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BIM GIS for the management of real estate assets of retirement homes



Relatore:
prof. Anna Osello

Corelatore:
prof. Matteo Del Giudice

Candidato:
Gabriele Buffa

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ABSTRACT

Nel contesto storico odierno si può individuare la questione anziani in Italia come un'esigenza sociale. Focalizzandosi nel territorio della Regione Piemonte è evidente un aumento della popolazione nella cosiddetta Terza età. Allo stesso tempo, lo sviluppo della tecnologia nel campo dell'edilizia e l'innovazione nella gestione di modelli di città Smart City svolgono numerosi passi avanti, integrando la progettazione tradizionale con rigorose metodologie per la gestione e progettazione degli edifici. Nello spirito di perseguire una soluzione alla sopracitata esigenza sociale, questo lavoro di tesi vuole analizzare il patrimonio esistente delle case di riposo, proponendo una gestione delle informazioni della banca dati immobiliare utilizzando due ambiti: alla scala edilizia è la metodologia BIM, alla scala territoriale è il sistema informativo GIS. I due ambiti sono messi in stretta relazione fra loro, con l'obiettivo di proporre una metodologia che identifichi una banca dati unica a livello della scala urbana: la metodologia DIM. Questa banca dati viene utilizzata per realizzare strumenti info-grafici che migliorino la visualizzazione e la chiarezza dei dati resi disponibili ai diversi utenti.

In today's historical context one can identify the elderly issue in Italy as a social need. Focusing on the territory of the Piedmont Region is evident an increase in the population in the so-called Third Age. At the same time, the development of technology in the field of construction and innovation in the management of Smart City models are taking numerous steps forward, integrating traditional design with rigorous methodologies for the management and design of buildings. In the spirit of pursuing a solution to the above mentioned social need, this thesis work aims to analyze the existing heritage of retirement homes, proposing a management of real estate database information using two areas: at the building scale is the BIM methodology, at the territorial scale is the GIS information system. The two areas are closely related to each other, with the aim of proposing a methodology that identifies a unique database at the urban scale: the DIM methodology. This database is used to create info-graphic tools that improve the visualization and clarity of the data made available to different users.

1. INTRODUCTION

1.1. Purpose of thesis

In the historical period in which we live it is clear that the problem of the elderly has become a necessity, as these people represent a precious gift for each individual. Analyzing the data related to the population of the **Piedmont Region** in the last eight years, it is evident an increase in the Third Age group. The fact turns into a problem of management of residential facilities used to accommodate these people, where the capacity becomes a determining factor. If on the one hand the effect limits the administrative choices of the facility managers, on the other hand it puts a brake on the choice of the patient or the relative or the user, who wants to use a building that can offer the best services to human needs. The problem therefore arises of how to manage an entire real estate asset, which extends to a territorial scale and embraces a large number of citizens and buildings.

As technology and digitization progresses, it becomes apparent that software is increasingly an integral part of the entire building process. The realization of **Smart Cities** is a founding example of this, where technology and construction merge to seek quality and well-being in the services offered to citizens. Technology is leading to a speeding up and automation of many parts of the process, especially in the phase after the execution of the work, i.e. the management of the building. It can therefore be observed two great areas just described: the **need** to better manage retirement homes and the **possibility** of using information technology applicable to solve or provide a solution to the need. Between the solutions turns out followuibile the BIM methodology and the informative systems GIS, applicable respectively to the building and territorial scale.

The objective of this thesis is the management of the real estate assets of nursing homes, in order to meet the above mentioned need and the use of data by different users, i.e. elderly people, patients and administrators of health facilities. Looking at illustrative projects in which **BIM** and **GIS** have been applied, the possibility of integrating these two realities into a single methodology, **DIM**, emerges. We take these projects as a starting point to try to recreate the DIM in this thesis work, since this process is a meeting point between the building and territorial scales, an urban scale that analyzes the database of real estate assets. In order to create the DIM, interoperability tests are performed with different software to identify its peculiarities and the possibility of creating a DIM.

From the DIM database, the main functions are identified, that is the technical-graphic tools that you want to obtain from these software such as 3D visualizations, collection of technical information on retirement homes. The software that performs these functions can be difficult to use for a user not working in the construction industry. In order to improve the use of

information on health facilities, we propose the creation of dashboards or interactive dashboards, which allow with immediate infographics a better reception of information, make choices and comparisons between different parameters, manage in real time the filtered information. In parallel to this flow of activities there is the search for a collaboration with the administrations of health care facilities, through a questionnaire sent to them; the aim is to obtain technical-building information from health care residences. This makes it possible to enrich the initial BIM and GIS database and optimize the information in the DIM, software tools and dashboard.

1.2. Retirement homes in Piedmont

1.2.1. Trend of the elderly population

The thesis work has as its catchment area the Piedmont Region. ISTAT data related to the population from 2012 to 2019 have been analyzed ¹. It is noted that the population over 75 years of age shows an increase in percentage, in the first period in strong growth (3.8%) and in the end in constant growth, albeit with lower values (0.6%). The graph below clarifies the numerical values.

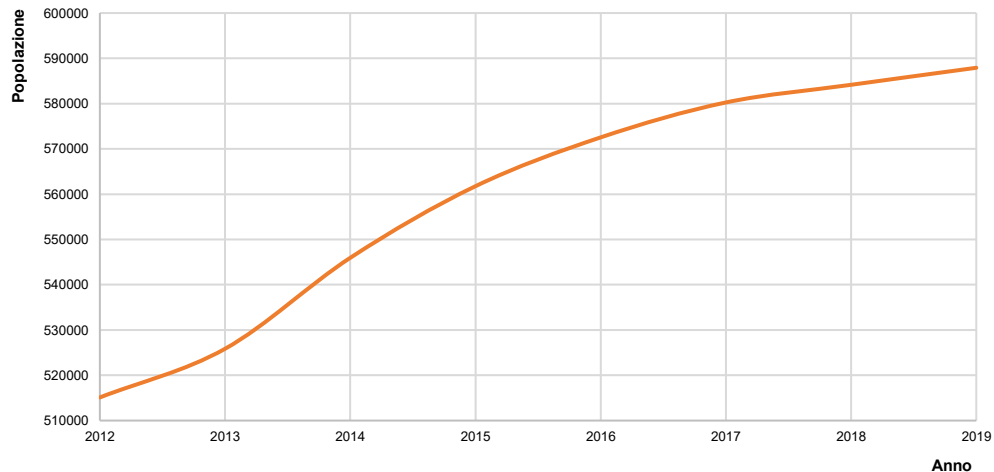


Table 1 - Population trend over 75 years of age

Reference year	Population 75 years and over	Increase of people	Increase in %
2012	515113	/	/
2013	525858	10745	2,1
2014	545945	20087	3,8
2015	561760	15815	2,9
2016	572538	10778	1,9
2017	580249	7711	1,3
2018	584150	3901	0,7
2019	587912	3762	0,6

Table 2 - Percentage population growth since 2012

Leaving aside the social and cultural causes that can influence the results, it is clear that the elderly population has increased over the years. This event is of vital importance in a society that is now dynamic and in constant movement, where the elderly often live far from their families. This is why the nursing home becomes a point of reference to prevent the detachment and isolation of the person. The increase in population is a determining factor for the administration in the management of health facilities, as it leads to changes in internal renovations, an increase in the number of beds or energy efficiency choices to meet the criteria of comfort of the proposed services. These solutions on the administrative side are to be considered in order to meet the demands of users who could grow in number and must be able to access facilities that give a certain minimum of standards on the quality of services of the person.

1.2.2. Reference standard

In Italy the word *retirement home* is associated with that building that can accommodate the elderly and patients, who have needs for hospitalization in various forms and levels of care. In reality, this definition is too simplified and incomplete, as each Italian Region establishes different terms and types for health care facilities. The Piedmont Region has in its regulatory past many definitions for Healthcare Residences, often incorporated and surpassed by the most recent regional decrees (DGR). Below is a list that clarifies how health residences are classified. A first distinction is made on the types of *users* and types of *structure*. The users or patients are *self-sufficient* and *non-self-sufficient*. Not self-sufficient are those "*persons with physical, mental, sensory or relational disabilities ascertained through the adoption of uniform criteria throughout the national territory*" ².

For the types of structure, reference is made to the national legislation, which establishes a unit of measurement to classify the types of health care residences: it is the **Nucleus**, or "*a distribution area of the hospitals autonomous for equipment and services*" ³. It is evident how the core conditions and divides the interior spaces into specific areas. The same building can accommodate several nuclei. At the level of structure intended as a building, the *Residential* and *Semi-residential* typology is distinguished.

Among the main categories present in the Piemontese territory, the following are defined ⁴: RSA, RA, RAF, NAT, CDI, CDIA, CDAA, CDAI. The functions and services provided by some types are based on current regulations but still retain an obsolete name.

- *RSA* - *Residenza Sanitaria Assistenziale* - Health Care Residence: a facility used for the care of non-self-sufficient patients. Often the term obsolete old people's home is to be understood in reality as an RSA.
- *RA* - *Residenza Assistenziale* - Care Residence: a facility designed to receive partially self-sufficient patients who are able to perform their primary functions with help ⁵.
- *RAF* - *Residenza Assistenziale Flessibile* - Flexible Care Residence: similar to the RSAs, with the only difference regarding the smaller number of healthcare facilities (only the outpatient clinic is provided and there are no physiokinesitherapy and podiatry areas) ⁶.
- *NAT* - *Nucleo Alzheimer Temporaneo* - Temporary Alzheimer's Unit: a garrison established in 2012 ⁷ and is a nucleus located within an RSA that welcomes people with dementia, who have behavioral disorders and / or health and care problems of high complexity and can benefit from intensive psycho-rehabilitation therapeutic intervention ⁸
- *CDI* - *CDIA* - respectively Integrated Day Care Center and Autonomous Integrated Day Care Center: are semi-residential facilities that care for partially non-self-sufficient and non-self-sufficient elderly who need care, relational and health care services, in order to promote the recovery of autonomy and maintenance in their own living environment, improve and develop residual capacity ⁹
- *CDAA* - *CDAI* - respectively Autonomous Alzheimer's Day Care Center and Alzheimer's Day Care Center embedded in an RSA: they are semi-residential facilities that care for people suffering from dementia, implementing rehabilitation and socializing programs through the combined combination of health and social care services ¹⁰

The following diagram summarizes all the types described in the paragraph:

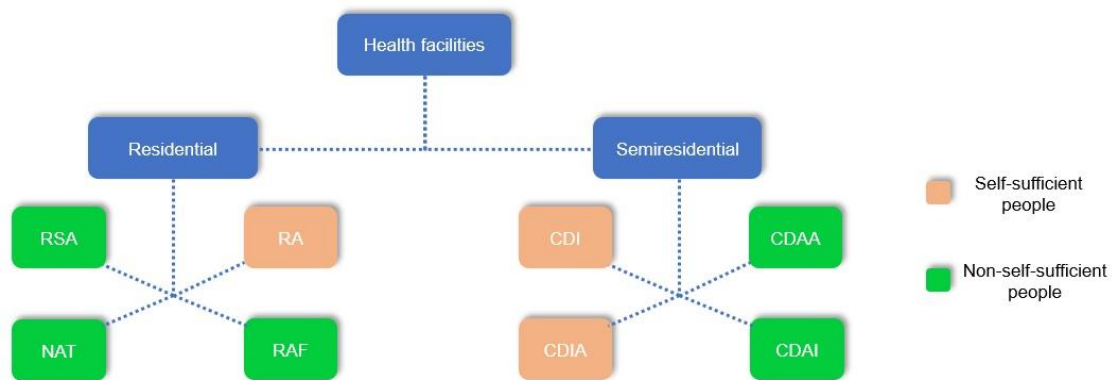


Figure 1 - Types of health facilities according to Piedmont regulations

1.3. Background

1.3.1. Introduction to BIM

BIM stands for **Building Information Modeling**. Its specific definition finds different meanings depending on the environment in which it is considered. The National Institute of Building Science indicates as BIM that working methodology, applied to the building world, that allows the *"digital representation of physical and functional characteristics of an object"*¹¹. It is important to stress that BIM is neither software nor information, but a **methodology**. BIM is not only about facilitating the visualization of an object in 2D or 3D, but it allows to associate to it, in the specific case of the construction field, non-graphic information such as data related to material data sheets, plant maintenance and building life cycle. This information can be shared with the various actors involved in the entire building process.

