

## INTEGRATING BIM AND GIS DATA TO SUPPORT THE MANAGEMENT OF LARGE BUILDING STOCKS

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### ABSTRACT

The survey phase is an essential prerequisite for effective management and improvement of existing buildings. The low accessibility of information regarding the design and construction phases and the current state of the buildings, are the main causes of inefficient actions on existing buildings. The lack of "As Built" documentation (building components, installations, etc.) and the complex task of detecting their current status in terms of use (intended use and space dimensions, environmental context, etc.) and maintenance (conservation status of building components, age of the technological installations, previous maintenance work, compliance with current regulations, etc.) causes deep difficulties in planning, scheduling and controlling appropriate interventions. Starting from these assumptions, this paper shows the findings of a research, aimed at testing the integrated use of Building Information Modeling (BIM) and 3D Geographic Information Systems (3D GIS) in order to structure knowledge. The research concerns a case study and it has actually led to the development of a BIM- 3D GIS workflow which formalizes knowledge and information involved of a significant building, according to its management: the INA houses by Enrico Mandolesi, a residential complex for about 2500 inhabitants built around 1960 in the eastern suburbs of Cagliari (Italy).

### 1. INTRODUCTION

Building Information Modeling (BIM) and Geographic Information Systems (GIS) have their respective roots in different areas of engineering and architecture. The BIM methodology was developed in order to provide an effective system for building management. Central to it is the use of accurate a detailed parametric model that simulate the building through its engineering and architectural life cycle, from the design to the construction and finally to the demolition (Volk et al., 2014) and (Azhar et al., 2011). GIS systems, on the other hand, are powerful tools for the archival and management of geospatial data that, integrated with other databases, allow for spatial analysis and land modelling operations (Longley et al., 2005), (Chang et al., 2006) and (Zhu et al., 2018).

Geographic Information Systems were developed since the 1960s to simplify the processing of georeferenced data. The first GIS was built in Canada, to automate the processing of the information from the Canada Land Inventory. In a similar way, the U. S. Bureau of the Census built a primitive GIS in preparation for the 1970 census, based on the fact that the computerization could have reduced the error rates in managing and organizing spatially the results of the census.

During the 70s and 80s, the advancement of GIS was measured part, on its ability to perform complex spatial analysis. Today, a GIS can be defined as an application that can create, memorize, manipulate and analyze geospatial information. Its foremost applications are in the management of resources and utilities, telecommunications, urban and regional planning, routing of vehicles, parcel shipping, and more generally any application concerning georeferenced data in the world (Goodchild et al., 2000).

The definition of BIM that best describes the real essence of the method is certainly the one in Eastman: "BIM is not a thing or a software, but a human activity that involves ultimately a vast change in the processes of the building industry." (Eastman et

al., 2011). BIM must then be intended as a paradigm change in the management of the building process, in which integration and systemic approach become essential.

In the BIM methodology, accurate virtual models represent the instrument on which all phases of the building life cycle are based, obtaining the maximization of the efficiency of the processes and the quality of the results.

It's very interesting to examine the markets of these two methodologies that keep growing and spreading, in parallel and independent ways, among users and stakeholders. The Geographic Information System market was valued at USD 5.33 Billion in 2016 and is expected to reach USD 10.12 Billion by 2023, growing at a CAGR of 9.6% between 2017 and 2023. Development of smart cities and urbanization, integration of geospatial technology with mainstream technologies for business intelligence, and growing adoption of GIS solutions in transportation are the key driving factors for the market.

In addition, for the BIM market, this is expected to grow from USD 3.16 Billion in 2016 to USD 7.64 Billion by 2022, at a CAGR of 16.51% during the forecast period.

