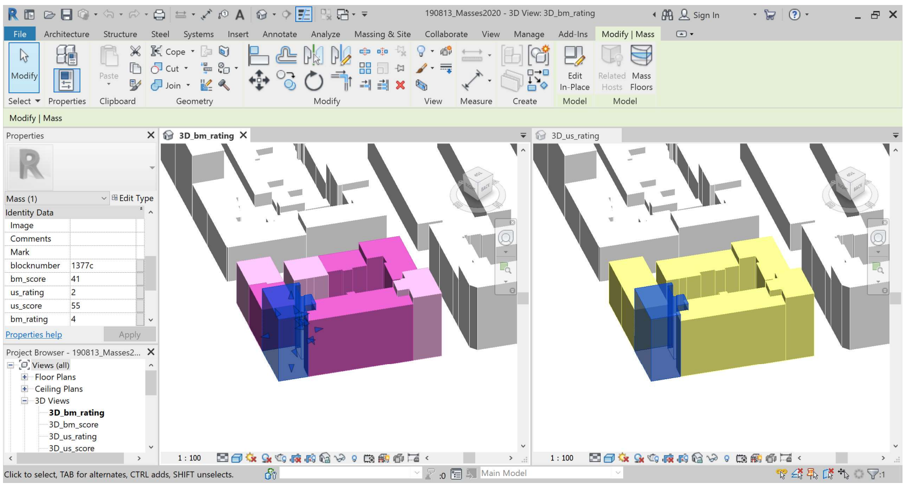

Fig. 16 First steps in the indicators' representation

Through specific nodes available on market -e.g. Color.byParameter node available using Modelical package (Tabanera 2015) a range of colours has been set to override each building volume without using specific view filters. Filling in the us_rating and bm_rating parameters, and running the related script, the urban model has the features of a graphical interface through the thematisation applied automatically to the volumes of buildings. This representation can be used by the professionals to manage buildings maintenance in the whole building life cycle.

4. Discussion and conclusions

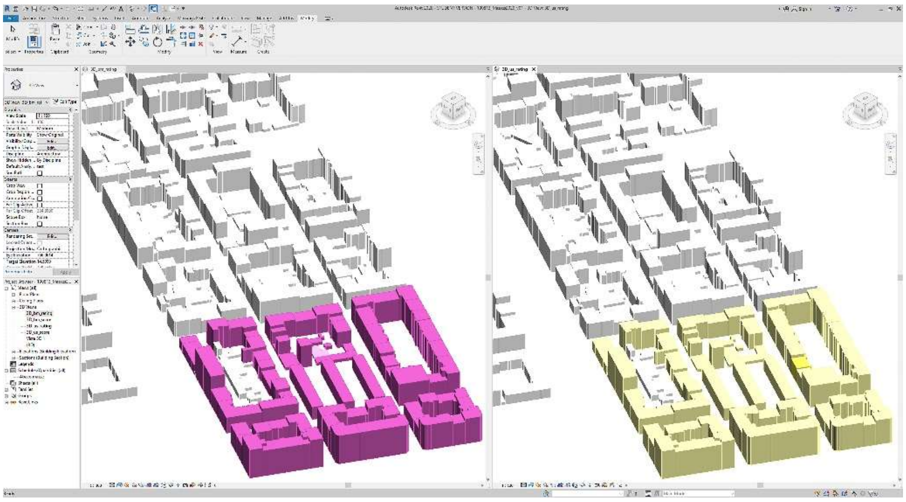

Fig. 17 Final indicators' representation

The results of the two indicators show (Fig. 17) a uniform framework of the portion of the analysed BF. This is because the blocks inspected are all situated in a central area of Turin, so only through a broaden analysis extended to more portions of the city it will be possible to obtain a different range of results. From an overview on the last census (2011), through an analysis of the collected data, it is possible to see that the results of our research are confirmed, even if the NSO investigates only the residential buildings' state of maintenance. This comparison has been possible because the district's blocks of our case study match with the NSO census area (Fig. 18).