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One of the strengths of BIM lies in the collaboration between the professional figures involved in all phases of the production process, from design to management. The BIM model can undergo extractions, insertions, updates or modifications of its geometric and functional characteristics. The operations just described are possible thanks to a feature that distinguishes the BIM method from classic design. In classic design, the method was based on the integration of classic freehand drawing (mostly used for feasibility study concepts) alongside CAD software operating in the 2D field. This methodology uses different actors involved in the process, where each one uses their own information that

they bring later and individually to the project, thus creating the danger of misunderstandings. In essence there were many sources of data as databases.

The innovation of BIM is to carry out the entire **building process** using a single database as a source of information. This allows the automation of data exchange and the reduction of errors.

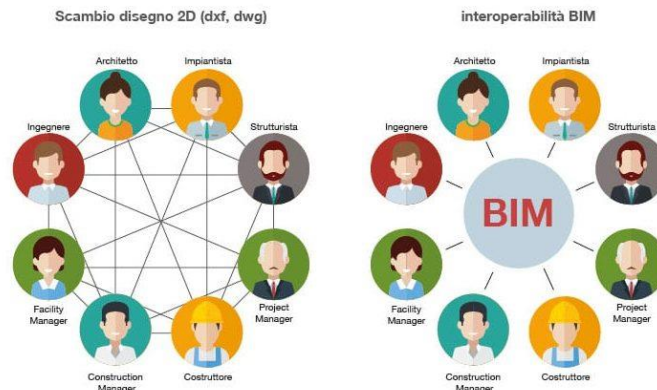


Figure 2 - Classic design methodology - BIM methodology (Source: <http://biblus.acca.it>)

Stakeholders have the same source of information with which to carry out their activities. This guarantees unambiguity in the passage of information and integration between processes. The collaboration between the building processes extends not only in the implementation but also in the disciplines that make-up the project ¹².

Within the same model it is possible to represent the architectural, structural and plant engineering objects, each of which is the responsibility of different designers; all the information can be obtained from the same file. For these reasons, the BIM methodology has the advantage of reducing time and costs in the process, but has the effect of a greater time investment in the initial phase, where all the information must be collected and inserted in the model that will speed up some subsequent phases, such as obtaining energy certification.

Another important advantage is the standardization of files and its information, enclosed in the concept of **Interoperability**. The software that uses the BIM methodology must be able to generate the model with an international exchange format that can be shared with figures outside the building process. Many software such as Revit, Archicad and ALLPLAN use the IFC standard as the exchange format, with the .ifc file extension. **IFC** stands for *Industry Foundation Classes* and represents an open exchange format of the model, with the aim of not losing or distorting the information exchanged between the various operators. ¹³.

The Standard classifies all objects and standardizes entities, properties and classifications. Objects are thought of as the BIM methodology, that is a part of a building such as doors,

windows, walls, and floors. For this reason, the parameters associated with the model in the proprietary format, such as cost, construction phase, and positioning, are also recognized in the .ifc standard. The use of the .ifc model makes it possible to share its information with external operators, even non-professional ones, such as local administrations which, in the absence of proprietary software, can quickly certify a Building Permit, for example.



Figure 3 - Exchange of information with IFC format (Source: <http://biblus.acca.it>)

The BIM potential also manifests itself in the graphical display of the model. From the international normative it is possible to establish for every object and for the whole model a level of detail in its visualization. The LOD is divided into two parts, the *Level of detail*, which defines how much information is contained in the model, and the *Level of Development*, which defines the detail with which a geometric object is displayed.

There are two regulatory references, one US and one Italian, which have been responsible for establishing the characteristics of each level of detail, which are also reflected in the IFC standard. In the American context, the American Institute of Architects (AIA) has published a Level Of Detail framework that defines 5 LOD levels: LOD 100, LOD 200, LOD 300, LOD 400, LOD 500¹⁴. Starting with LOD 100, which represents a simple conceptual mass model, the content increases to higher LODs but also the scope of application. Example a LOD 300 is applicable for an executive project but the LOD 500 is used if it needs to build an *As built*.

The Italian legislation transposes the American one and identifies itself in the UNI 11337-4 standard, decomposing the concept of Development Level in the geometric and informative part, respectively the LOG and the LOI. The UNI standard establishes seven classes of LOD, from LOD A to LOD G. Starting from LOD A that refers to a *generic object*, you get to an *executed and updated object* of LOD F and LOD G¹⁵.

1.3.2. Introduction to GIS

The acronym GIS, from the English **Geographic Information System**, translates to Geographic Information System. It represents a system formed by a set of computer tools with the ability to *collect, store, manage and make available useful information for the territorial organization*.¹⁶

The GIS allows you to analyze the territory by collecting a lot of data of different nature, data that are mainly **geo-referenced**. They are used for the management and planning of the territory, with considerable development in urban planning.

Normally a GIS is composed of:

- a map base (vector/raster);
- a database (or database);
- a software for the management of spatial data;
- people that interfaces with the software and information to be managed;

These are computer/geographic systems designed primarily for¹⁷:

- the management of the territory;
- urban and infrastructural planning;
- the study of the transformations of the territory over time;
- the realization of thematic cartographies (hydrographic, sismical, demographic, traffic, etc.);
- statistics, demography;
- the study of the archaeological-cultural/environmental/building heritage;
- GPS applications;

A GIS system locates in space, and then on a map, objects contained in a database and grouped according to similar characteristics, managing them as georeferenced thematic information layers. The concept of **layer** is one of the main features that allow the GIS to become a much appreciated tool in the field of urban planning and stakeholder decision-making.

The layer materializes a precise collection of a certain type of data, such as a building, vegetation, an orthophoto of the ground. Within a GIS, grouping by layers greatly simplifies the visualization. For example, layers of polygons, raster layers, point layers are created. Depending on the theme to be displayed, the layers are filtered or superimposed on each other.

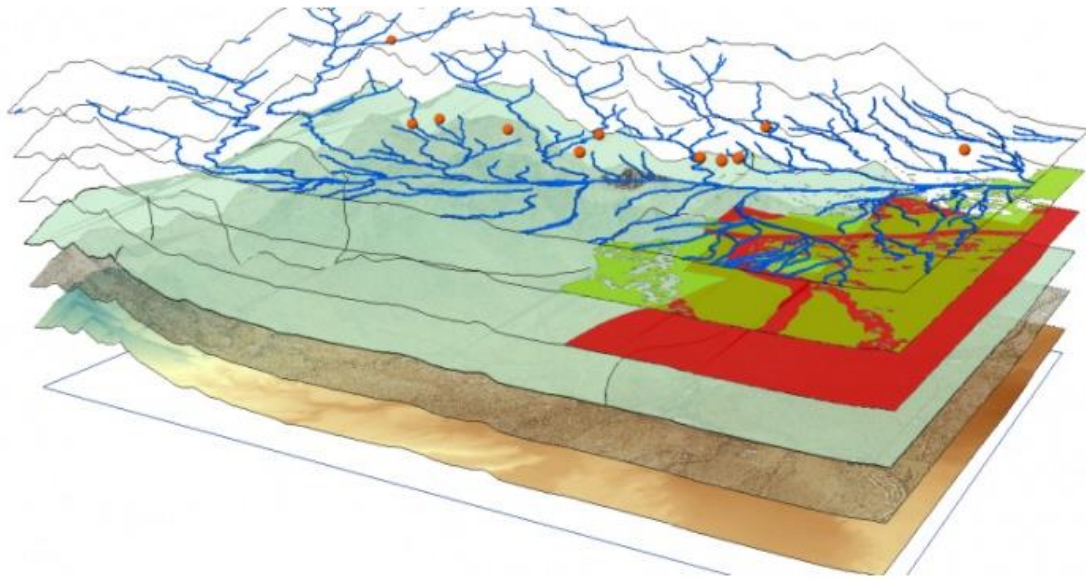


Figure 4 - Layer Concept in GIS Systems (Source: <http://bim.acca.it>)

A GIS is built from the definition of the type of data you want to manage, data that often have different formats and therefore it is necessary to identify technologies for data integration. This makes it clear that the set of technological resources, software, input data and personnel interacting with the system, creates a GIS depending on the **objective** you want to achieve. Therefore, the GIS should not be seen as a geo-referenced database, but is an information collector built ad hoc to solve a need, for a *goal*.

The reference to the intrinsic meaning of GIS precludes those frequent cases where the GIS system created is huge, consisting of more data than necessary. This causes slowdowns in the management of the process and is beyond the scope for which the GIS was created.

It is therefore essential to have a complete knowledge of the target, in order to know the input data to be entered into the GIS model. The input data in the broadest sense is nothing more than the description of reality, filtered by our mind when it is aware of the goal to be achieved. You could use the word modeling to define the act of building a GIS. Modeling implies the creation of a **Data Model**.

Through a modeling process, which by subsequent approximation transforms the perceived reality into a computer language that can be used by software, a sequence of data models can be identified that achieve the objective set for the construction of GIS.