GIS was already used in the past years as a tool for managing and planning infrastructures and/or buildings, both in the design phase and in the construction and maintenance ones (Bansal et al., 2006), (Ebrahim et al., 2006) and (Chaitanya Kumar et al., 2017). With the further establishment of BIM, the research is orienting towards a stronger BIM-GIS integration, in order to maximize the efficiency in the management of buildings through their full life cycle (Zhu et al., 2018) and (Vacca et al., 2018).

The BIM-GIS integration is a strong support for designing a smart sustainable city, due to its capabilities in data integration, quantitative analysis, application of technologies and urban management (Ma, et al., 2017), (Fosu et al., 2015), (Yamamura et al., 2016) and (Ding et al., 2017).

BIM has advantages on rich geometric and semantic information through the building life cycle (Volk et al., 2017),

while GIS is a broad field covering geovisualisation-based decision making and geospatial modelling (Berry, 1996).

BIM and GIS are two very different systems that can be used complementarily in different phases of an asset's life cycle, requiring thus some level of interoperability between them. The three differences between the software, standards and data types used by both systems poses some problems to their integration, problems related to the geometry and semantics used in either system. The BIM-GIS integration process requires the extraction and transformation of the geometric and semantic information of the BIM model into the GIS project. GIS and BIM are similar in that they both model spatial information - the former is used for outdoor modeling and the latter for indoor modeling - and have common use cases, such as location-based municipal facilities information queries and management. To realize use cases based on BIM and GIS, effective interoperability between GIS and BIM should be guaranteed and achieved (Wook Kang et al., 2015). In order to facilitate this integration and interoperability, the buildingSMART consortium, in partnership with the International Organization for Standardization (ISO), developed the Industry Foundation Classes (IFC) standard for sharing and exchanging BIM data across different software. The aim of IFC development is to facilitate interoperability in the building industry and sharing information among different participants and stakeholders (El Mekawy et al., 2012).

The BIM-GIS integration concerns both the cases of new buildings, and of already existing ones that are under maintenance or restoration.

This paper presents the results of a research about the integration between BIM and 3D GIS, applied to a housing project in the city of Cagliari (Italy).

The work led to the development of a BIM-3D GIS workflow able to formalize the cognitive process of those buildings, according to their management. The first part of the article concerns the problems of BIM-3D GIS integration and its potential. The second part presents the case study; a parametric model of the buildings was created within the Revit software (Autodesk) and subsequently it was integrated into a 3D GIS created with the ArcGIS Pro software.

This work is part of the Italian research project called "Tecniche murarie tradizionali: conoscenza per la conservazione ed il miglioramento prestazionale" (Traditional building techniques: from knowledge to conservation and performance improvement).

## 2. BIM-GIS INTEGRATION

This contribution presents the first results of a research, still in progress, centered on the study of the potential for integrating BIM data into a 3D GIS. The target was to explore and experiment novel strategies for improving the efficiency in the management of the public housing properties.

The questions at the root of the research can be expressed as such:

- What is the added value of the integration of BIM data in a 3D GIS?
- What are the common points and the differences between the two methodologies regarding the data structure, the level of detail (LOD), the topology, the semantics, and the standards?
- How can this integration simplify the management process of the housing properties?

In order to answer these questions, we performed a complete analysis of the two methodologies and the associated software,

underlining their capabilities, their functionality, and their potential criticalities.

The benefit of using BIM methodology consists, besides the ease in producing axonometric and perspective views of the modeled asset, in complementing the 3D model with all the information that is deemed relevant for the knowledge and management of the building. The models such built are ready for visualization, navigation, and analysis through a process of selection of their component elements.

Working with a BIM approach requires before all the definition of the most appropriate level of detail (LOD) of the parametric model, in accordance with the final purpose. This operation is complex when modelling an existing building. These problems are then compounded by the wide range of heterogeneous information concerning the former. Current state of conservation, materials, techniques and construction technologies used, conditions of deterioration, interventions carried out, treatments carried out, simulations of new interventions, etc., represent the wide range of data that the BIM information model has to structure and handle.