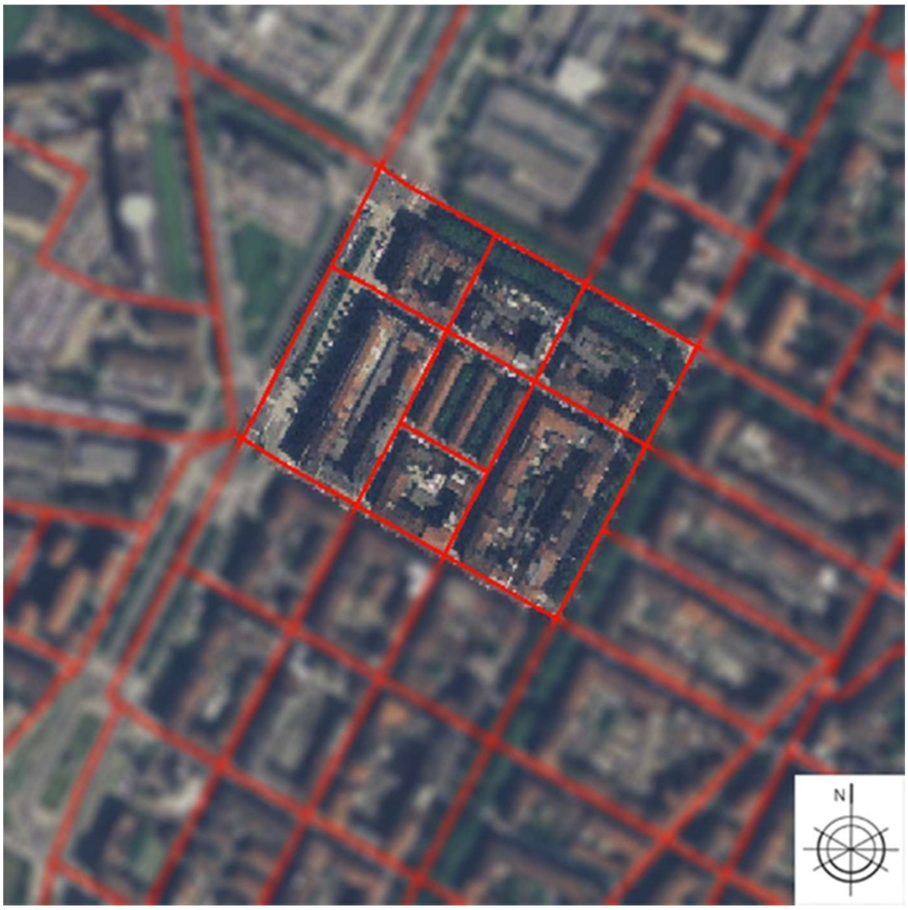

Fig.18 Representation of the minimum census units established by the NSO

Undoubtedly, the designed method has got some weaknesses, which are emerged only throughout its application to the case study.

The first problem is the unavailability of the street view tool for some portion of the city, for instance the suburb's areas. However, this one could be solved with the use of unmanned aerial vehicles for the inspections. Another matter is the flattening of the results of the inspection of each building on a unique plane. Indeed, the visual analysis, through which each parameter is assessed, involve, for every buildings' facades, both horizontal and vertical elements, so we should have two different scores for each parameter, one for the horizontal and one for the vertical surfaces. However, the final results must be unique for each elevation plane because of the level of detail requested for the representation of the digital model at urban scale. Therefore, the distinction between vertical and horizontal elements is lost. Moreover, the low degree of discrimination between the stakeholder competences is another weakness, but it could be solved involving more professionals during the parameters' weights evaluation phase.

Then, on the BIM model there are two main problem concerning: the data input, as they must be pure numbers and not a fractional one, and the BIM software interoperability, because of the preliminary definition of the script, needed for the automatic representation of the provided data.

As mentioned in the introduction, the models are designed to collect and manage a lot of information not only from the external environment; the usability over time of data in digital systems, gradually implemented in quality and quantity, as the systems of elaboration and management change more and more, bring us back to the themes, already presented above in relation to material systems, of the overcoming of time, with its action of decay, and of the permanence of form, material and technology. To increase the efficiency and effectiveness of the model over time, two methodological actions are needed: the first one concerns the "process of deconstructing the real physical element in several finalized models with different purposes and users"; the second one concerns the economic feasibility of the model: "even though theoretically it is possible to have a model more and more corresponding to what is to be realized or realized for each operator, the examination of its feasibility is required, above all in monetary terms" (Moglia et al. 2019).

This switchover is both from perception to representation and from the subjectivity to desired objectivity, "expression by means of signs, figures, and images", or "the need to reduce in concrete and readable signs an abstract or concrete entity". The model feasibility, in which the representation is realized, is the desired connection of the model with reality. Venturi offers the topic of "The obligation Toward the Difficult Whole", which evokes, in this context, the desire to develop the relationship between survey and project.

Despite these limitations, the existing public databases could be used to implement the model with the data in them collected. As well as the NSO before described, as instance, there are: the Cadastre; the Information System for Building Energy Performance; the database of the National agency for new technologies, energy and sustainable economic development; etc.. All these databases stand-alone and don't interact each other; so, depending on the authorizations' disposability for the consultation of the data, it could be useful to pick up all the information in a unique digital model, in order to provide an effective data management.

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