- an *external model*: it is a simplification of reality through the analysis of the objects to be described, identified as entities, which will be those necessary to meet the objective of GIS. Often the formalism with which this model is realized is reduced to a simple list of objects;

1. EDIFICI;	
2. INDIRIZZO;	
3. STRADE;	
4. PARCHEGGI DISABILI;	
5. FARMACIE;	
6. VIGILANZA;	
7. SERVIZI SANITARI;	
8. AREE DI RITROVO;	
9. PUNTI DI RITROVO.	
<hr/>	
1. EDIFICI: si intendono tutte le unità immobiliari adibite ad ospitare persone o attività (poligoni).	
ATTRIBUTI:	
<ul style="list-style-type: none">- SUPERFICIE (double, precision=6, scale=2) metratura totale in mq.- CAT_USO (text, leng=80): corrisponde alla categoria d'uso dell'edificio	

Figure 5 - External Model – Entity (Source: Project Exercise of the Course Cartografia Numerica e GIS, 2019, Politi C, Sassaroli E, Buffa G)

- a *conceptual model*: that defines the entity-relations model, that is, it allows to formalize the problem through simple rules; normally such model consists in a diagram that associates the various entities;

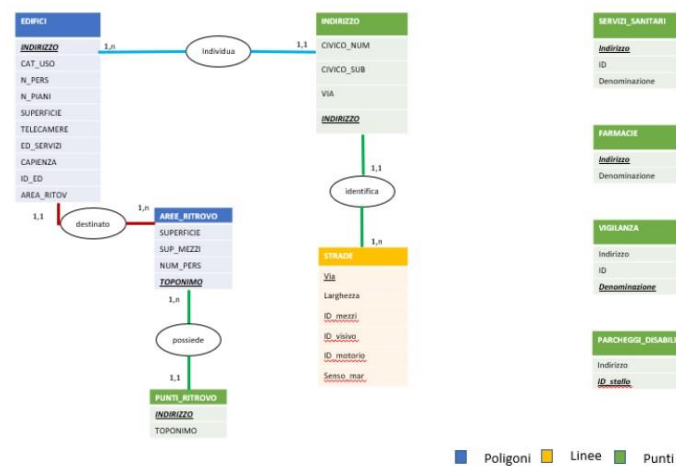


Figure 6 - Conceptual Model - Entity Relationship (Source: Project Exercise of the Course Cartografia Numerica e GIS, 2019, Politi C, Sassaroli E, Buffa G)

- a *logical model*: such process allows the schematization of the conceptual model, previously written, in a language comprehensible by the computer. It is therefore necessary to schematize some useful associations to tie the various entities. The concept of cardinality is used in order to formalize the associations between the **attributes**, that is the information of each entity;



Figure 7 - Logical model (Source: Project Exercise of the Course Cartografia Numerica e GIS, 2019, Politi C, Sassaroli E, Buffa G)

- an *internal model*: this model provides a real translation of the logical schema into the language of the machine, composed, therefore, of files. It requires the use of software for the management of alphanumeric and graphic data;

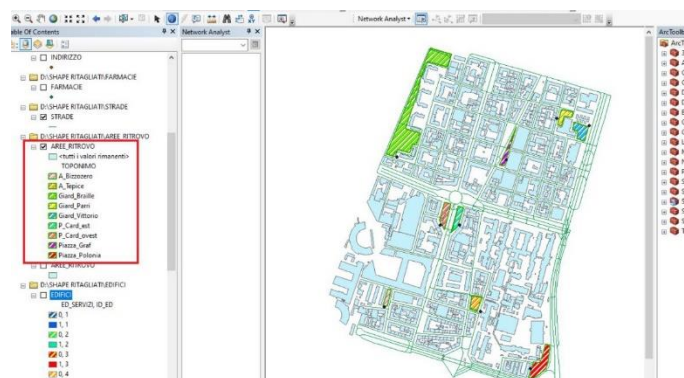


Figure 8 - Internal model (Source: Project Exercise of the Course Cartografia Numerica e GIS, 2019, Politi C, Sassaroli E, Buffa G)

GIS was developed to manipulate, manage, visualize and analyze spatial data, based on geometric technologies. Since the system allows spatial information to be stored in the object-oriented relational database, GIS is not limited to the data storage system alone, but goes beyond that. Attribute data is stored in the database which allows spatial analysis¹⁸. At this point it is clear that GIS has the possibility to interface with the construction world, which is mainly organized by objects. The search for a relationship with the BIM world leads to the search for a system for reading and archiving 3D data.

The **City Markup Language (CityGML)** is developed: according to Deng et al., (2016), CityGML "is an open standard data model and exchange format that has the ability to store 3D models of cities and landscapes based on GML (Geography Markup Language), as identified by the Open Geospatial Consortium (OGC)"¹⁹.



Figure 9 - Logo CityGML (Source: <http://www.citygml.org>)

CityGML becomes the standard for interoperability between 2D and 3D geospatial information. CityGML has definitions for different levels of detail (LOD) in order to reflect the amount of detail included in a model. Construction models of a single residential building from LOD1 to LOD4 are presented in Figure 10. LOD0 shows the building footprint in 2.5D: models with LOD1 are referred to as the basic block model with flat roofs: LOD2 is a basic block model with a different roof style. Since LOD3 and LOD4 models incorporate windows and doors that have close external views, their internal components are quite different. LOD4 contains interior spaces and interior walls. However, the building model in CityGML is less complete and mature as in BIM, even in LOD4 ²⁰.



Figure 10 - Schema LOD CityGML (Source: Sami, Rahman, 2018, GIS AND BIM INTEGRATION AT DATA LEVEL: A REVIEW, International Conference on Geomatics and Geospatial Technology, Kuala Lumpur, p.300)

1.3.3. Introduction to DIM

This thesis work proposes a methodology to manage the data of nursing homes. It is intended that the catchment area in this case extends to an urban scale, where there are many structures to consider, each containing a large amount of data to analyze. The amount of data is a determining factor for successful management. In these years of technological revolution two important changes are taking place:

- the construction of Smart Cities makes city management, service and community life more efficient;
- the construction industry is considering developing parametric 3D models to optimize the construction process ²¹ ;

These two events lead to increasingly heterogeneous information being added to the database. This could affect the management result of the entire asset.



Figure 11 - Smart city and Data (Source: <https://www.lumi4innovation.it>)

In light of the above, the two areas BIM and GIS have advantages that can optimize the management of this database. If they have been analyzed individually so far, BIM and GIS can be compared to find common points of value.

Observed the GIS Information System, it can be seen that it was developed to manipulate, manage, visualize and analyze spatial, geographical data based on geometric technologies. The possibility that the type of system, associated with specific software, allows you to store object-oriented information in your databases, allowing an openness also to the exchange of geometric data.

BIM is relatively rich and detailed in construction information for both geometric and semantic information, however, the limit of BIM in construction planning are obvious²². For example, topographic information for the construction of infrastructure such as dams and bridges is data that can only be found in GIS.

Basically, it turns out that the two domains were developed for different purposes and to work on different platforms, but they complement each other through the exchange of data. The levels and application ranges of BIM and GIS are different, but at some point you can reach a common level, which is the building level.

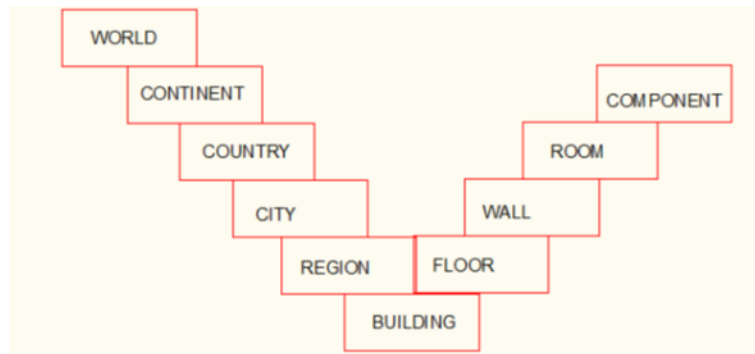


Figure 12 - Overlapping BIM - GIS levels (Source: Sami, Rahman, 2018, *GIS AND BIM INTEGRATION AT DATA LEVEL: A REVIEW*, International Conference on Geomatics and Geospatial Technology, Kuala Lumpur, p.300)

Achieving a common level implies that the two areas can dialogue with each other, specifically that heterogeneous databases can dialogue with each other. A data **connection** process is created. In parallel to the management of nursing homes, to make the data more easily usable by possible users, a process is created where a unified database could implement the quality of management. Surely having two available sources such as BIM and GIS is already a high level of integration, but for this thesis work we try to achieve the union of the two fields, because it would allow to improve the process in the hypothesis of large amounts of data, as it happens in an urban scale. BIM and GIS integration is developed in a single model, ***DIM District Information Modeling***.

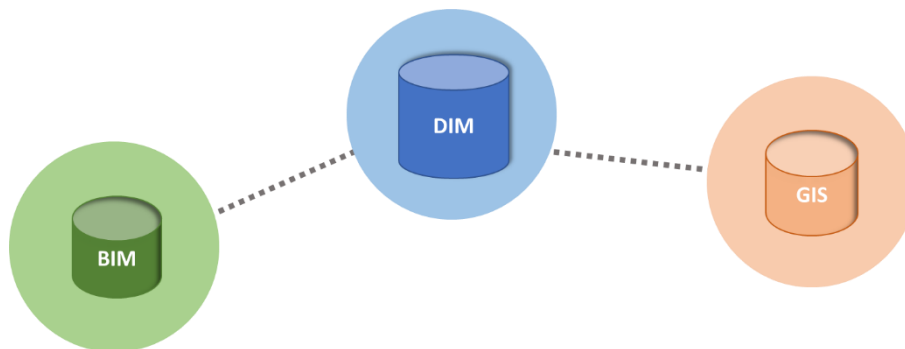


Figure 13 - BIM - GIS integration into DIM

However, the unique model must evaluate two aspects, ***geometry*** and ***semantics***. The geometry takes the form of a pure 3D object. Semantics is the pure alphanumeric datum. In both BIM and GIS, databases are made up of both types of data, so the DIM that is created must be able to store this information without splitting or losing it.

Geometry and semantics are part of the objectives of individual BIMs and GISs, where the respective Levels of Detail classify the data they have available. Once BIMs and GISs are merged, the DIM acquires a large amount of data and because of their heterogeneity of format, it is no longer possible to deal with the original LODs. Therefore it is necessary to

have the ranges that, depending on the scale of display and detail, are able to identify the correct data each time. A new LOD DIM is created.

These ranges are nothing more than Detail Levels, which are neither LOD BIM nor LOD GIS, but new Levels, for which the differences in range are not only related to the display of the object, but also to the origin of the data. Chapter 2 Methodology documents the LOD DIMs used in this thesis.

1.3.4. Examples of DIM application

After analyzing the concept of DIM as a BIM GIS integration, we identify a number of existing projects where the application of DIM has been significant to the evolution of the process.

DIMMER

The DIMMER project (*District Information Modeling for Management and Energy Reduction*) is a Smart City project funded by the European Union. It lasted three years and has seen the participation of realities such as the Politecnico di Torino, ARUP, IREN energia and CSI Piemonte. The idea of the project is to reduce the consumption of energy and carbon dioxide through a sophisticated monitoring system of data, coming from different sources ²³. The fundamental part of the methodology is to integrate BIM and GIS. In essence, the analysis of emissions is no longer seen as a single datum from a single building, but from a more or less extensive set of them, expanding the scale of the problem from building to urban.



Figure 14 - The DIMMER project (Source: Osello, Del Giudice, Rapetti, Semeraro, 2016, *Il BIM per la gestione dei dati alla scala urbana e edilizia*, <http://www.ilnuovocantiere.it>)

Starting from the GIS we have identified typical buildings, with different characteristics for type, age of construction and orientation. After installing sensors inside the buildings, the accurate BIM modeling of the sensors made it possible to recreate energy simulation scenarios. The results of the simulations have been optimized with the interoperability between the software, made available to different decision makers and stakeholders with different visualization tools, if necessary as a dashboard and benchmark tool.

In order to manage the amount of data, special LOD DIMs have been created, whose logic is as follows: with a nominal scale similar to the CityGML standard, an intermediate equilibrium point is reached that represents perfect interoperability between BIM and GIS systems. In extreme cases of high and low LOD DIM, there is no interaction between the systems because the data used in the process comes only from BIM or GIS.