In (Foxe et al., 2010) the author notes that in the case of an existing building its model is always to a certain extent different from the actual object. There is always a certain level of simplification and abstraction and too much detail can even be inappropriate, considering the increasing amounts of data that must be processed during further work with the model. Moreover, it is worth mentioning that the level of detail does not only apply to geometry, but it is also related to the accuracy of attributes - descriptive information. In this context, the term "level of development" is more suitable with respect to the LOD (Vacca et al., 2018).

As previously said, the strength of a BIM lies in creating 3D models using parametric elements taken from common libraries that are suitable for all buildings; what is still a problem is the construction of complex 3D spatial queries, and the integration of the 3D model in its surroundings (and possibly in an urban model). This fact does not allow to plan for the interventions taking into account also information concerning the specific context. GIS, however, is able to represent the environment and all the information related to it, besides building those complex and spatial queries that are not possible within the BIM.

Several works have evidenced the importance of integrating BIM and GIS, such as (Isikdag et al., 2008) noting that an implementation of BIM in the geospatial context can be useful for site selection analyses, simulations to determine energy consumption and lighting requirements in buildings, fire response management operations and N-dimensional analyses at the urban level. In (Donkers et al., 2013) state that such integration can also be useful for cadastral uses, environmental analysis, architectural uses, or for real estate agents.

The integration of the two systems still presents several problems such as the different ways of representing geometries, the use of different datum and coordinate systems, the different semantics used. The effort of the researchers in this field is directed towards solving these problems.

The presented research is specifically focused on the construction of a workflow able to integrate the contribution of the BIM and 3D GIS methodologies, in the structuring and management of a wide range of digital data and information about the case study selected.

### 3. THE CASE STUDY

#### 3.1 The public owned housing projects

In this contribution we aim to confront the primary problems in the management of public owned building properties and to propose strategies that can improve the efficiency of this thorny and complex activity.

In this specific case, we considered the AREA (Azienda Regionale per l'Edilizia Abitativa, "Regional Agency for Housing"), which among its other duties, manages the public owned building assets belonging both to the State and to local agencies, leased for a minimal rent to the disadvantaged categories. If the management of the public patrimony is in general very complex, in the AREA case this is compounded by the fact that every building is divided into individual apartments each with their own tenants.

In order to achieve an effective management of the real estate it is necessary to tackle the main obstacle: the scarcity, and in some cases total absence, of information on the estate itself. The lack of documentation about the history of the project and the actual layout of the buildings (in terms of components, installations, systems, etc.), the lack of activity in surveying their current state, both for use (energy efficiency and consumption) and maintenance (conservation state, previous interventions, conformity to regulations, etc.), all cause a deep inefficiency in the planning of maintenance, renovation and/or repurposing works. Overcoming these limitations requires a paradigm change in the approach to the management of public owned real estate, based on an integrated and systemic information program.

#### 3.2 INA houses by Mandolesi, Cagliari

The examined case study is in the La Palma district, on the eastern periphery of Cagliari, beyond the Terramaini channel and bordering the big Molentargius saltworks. It consists of the row houses designed by Enrico Mandolesi in the early 1960s, an important architectural point in the reconstruction age of the city of Cagliari. The project, built to house the employees of the Ministries of Defence, Justice and Internal Affairs, is of remarkable architectural and urban interest, and occupies an area of 1.5 hectares with 77 apartments. A general look at the project shows a small number of building modules variously composed in a schema that forms several inner courts (Sanjust, 2003).