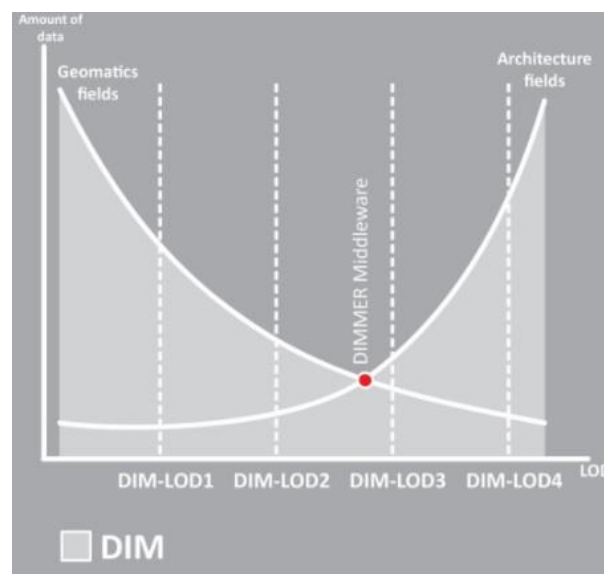


Figure 15 - LOD DIM Graph (Source: Osello, Del Giudice, Rapetti, Semeraro, 2016, *Il BIM per la gestione dei dati alla scala urbana e edilizia*, <http://www.ilnuovocantiere.it>)

The DIMMER is an example of how the District Model can innovate a branch of the building industry such as energy saving, where the lack of software that analyze the interoperability between heterogeneous data has not allowed in the past to extend the problem to an urban scale, focusing only on the individual energy results of a building.

3D City Model

3D virtual city models represent spatial and geo-referenced urban data through 3D geovirtual environments that basically include terrain models, building models, vegetation models, and road and transportation system models. The main potential of 3D virtual city models is to visualize heterogeneous data in a single model ²⁴. These virtual cities are

becoming an essential tool in planning and redevelopment processes. The high value of the information, good spatial readability and the associated variety of possible uses make 3D city models a valuable tool for a wide variety of problems, such as solar and visibility analysis.

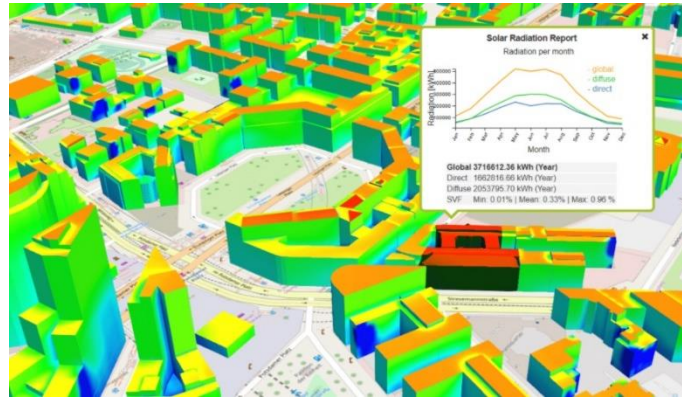


Figure 16 - Solar analysis 3D city model (Source: <https://vc.systems/loesungen/3d-stadtmodell/>)

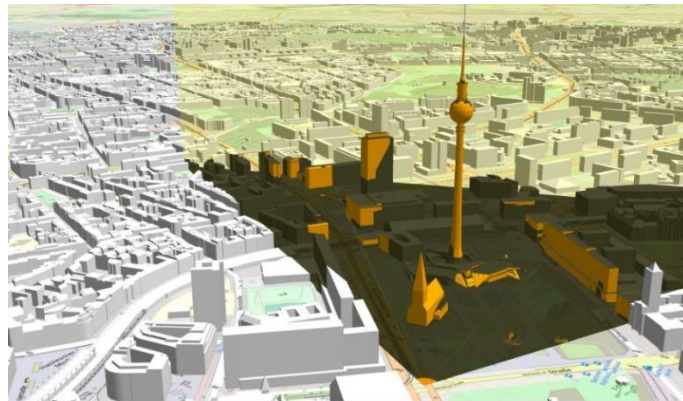


Figure 17 - 3D city model visibility analysis (Source: <https://vc.systems/loesungen/3d-stadtmodell/>)

The 3D City Model is a tool suitable for the representation of the urban but also territorial scale. For this reason the content of a 3D model is created for a purpose of visualization, management and the contents are chosen in advance to build such model.

GIS data provides the basic information to build a 3D city model, such as digital terrain models, road networks, land use maps and georeferenced data. The main components of 3D city models form digital terrain models (DTM) represented, for example, by TINs or grids. BIM models represent another category of geo-spatial data that can be integrated into a 3D city model, as they provide the highest level of detail for individual building components ²⁵.

Multi LOD

The visualization of a 3D model is certainly one of the objectives for those who produce data in view of an urban scale of buildings. The 3D model allows to concretize that technical information that support alphanumeric data. In the building sector, it is important to decide in advance what needs to be visualized. The concept of *Level of Detail* becomes fundamental because it relates the technical-graphic semantics of a model with the corresponding building in the real world. This relationship creates the choice of what to want to visualize; this choice is linked to the use of the model itself.

Even more important is the possibility to produce data with a different Detail Level. We are talking about **Multi LOD**.

Modern techniques for 3D data production are now able to produce outputs with different LODs. However, multi LOD data sets are very rare; this is due to some causes, such as the lack of GIS software to be programmed to produce data at multiple LOD levels ²⁶. Often 3D returns are required at the highest possible level of detail, leaving out the less graphically rich views.

It should not be forgotten that the concept of Level of Detail is not only about geometric data and how they are displayed by a user; there is also a Level of Detail on non-graphic information such as energy, economic and maintenance data.

Nowadays there is no denying the fact that current software allows in most cases to integrate different formats. This is the luck of the Multi LOD approach.

In the construction industry there are many data formats involved in the construction process. You can collect alphanumeric data such as tables, calculation reports, costs from metric calculations; there are geometric data related to surfaces, property boundaries in vector format such as a .dwg or shapefile; geometric data in raster format for photogrammetric aerial capture and reconstruction of urban areas; 3D geometric data from the BIM world for building modeling. Each of these formats allows for the recognition of a certain amount of information (for example, a raster file of an aerial socket has no geometrical information about the interior of the building).

With some software it is possible to manage several formats simultaneously in a single output environment. This is the basis from which to develop a multi-LOD. For the management of cities and environments in a detailed urban scale, Multi LOD finds good application opportunities, since many are the views related to the uses that can be generated in Smart City management.



Figure 18 - Composite rendering of a few exemplary datasets (Source: Biljecki, Ledoux, Stoter, GENERATION OF MULTI-LOD 3D CITY MODELS IN CITYGML WITH THE PROCEDURAL MODELLING ENGINE RANDOM3DCITY, 1st International Conference on Smart Data and Smart Cities, 2016, Croatia p.56)

You can make a consideration about the Building Smart from the perspective of real estate asset management. In the presence of more buildings, it is necessary to define bands related to the degree of information; if the generated model has a certain amount of information it can be displayed at a certain LOD and only the buildings that have that LOD can be compared with each other. If a model does not reach a certain information content it is displayed at a lower detail. This allows the stakeholder to filter the decision making part, focusing only on the buildings that meet the objective of the choice.

2. METODOLOGY

2.1. Workflow of main topics

By analyzing the innovative features of BIM and GIS, then incorporated into a single DIM database as in the examples cited in the previous chapter, it is clear that DIM is a useful means to achieve the goal set in this thesis. Being able to view data on retirement homes from a single database has the potential to reduce the risk of errors and improve the integration of data that can complement each other. On the basis of these considerations it is proposed to reach the objective with a precise flow of activities; this methodology is schematized with the following workflow:

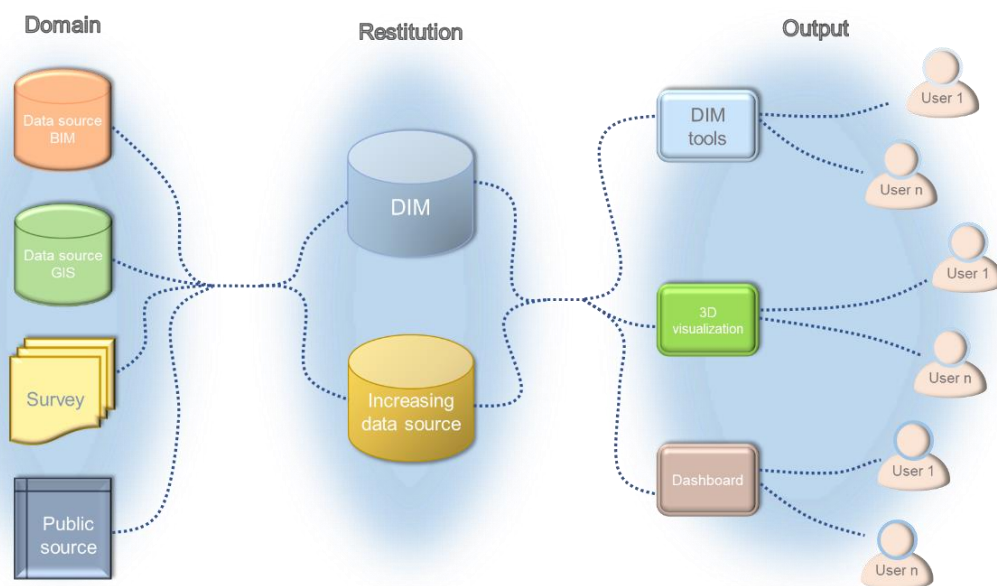


Figure 19 – Schema Methodology of the thesis

Briefly summarizing the schema, you can state the following: from different input data from the BIM world, GIS, and additional sources, you can make an integration to obtain a single DIM database. From this database, you get graphical and technical outputs that meet the demands of end users who will use the DIM data more easily.

BIM - GIS integration is sought in some software through interoperability testing, identifying strengths and weaknesses, and the susceptibility of these to create a single database. At the same time, the enrichment of the data source can be done automatically through a questionnaire, which contains additional information about healthcare facilities. The results obtained define some operations to be carried out in the software such as interactive queries of data models, 3D visualizations. In order to have a direct visualization of decision support to the choices of the users, we proceed to the creation of dashboards.

2.2. Data domains

2.2.1. Data source BIM



The BIM sources used in this thesis are .rvt files, which is the data format used by Autodesk Revit modeling software. The files contain the modeling of *buildings that make-up the **Sanctuary of the Blessed Virgin of Trompone***.

The complex is located in the countryside of Moncrivello, in the province of Vercelli, about 40 km from Turin and less than one km from Villareggia, the nearest town.

There are several buildings that make-up the Trompone, different for use and time of construction, which are listed below. The location had historical importance already from the sixteenth century, where it was born as a shrine to celebrate an apparition of the Virgin Mary. In the following decades the construction of the Church and the Convent was completed.



Figure 20 – Trompone Sanctuary

(Source: https://it.wikipedia.org/wiki/Santuario_della_Beata_Vergine_del_Trompone#cite_note-2)

Starting in 1893 work began to build the sleeve to the north in Neoclassical style. Around the seventies there was the intention to create in a part of the Sanctuary a rehabilitative health facility²⁷. Still today this garrison is managed by the Onlus Association Silent Workers of the Cross, where they are active:

- *CRRF Centro di recupero e rieducazione funzionale mons. Luigi Novarese*. Opened in 2006 in front of the sanctuary, is a Center specialized in intervening on the patient in the rehabilitation phase of orthopedic, neurological, cardiovascular diseases. Rehabilitation also for logopedics.



Figure 21 - CRRF Trompone (Source: <http://www.trompone.it/casa-di-cura/>)

- *RSA Virgo Potens*. The nursing home "Virgo Potens", active since 2015, houses a NSV (Nucleus vegetative states and minimum consciousness of 10 beds) for the reception of people in persistent vegetative state, a NAC (High Neurological Complexity Neurological Nucleus of 10 beds) for the reception of people suffering from neurological diseases such as ALS and Locked-in Syndrome and a department with 20 beds for the reception of dependent elderly people in need of high intensity care ²⁸.

To complete the Sanctuary complex there is a large park to the north of the buildings.

The three models .rvt available concern three parts of the Sanctuary: RSA, Convento and Parco. Specifically we describe the BIM model of the RSA, as this building is the example case used to analyze the functionality and potential of the Methodology proposed in this thesis.

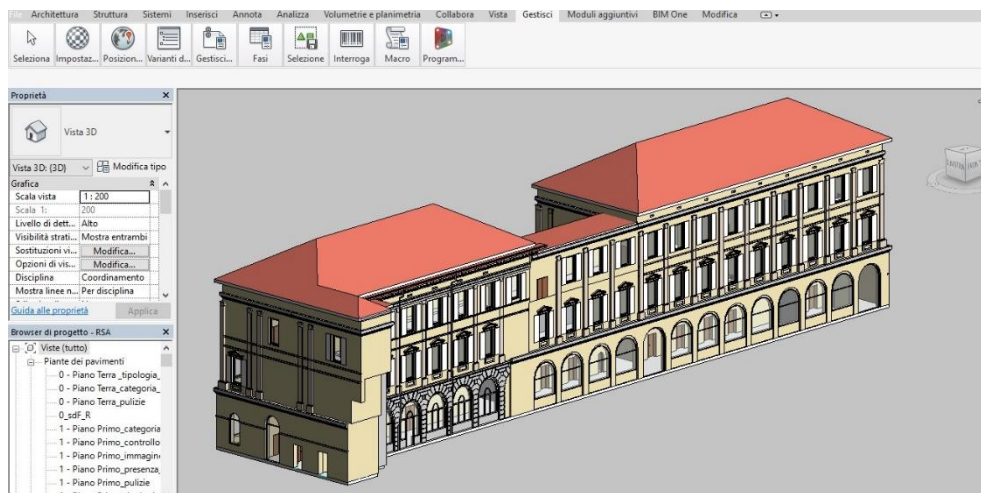


Figure 22 - RSA Trompone BIM Model

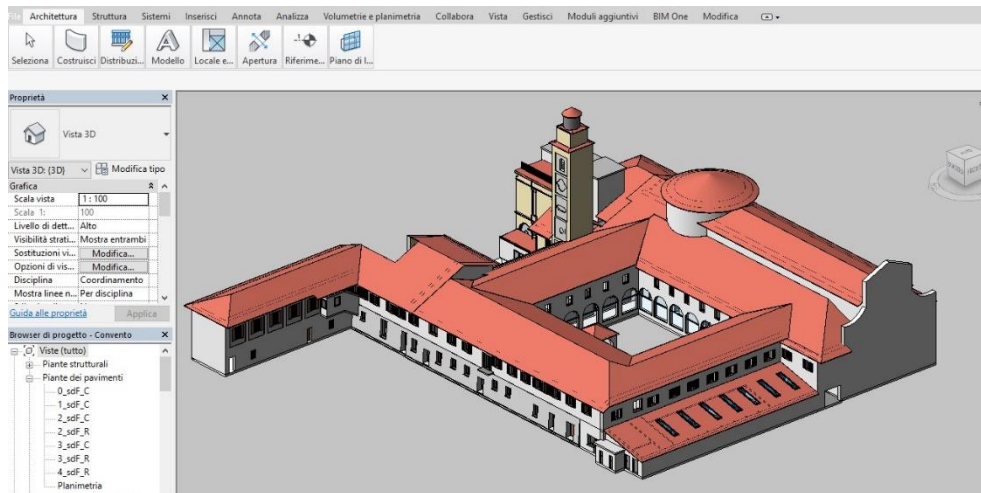


Figure 23 - Convento Trompone BIM Model

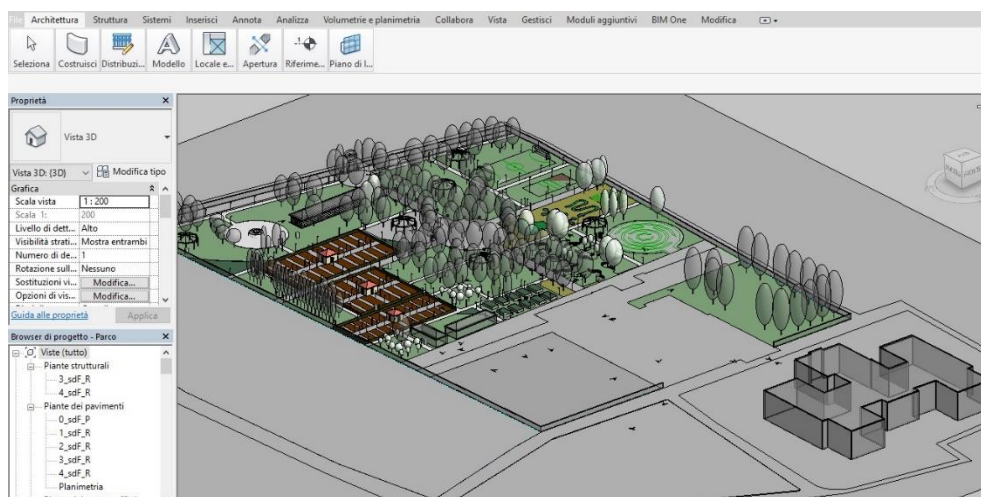


Figure 24 - Parco Trompone BIM Model

RSA Virgo potens is a neoclassical style building, rectangular in shape, divided into three floors above ground for a total of about 2600 square meters of internal surface. The structure is in load-bearing masonry. Particularly striking is the external facade, full of overhangs and pilasters as the neoclassical tradition wants. The modeling of the building and in particular of the facade results in a very high LOG, about LOD F. The result was obtained with LIDAR detection techniques and generation of BIM objects from a Cloud of points. As far as the LOI levels are concerned, it is necessary to evaluate the individual categories of objects, as the element with the May number of parameters are the Locals. They include dimensional, topological and functional data and for this reason they are to be considered with a medium - high LOI level, equal to LOD E. Other categories such as pilasters, curbs, downspouts have a low LOI, equal to LOI B.



Figure 25 – Section 1 RSA Trompone

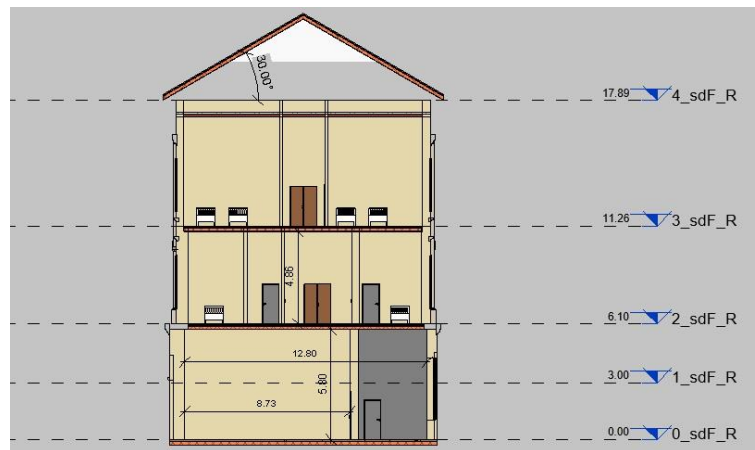


Figure 26 – Section 2 RSA Trompone

2.2.2. Data source GIS



The GIS sources used in this thesis are **Shapefile**. It is a storage format for **vector data** (points, lines, polygons) capable of identifying the location, shape and attributes of spatial entities. A shapefile is composed of several files related to each other, which have the same name but a different extension. Normally it is composed of three extensions, to which a fourth one is added:

- **nomefile.shp**: is the file that contains the geometric information;
- **nomefile.dbf**: is the file that contains the tabular information that is attributes;
- **nomefile.shx**: is the file that keeps the geometrical information and the table information together;
- **nomefile.prj**: is the file that records the geographic reference system of the shapefile;

The data used can be freely downloaded online from the Geoportale Piemonte, where there is a section dedicated to the **BDTRE** files. It corresponds to the Territorial Database of

Reference of the Entities ²⁹ and from 2014 is the reference cartographic base of the Piedmont Region, for all public and private entities. The BDTRE is published in different formats (such as the Shapefile or Raster image) and services (such as the WMS Web Map Service).

For this case of the BIM source, a list of Shapefiles was found in the BDTRE. From the Geoportal site, by filtering the search with the BDTRE field, it is possible to select from an online map a reference area from which to obtain all the vectorial data.

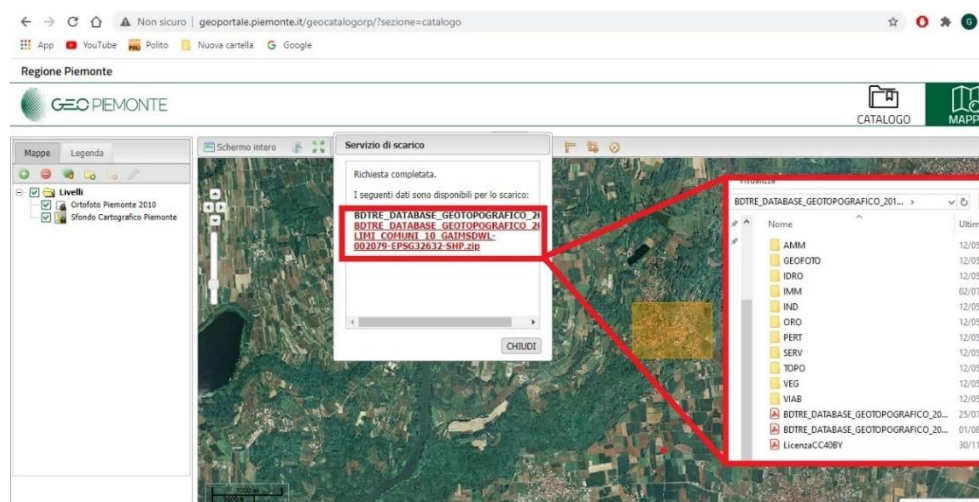


Figure 27 – Download shapefile BDTRE from Geoportale Piemonte

These data are collected in a .zip folder that contains all shapefiles divided into subfolders, by type (e.g. IMM Immobili, VIAB Viabilità, VEG Vegetazione). In order to improve the functions and specifications of the 3D output tools, three other Shapefiles are used that are not derived from the BDTRE database but are freely downloadable from the Geoportal.

The Shapefile related to *Municipal Boundaries* is a Polygons feature that delimits the geographical boundaries of each municipality in Piedmont. This data has very important attributes including the ASL attribute: this field is useful in the GIS environment in order to graphically filter all municipalities, creating similar color fields that correspond to a Sanitary Azzonamento.

This shapefile will be used as a *Pane* in the online *Dashboard* created with Operation Dashboard (see Chapter 2.4.3.).