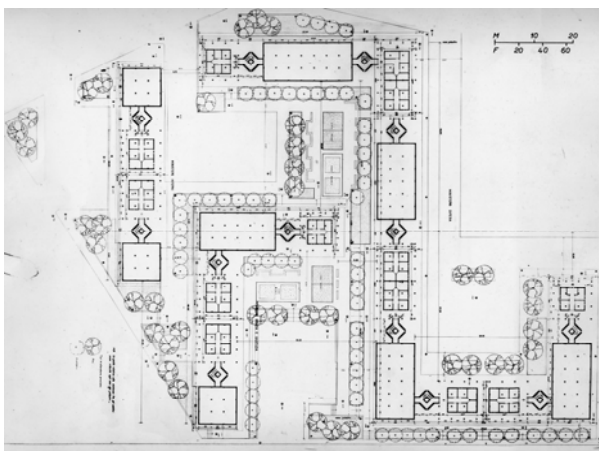


Figure 1. Plan of the project as built

Owned by the AREA authority, the row houses are council houses designed on the core module of a staircase block connecting two housing blocks with three floors. The square-section staircase block is distinguished by being rotated 45° with respect to the housing blocks. The staircase is lit by a tall and narrow window on the corner. The project is typified by the homogeneity of the construction elements: the structure is reinforced concrete in full view, this frame being filled with red brick walls and full height window fixtures. The slight withdrawal of the concrete frame with respect to the filling wall almost inverts the hierarchy between structural frame and fixtures. Another characteristic element is in the recessed balconies.



Figure 2. The current state of the buildings in the "La Palma" district.

The apartments designed for the project fall into two categories: one with five rooms, and one with six rooms and double bathrooms. Every apartment has two balconies, one in the living area and one for the service area.

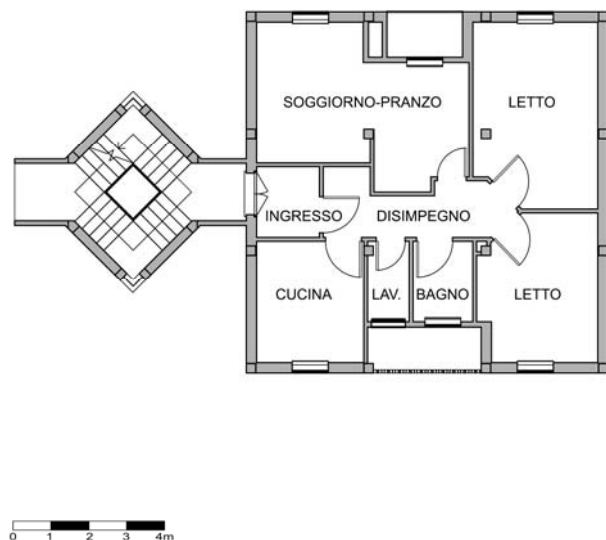


Figure 3. Plan of the typical five rooms apartment.

Regarding the current state of the buildings, we can certainly say that the overall conservation state is good, thanks to the use

of durable materials and techniques. The few signs of degradation concern the superficial layer of the concrete. The progressive aging of this material was until now tackled with several layers of plastic paint, which, rather than presenting a definitive or even lasting solution, is a quick and mostly cosmetic action. The foremost form of decay in the building chosen as case study was not the degradation of the building materials, but rather the uncoordinated interventions performed by the tenants: additions, modifications and substitutions done with different materials and for subjective ends. The result is a clash of solutions, materials and colors, sometimes with a rather unpleasant impact.

#### 4. BIM-3D GIS WORKFLOW

##### 4.1 The information model of the buildings

In order to have full information about a building it is necessary to know its history, from the design, through the construction techniques and technologies, the interventions during its lifetime, to end with the survey of the current performance of the technical elements. All the information related to the case study was thoroughly collected in this phase and digitized in order to ensure a quick and simple consultation.

Starting from the careful analysis of the propriety information, we proceeded with the selection of the subject for the parametric modelling. The BIM model, in fact, does not represent the universal container for every type of information, but must be designed within a specific and focused programme. The work continued with the definition of a conceptual scheme for the decomposition of the building in categories of constructive objects (PBS), with the choice of alphanumeric content to be capitalised for each one of them and, therefore, with the definition of the detail level of the model. Finally, we selected a set of parameters required to “inform” the components of the model. In particular, the parameters were defined to capitalize the construction techniques used, the prevailing materials, the state of degradation, the type of degradation, etc.