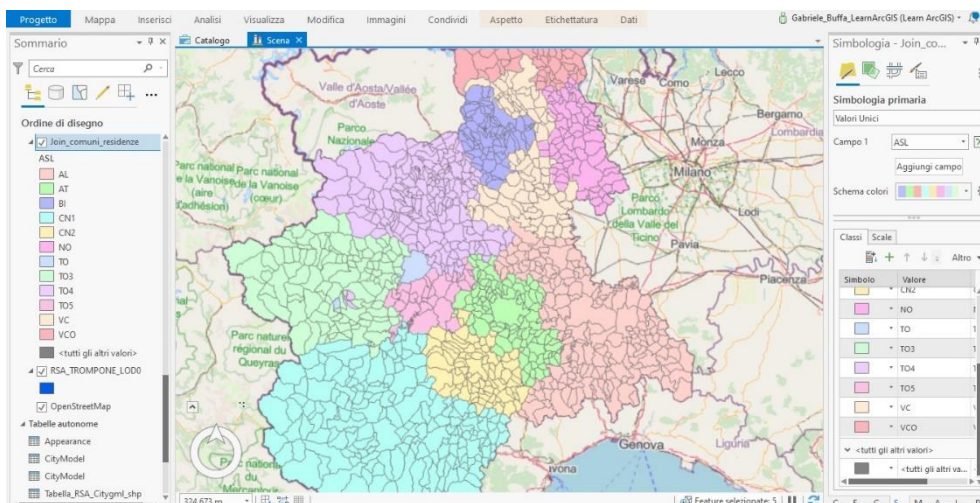


Figure 28 – Shapefile Municipal – Sanitary Azzonamenti Piedmont

The Shapefile relating to *Healthcare Residences* is a feature of Punti that frames all the Structures present in the Piedmontese territory. The GIS data actually derives from the Public Source, that is the table list in Excel format of all the buildings. The Excel worksheet has been imported into the ArcGis Pro catalog as a *Table*. Since the source has a parameter related to the x-y coordinates of each building, the software uses that attribute to create a Shapefile of points. The tool used is *From Table XY to Point*.

This shapefile will be used as a Pane in the online Dashboard created with Operation Dashboard (see Chapter 2.4.3).

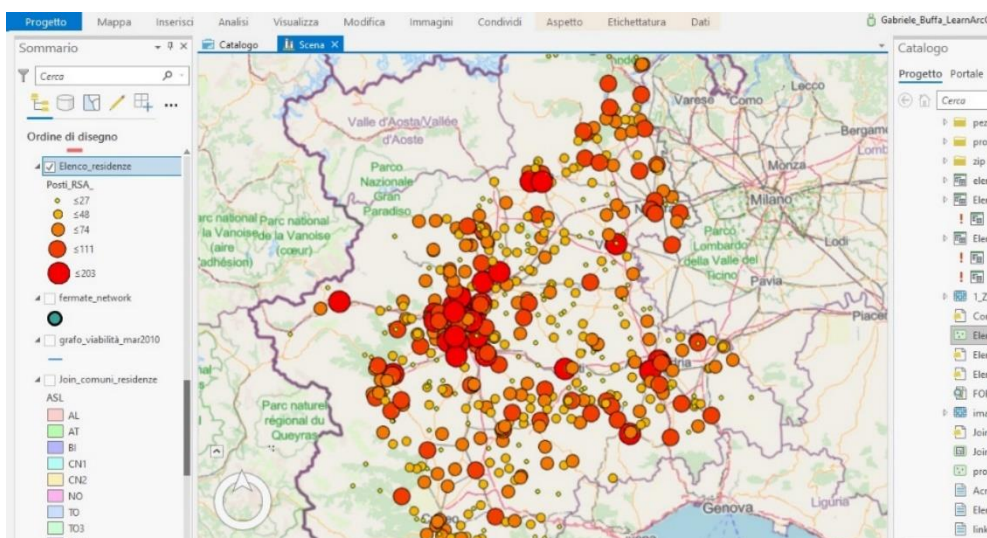


Figure 29 - Facilities List of Piedmont

The Shapefile relative to the *road graph* materializes the main road and freeway networks of Piedmont. This source will be used as a database for tracking the Network Analyst, ArcGis Pro tool explained in paragraph 2.4.1.2).

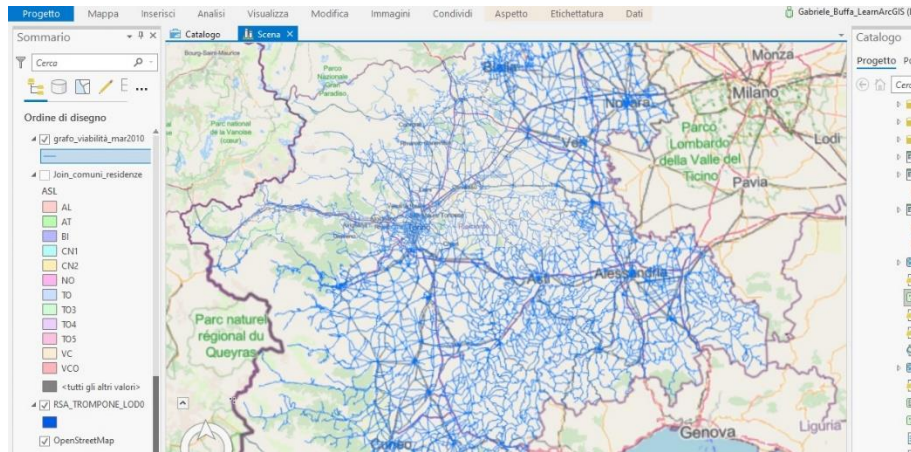


Figure 30 - Road graph Piedmont

2.2.3. Survey



As mentioned in the introduction, this thesis work proposes both the use of the DIM to manage BIM and GIS data together, and the improvement of the initial database. The BIM and GIS sources described above are those publicly obtainable in this historical period, with their level of reliability and quality of information. However, it emerges that these sources do not contain any data that could improve the knowledge of individual health care facilities and the management of the entire process. For this reason it was decided to directly involve the administrations of nursing homes, through the completion of a questionnaire.

The answers obtained from this questionnaire provide information that increases the information content of a health residence. The operation has a double effect. On the one hand, it allows administrations to quickly benefit from more complete information, contained for example in a table where technical and building characteristics of their buildings are listed. On the side of the user, patient or interested person, he would be faced with a list of health residences provided with technical information and services provided, which improve the knowledge of a structure and the comparison between different solutions, choosing the most suitable structure to meet his needs.

The questionnaire was created with the online platform of Google Modules and consists of 34 questions, both technical and construction, the details of each question is referred to Annex 1.

The information enrichment occurs since 26 of the 34 questions (and related answers) are translated into **attributes** that implement the GIS database and **project parameters** that implement the DIM database.

The following table contains the data that can be used in the information enrichment, defining from which question of the questionnaire the data is obtained, the database that it goes to enrich, the type of data and the LOD to which it is applied.

From question n°	Parameter name	Parameter Description	Enrichment data source	Parameter type	Parameter application category	LOD parameter
1	DENOMIN	Denominazione Residenza	GIS	STRINGA	Shapefile	0
2	INDIRIZZO	Indirizzo della Residenza	GIS	STRINGA	Shapefile	0
3	NUCLEO	Tipologia di nucleo/i gestiti	GIS	STRINGA	Shapefile	0
4	PL_RESIDE	Posti letto residenziale	GIS	INTERO BREVE	Shapefile	0
5	PL_DIURN	Posti letto centro diurno	GIS	INTERO BREVE	Shapefile	0
6	ZONA	Posizione della Residenza	GIS	STRINGA	Shapefile	0
7	MEZZI_PUBB	Accessibilità dei mezzi pubblici	GIS	STRINGA	Shapefile	0
8	ANNO	Anno o periodo di costruzione	GIS	STRINGA	Shapefile	0
12	N_PIANI	Numero di piani fuori terra della Residenza	GIS	INTERO BREVE	Shapefile	1
14	TETTO	Forma del tetto	BIM	TESTO	Informazioni del progetto	2
15	CORTE_INT	Area interna, corte interna della Residenza	GIS	STRINGA	Shapefile	0
16	AREA_VER	Area verde della Residenza	GIS	STRINGA	Shapefile	0
17	ATTREZZ	Attrezzatura dell'Area verde	BIM	TESTO	Informazioni del progetto	3
18	SALONE	Spazio interno condiviso della Residenza	BIM	TESTO	Informazioni del progetto	4
19	SALA_PREGH	Sala dedicata alla preghiera	BIM	TESTO	Informazioni del progetto	4
22	N_CAMERE	Numero di camere da letto	GIS	INTERO BREVE	Shapefile	0

23	ESPOSIZIONE	Orientamento delle camere rispetto ai punti cardinali	BIM	TESTO	Finestre	3
25	BALCONE	Accesso ad un balcone dalle camere da letto	BIM	TESTO	Locali	4
26	TIPO_RISCALDAMENTO	Tipologia di riscaldamento	BIM	TESTO	Informazioni del progetto	4
27	RAFFRESCAMENTO	Presenza di stanze con sistema di raffrescamento	BIM	TESTO	Locali	4
28	TIPO_RAFFRESCAMENTO	Tipologia di raffrescamento	BIM	TESTO	Informazioni del progetto	4
29	QUALITA'_ARIA	Sistema di ricambio e controllo aria	BIM	TESTO	Informazioni del progetto	4
30	SISTEMA_CHIAMATA	Sistema di chiamata intelligente nelle camere	BIM	TESTO	Locali	4
31	SENSORI_COMFORT	Sensori di presenza e accesso Internet	BIM	TESTO	Locali	4
32	REGOLAZIONE_LUCE	Sistema per regolazione luminosa camere	BIM	TESTO	Locali	4
33	DOCUMENTAZIONE	Elaborati grafici per la modellazione	BIM	TESTO	Informazioni del progetto	2

Table 1 - Parameters list from the questionnaire

2.2.4. Public source



The **Public source** represents a source that can be freely consulted by a citizen, available on the website of the Piedmont Region.³⁰, which reports the census of all nursing homes operating in Piedmont. The format of the data is tabular (Excel file). The information contained is of technical - administrative nature (Example: Address, number of beds, accredited structure). The list can be downloaded from the Piedmont Region website.

File Home Inserisci Layout di pagina Formule Dati Revisione Visualizza Guida Progettazione Cerca					Condividi Commenti	
G32 VIA SAN GRATO 25, 13011 BORGOSIESIA (VC)						
1	A	G	H	J		
1	Id	Indirizzo	Tipo_Struttura	E_mail	Tipologia	
2	1	VIA MONDALFORNO SUPERIORE 4, 13050 MEZZANA MORTIGLII (VC)	RSA	rsamezzana@ecosociale.it	ANZIANI N	
3	2	VIA CARLO ALBERTO TRON 13, 10065 SAN GERMANO CHISONE (TO)	RA,RAA,RSA	-	ANZIANI A	
4	3	VIA G. MALAN 43, 10062 LUSERNA SAN GIOVANNI (TO)	CDI,RA,RAA,RSA	-	ANZIANI A	
5	4	VIA FORTE 33, 13862 BRUSNENGO (BI)	RA,RSA	casariposobrusnengo@libero.it	ANZIANI A	
6	5	VIA AL FORTE 5, 10066 TORRE PELLICE (TO)	RA,RSA	-	ANZIANI A	
7	6	VIA C.BATTISTI 16, 10043 ORBASSANO (TO)	RSA	info@asg-orbassano.it	ANZIANI N	
8	7	VIA L. EINAUDI 89, 10040 RIVALTA DI TORINO (TO)	RSA	biancadellavalle@tiscali.it	ANZIANI N	
9	8	STRADA LERCARO 3, 15076 OVADA (AL)	RA,RSA	cssas@libero.it	ANZIANI A	
10	9	VIA ABEGG 16, 10059 SUSÀ (TO)	RAA,RSA	laura.robba@libero.it	ANZIANI A	
11	10	VIA GARIBALDI 14, 14048 MONTEGROSSO D'ASTI (AT)	RAB,RSA	coop.quadrifoglio@pec.it	ANZIANI A	
12	11	VIA MOMPILLATO 10 - BORGATA LOURDES, 10040 RUBIANA (TO)	RSA	residenza.lourdes@gruppoagape.it	ANZIANI N	
13	12	PIAZZA SAN MARTINO 6, 12040 VEZZA D'ALBA (CN)	RA,RSA	socialcoop@pec.confcooperative	ANZIANI A	
14	13	VIA CASCINE PONENTE 30, 13886 VIVERONE (BI)	RA,RAA,RSA	info@sereniorizzonti.it	ANZIANI A	
15	14	VIA ROMITA 22, 28845 DOMODOSSOLA (VB)	RSA	residenze.assistenziali@comune.domodossola.vb.it	ANZIANI N	

Figure 31 – Excel list of health residences in Piedmont

This source is used as a basis of comparison to solve any inconsistencies with similar data obtained from the questionnaires and for the creation of tables and graphs, useful to frame an area quantifying it by types, nuclei present and to have an overall territorial vision of how the various garrisons are located in Piedmont.

2.3. Restitution

2.3.1. DIM



2.3.1.1. Interoperability test

"Interoperability is the possibility to exchange the data contained in the initial project model between different software platforms and applications for the different functionalities involved in the activities" ³¹. The fundamental objective is not to lose data. This is how the model file exchange format becomes the key feature to ensure the effectiveness of interoperability. Given the nature and characteristics of the BIM methodology, the possibilities offered by the IFC standard are the ideal and indispensable complement to interoperability. However, it should be emphasized and anticipated that the .ifc format is continuously being improved and developed to fill the gaps in some application areas. The tests analyzed in this thesis work use as a reference model the BIM data source model (described in section 2.2.1.), on which the passage of information through output software is tested. The information analyzed during the test is contained in the following scheme and numbering:

Analyzed information:	1 - Geometry and shape
	2 - Geolocalization
	3 - Display, color of individual objects
	4 - Object name
	5 - Custom Parameters

Table 2 - Information analyzed in Interoperability tests

- 1 – Geometry and shape: It is assessed that the original shape of the model and each part of it is maintained in the output software and that there are no deformations or simplifications in some parts.
- 2 – Geolocalization: It is evaluated that the position of the model with respect to its original reference system is maintained in the output software.
- 3 – Display, color of individual objects: The texture of the material and its possible degree of visual simplification is evaluated in the output software
- 4 – Object name: The name of the objects is evaluated according to the Revit nomenclature, i.e. object intended as Family and of which types are identified. We check the alteration of the name, for example if it is incorporated in a single string of text
- 5 – Custom parameters: Non-geometrical information is evaluated, i.e. how the model's design parameters are identified.

In order to be able to give a judgement on the degree of information received in the output software, a nominal and chromatic scale has been created for the quality of the information.

Information quality scale:	Insufficient
	Discreet
	Good
	Very good
	Excellent

Table 3 - Values and colors scale quality information

2.3.1.2. Investigated software

After the evaluation of the five information of the interoperability test, we proceed with the creation of the DIM. The specific steps for each software analyzed are developed below.

Autodesk Infracore

Infracore is a software for the modeling, design and simulation of civil infrastructures, in view of the BIM methodology. The potential is summarized in the ease of *generating 3D models of the terrain* in a significantly short time. The fact of saving time in this phase of the process allows the designer to optimize the subsequent decisional phase, where it is possible to propose variations to the project. Created primarily for infrastructure, the software uses terrain data ³². For this reason Infracore is able to use data from the GIS world. From the BIM world, being an Autodesk program, it allows you to easily import a Revit .rvt model.

The procedure when a DIM dataset is reached is schematized with the following Flow of Operations:

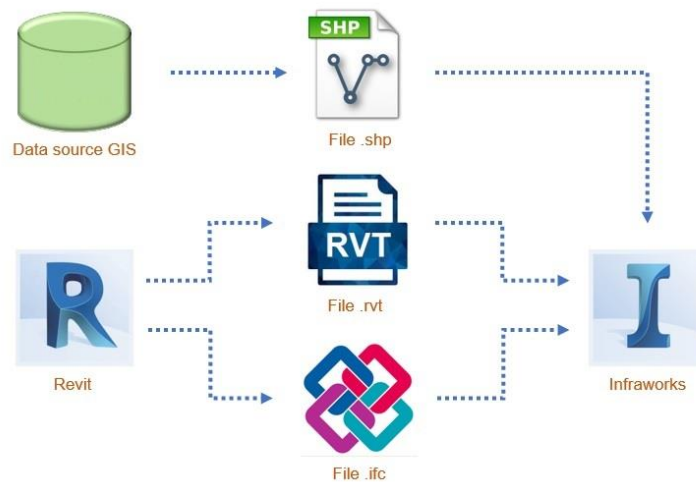


Figure 32 – Operations Flow Interoperability with Infracore

It starts with the creation of the 3D model of the ground around the building. Using the command **Model Builder** Infracore connects to an Open Street Map screen, from which you can select the area of interest that will be generated in 3D. Once the project has been created, you proceed to define its reference system to which all the objects imported or created in the project will refer. A projected **UTM84-32N Reference System** is used.

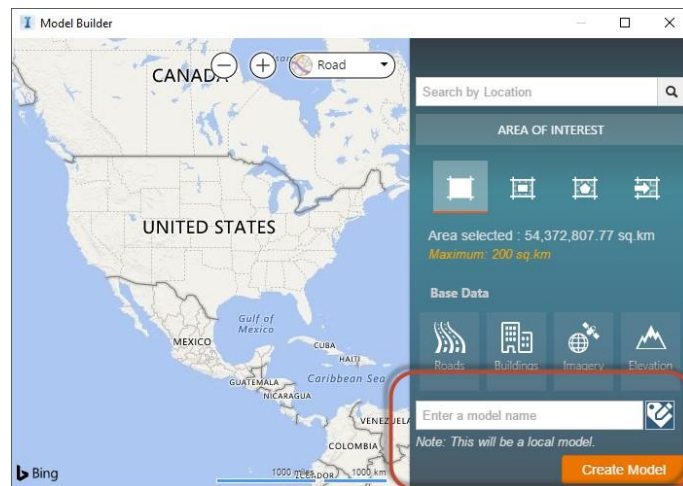


Figure 33 – 3D model generation from Model Builder

The model is now imported into 3D terrain. This is done once with the .rvt file and then with the .ifc file.

For both cases it is necessary to geolocalize the model correctly in the project. The most immediate operation is the **Interactive Positioning** command, where the model is geolocated manually by typing a point on the ground. The altimetry is recognized as the cursor moves over the topography and reads the relative altitude above sea level. The coordinates are cartographic. For the orientation of the building the imported model preserves in its specifications the information of the **Base Project Point** inserted in the Revit software, where coordinates N, E and Real North are set.

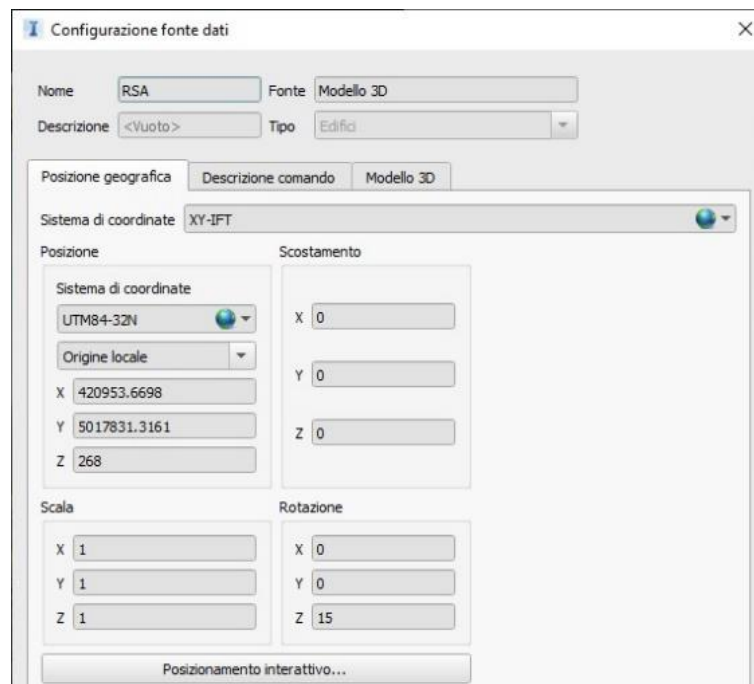


Figure 34 – Positioning BIM model in Infracore

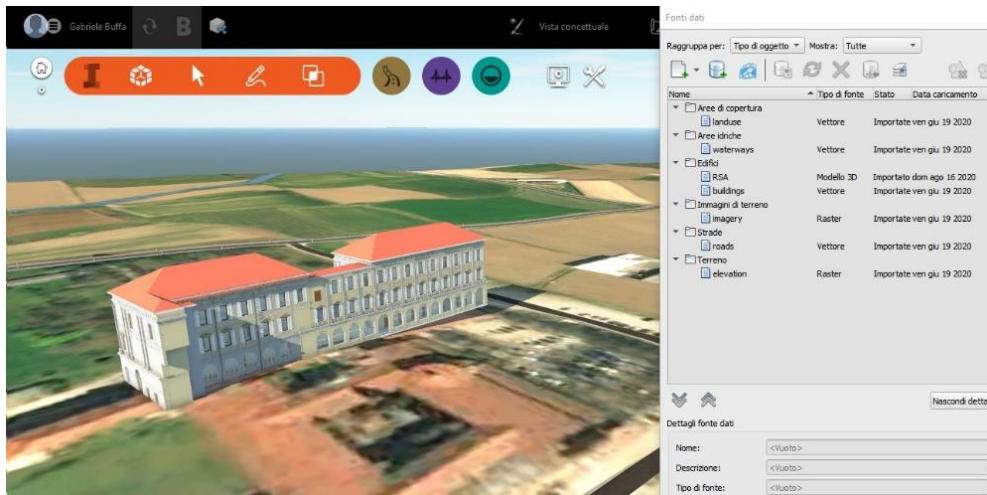


Figure 35 – Displaying Model .rvt in Infracore

Infracore reads the Shapefile. In this way it is possible to insert GIS data in the project in .shp format. The file that identifies the outline in the building plan, which identifies it at a level of LOD 0, is imported into the model. For an immediate import of the file you can use the **ArcGIS Online** platform; it is an online server where you can collect **Web Layers** that can be used in GIS software. Loading the file in the Infracore project allows you to define its Type; setting the dropdown as Building, the shape is extruded with a simplified 3D geometry. As far as geolocation is concerned, the shapefile has in its parameters the Reference System, which conforms to that of the project. The positioning operation is therefore automatic.