Starting from the 2D survey, we proceeded by developing the parametric model with the BIM Autodesk Revit software.

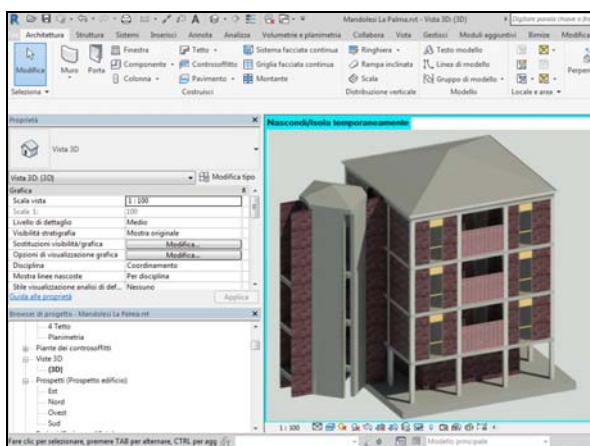


Figure 4. The informative model BIM developed in Revit

The construction of the information model of the buildings of the project allows structuring all the information pertaining to each component, in order to define clearly the materials used, the measurements, the level of decay, the urgency of intervention, etc. The contribution of the Building Information

Modelling is thus substantial, being capable of developing, for each building in the project, a virtual “twin” that can faithfully represent the real one, taking advantage of the collected information detailing every part of the building.

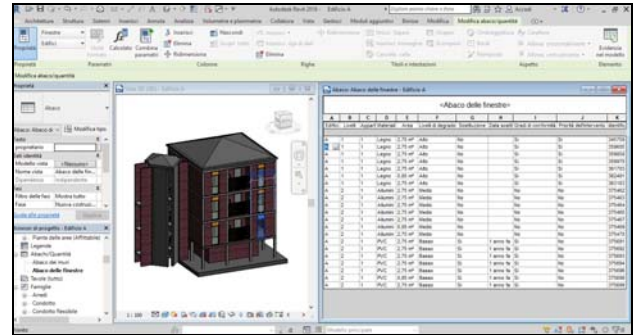


Figure 5. Objects, data and information in Revit

##### 4.2 From BIM to 3D GIS

The aim of this experimentation was to create a working BIM-3D GIS protocol, with the purpose of digitizing and optimizing the processes of accurate surveying aimed at the correct management of public building stock through the modern tools of BIM and 3D GIS.

The GIS software used is ArcGIS Pro by Esri. In order to import the data into ArcGIS we developed a workflow that, through several complex passages, allowed us to integrate the 3D model of the “INA houses” into ArcGIS.

A parametric model created in REVIT cannot be directly imported into any GIS software; this forced us to find an external software tool that could interface the BIM and the 3D GIS. The chosen software was FME by Safe Software- FME is able to transform a parametric model of a building into GIS features, starting from two different REVIT output files: .rvz or .ifc. Both paths produce the same geometric information; the difference is in the complexity of the related tables. When converting from the ifc format, a smaller number of tables is created; starting from .rvz, the database is more complex but all the added fields are empty. For this reason, we proceeded by converting the .ifc parametric model.

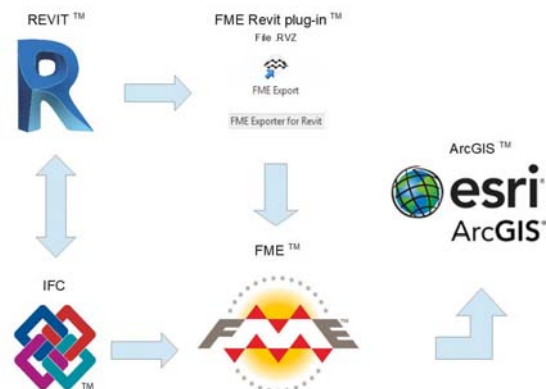


Figure 6. BIM-3D GIS Workflow



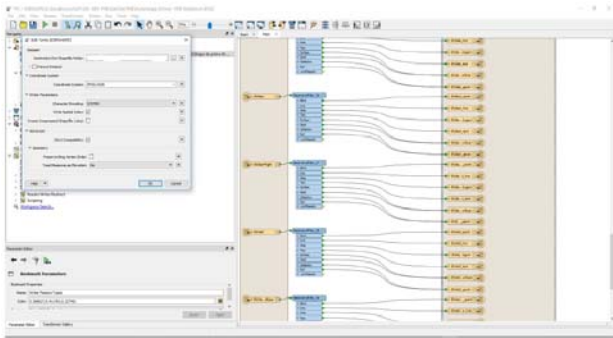


Figure 7. FME workflow

The .ifc file thus created was verified with the “FME Inspector” application in order to ensure that all the structured information from Revit was correctly exported. After verifying the .ifc file, the same was opened in the “FME Workspace” application and then converted into a .gdb (geodatabase) file, in order to manage the model and related information in ArcGIS.

Figure 7 shows the FME workflow for converting a REVIT .ifc file into an ArcGIS .gdb one.

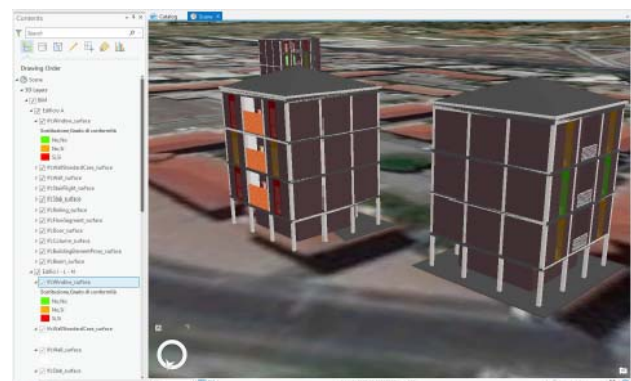
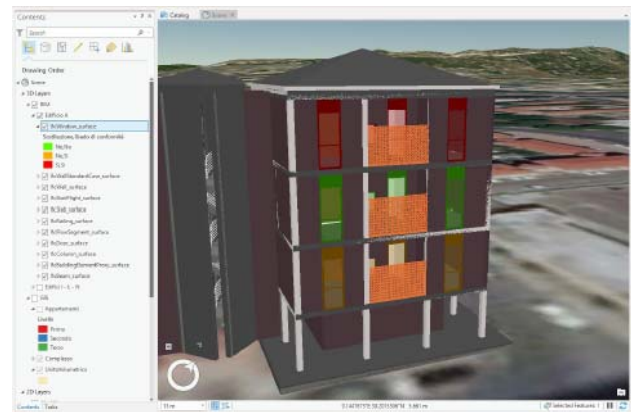
The output of FME is a geodatabase file (.gdb) that allows us to insert the model of our building into a 3D GIS scene, in order to view how this building interacts with other elements in the surroundings, and also perform geospatial or network queries.

A GIS is an information system that allows querying geometries through their related attribute tables and performing spatial analysis. The virtual components of the BIM model (walls, windows, pillars, floors etc.) are linked to external tables (schedules) exported by REVIT, defining their features and performances. The schedules were imported into the ArcGIS geodatabase to be able to perform complex queries that would not be possible inside REVIT.

The cartographic base used is the orthophoto with GSD of 20 cm of the Sardinia Region (WebGIS Regione Sardegna, 2013), while the GIS 3D was built from the “Unità Volumetrica” (Building—Volume Unit) class of the geodatabase of the Sardinia region (WebGIS Regione Sardegna, 2013). The features in this class represent a part of a building having constant ground and a top altitude and are polygon primitives with “ground altitude” and “top altitude” attributes. Using this information, it is possible to extrude the polygons into 3D models of the architectural units. (Vacca et al., 2018; Deidda et al., 2013).

The information present in the tables allows us to classify the elements on one or more attributes.

Figures 8 and 9 show the selection and classification of the “window” components, based on the values of their associated parameters (level of decay, priority of intervention, possible substitution, conformance level of the replaced element, etc.)



Figures 8 e 9. Selection of the windows replaced and level of compliance in ArcGIS

The queries can be performed on a single building or on all the buildings in the housing complex, in the case that it was necessary to plan, and program maintenance works on the entire project. This is a concrete need, considering that the buildings in the project all have the same material and technological characteristics, and also the same age level (they were all built at the same time).

Such queries are of, great importance, especially in the management and maintenance phases of the building’s life cycle, as they give the ability to structure rationally the interventions for the restoration and maintenance of the buildings.

All tables can be edited within ArcGIS. Should some attribute of the schedules be modified, it is possible to export the affected table in .xls format and re-import it in REVIT, in order to update the parametric model information modified in the GIS.

The ability to identify on the parametric model and on the related urban context the components that primarily need intervention allows us to consider and evaluate the important economic, logistic and operative aspects of the intervention, also optimizing the management of safety measures in the restoration work environment (with a correct choice of the machinery, tools, temporary works and procedures to be employed).

In order to offer a versatile and effective tool for the different informative needs of a public administration managing a sizable real estate, the result of our work allows for different levels of detail and depth about the housing project.

For that purpose, all the documentation collected about the buildings was archived in the GIS. Working plan, static test, systems conformity certifications, etc., all have their appropriate place in the ArcGIS database.

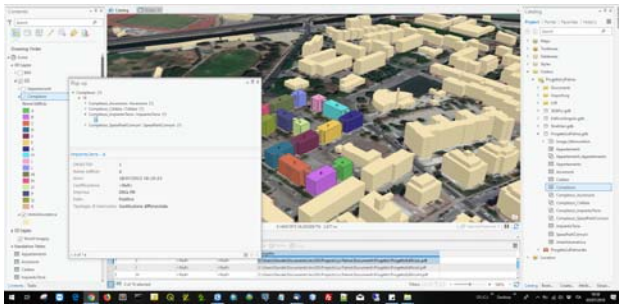


Figure 10. Archiving the buildings' and apartments' documentation in ArcGIS.

We also structured the GIS to collect information pertaining to each apartment, such as the tenants, cadaster data, area, certifications, authorizations for inner works, and regularizations for past infringements.

The proposed approach thus allows three levels of information depth: building, apartment, and construction element. Depending on the current need, the system will supply the required level of detail: from quick browsing of the documentation about each building and apartment in the housing complex, to a detailed analysis of the materials and techniques used in a specific construction element, its level of decay, etc.

## 5. CONCLUSIONS

The experimentation illustrated in the present contribution allowed us to arrive at some considerations about the results obtained and the possible implementations of the research.

The most important result is the awareness of the need to reason in terms of interoperability: starting from the identification of the physiological limits of each ICT, we worked on the structuring of communication and relationship interfaces between 3D GIS and BIM. From the experimentation carried out it emerges that the integrated BIM-3D GIS system is configured as a viable and sustainable solution for structuring the knowledge process of large public building stocks. All this provided that the objectives of the work are adequately identified, and an adequate selection of the necessary information has been carried out, as well as the introduction of reporting parameters on which a possible comparative analysis can be carried out.

According to this approach, the maintenance activity is configured as the result of appropriately "informed", rational and conscious choices. Such a system, being a support for structuring the information on the public real estate, would provide the administrations a key to optimizing the local services through a better programming of the interventions on the real estate itself

Future developments include the possibility of gradually replacing the commercial applications used in this experiment with open source applications.

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