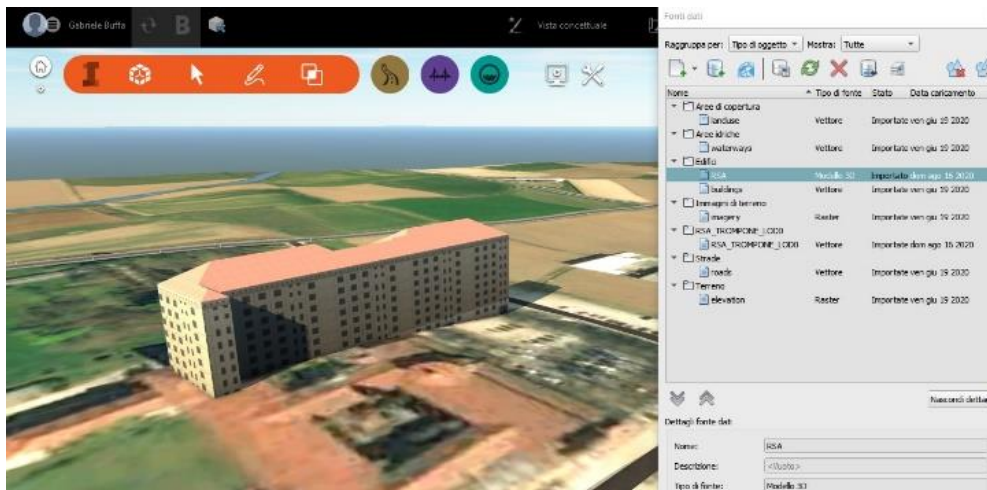


Figure 36 - Shapefile Display in Infracore

After completing the import of the files, you can analyze some significant aspects: between the two models derived from the BIM and GIS sources, there is no perfect overlap; moreover, each model is displayed as a **single block**, equipped with some parameters managed by Infracore, but which cannot be interrogated for individual entities such as doors, windows, walls.

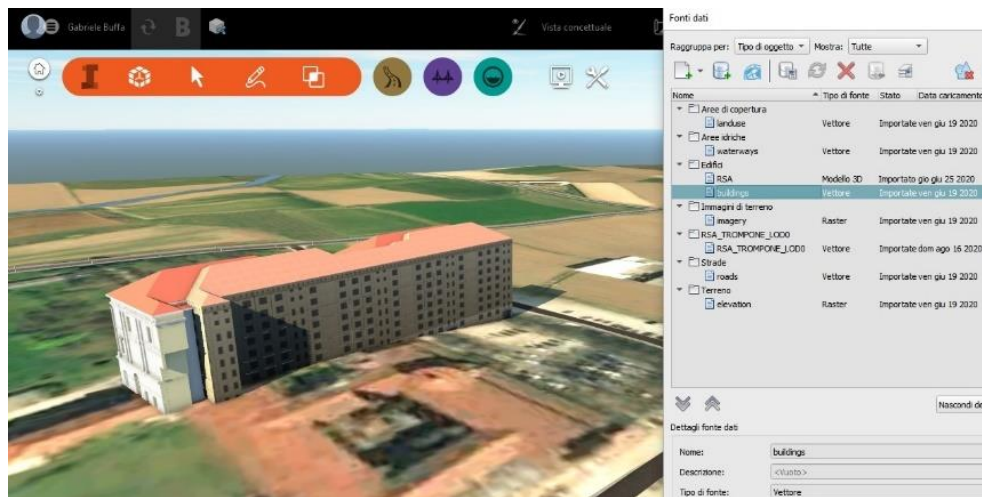


Figure 37 – Overlay .rvt and Shapefile in Infracore

ArcGIS Pro

ArcGIS Pro is a GIS platform managed by ESRI that allows you to create, view and edit maps and scenes, within multiple windows of the interface. In addition, maps that can be inserted can be either 2D or 3D. A fundamental aspect of the software, which finds a good application in this thesis work, is the ability to interact with the BIM world. Within the project, in addition to the files that can be loaded with the IFC and CityGml standards thanks to the **Data Interoperability** extension, it is possible to directly load and manage an .rvt file. These Revit files are automatically interpreted by ArcGIS Pro as a set of design elements (three-dimensional geometries and attributes) and categorized according to different groups of objects called *Building Discipline Dataset* (Architectural, Structural, Electrical, Mechanical and Piping). These features allow the software to establish a strong interaction between BIM and GIS, extending the information contained in the BIM model to higher scales than the individual work, such as the urban scale.

The procedure for reaching a DIM dataset is schematized with the following Flow of operations:

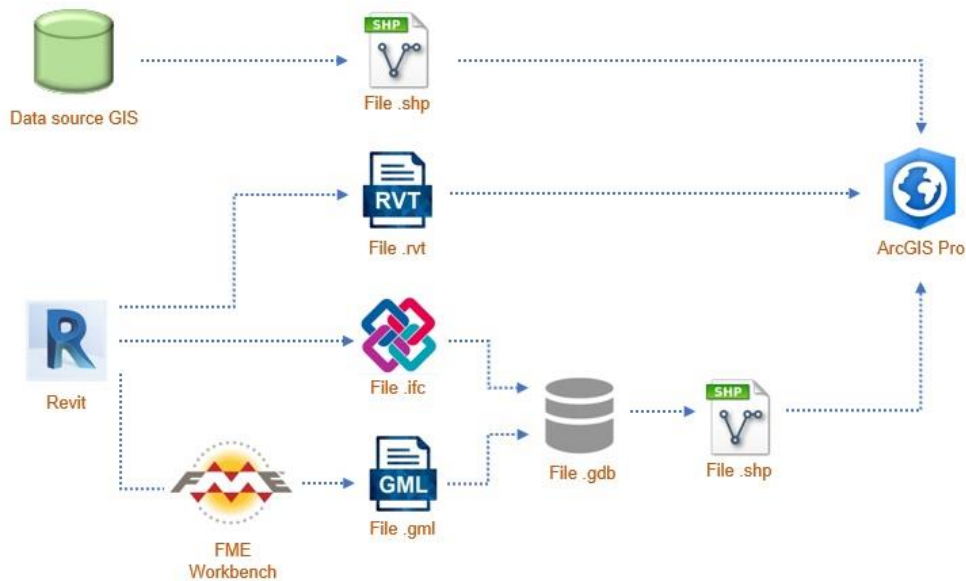


Figure 38 – Operations Flow Interoperability with ArcGIS Pro

The procedure starts with the creation of the project file in ArcGIS Pro. A New Map is created where a World Topographic Map is preloaded, which visually supports the geolocation of imported objects. The BIM data source is imported into the project in .rvt .ifc and .gml formats. For the .rvt and .ifc files, the geolocation data must be set in the Revit software. You assign to a point in the model (you choose a building edge shown in Figure 39 with a red cross) the coordinates in its actual spatial position. The values are extracted in cartographic coordinates from the ArcgisPro Topographic Map by clicking on the same building edge. In Revit you use the *Specify Point Coordinates* command to import the coordinate values. Despite this initial specification, the model imported into ArcGIS Pro has an incorrect positioning. This is due to the lack of model projections. The projection of the model consists of a **.prj file** that can be downloaded from the **Spatial Reference** website³³; you use the code³⁴ **EPSG:32632** and the .prj file is renamed with the same name as the .rvt file and placed with the same directory in the pc. The .rvt model is now correctly geolocated in ArcGIS Pro and every single object can be interrogated with the software's features³⁵.

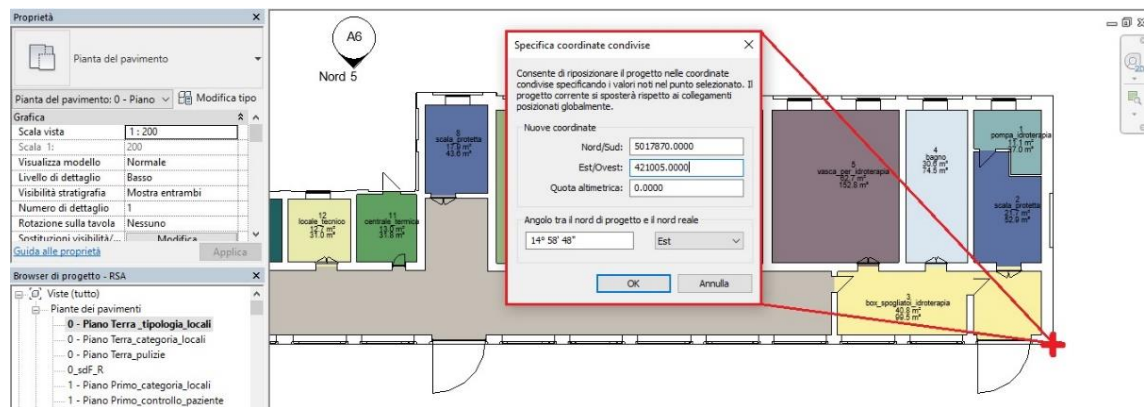


Figure 39 – Specify coordinates in Revit

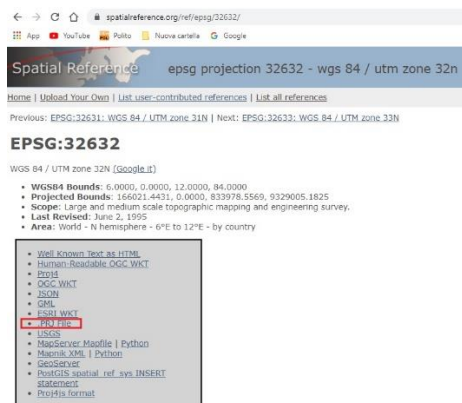


Figure 40 – Download .prj projection file from Spatial Reference

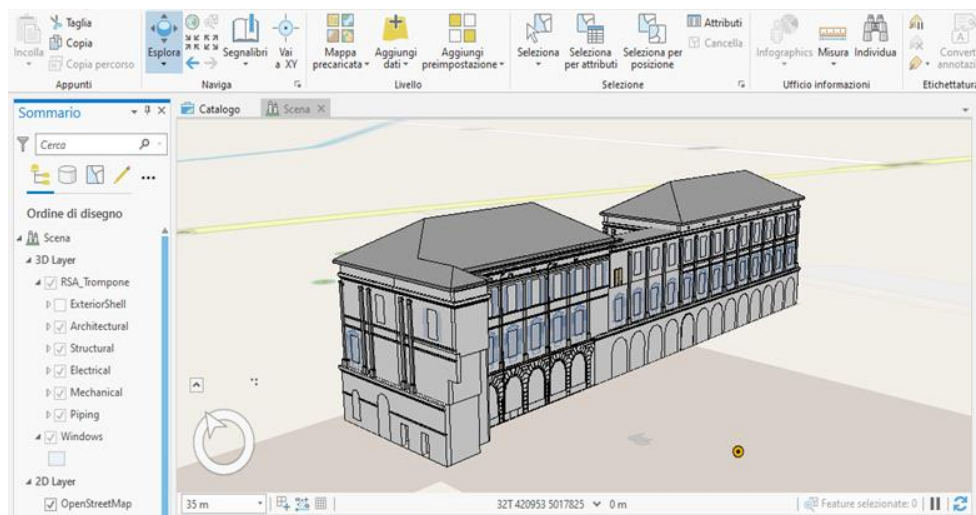


Figure 41 – Viewing Model .rvt in ArcGIS Pro

As far as importing the model in the Citygml standard format is concerned, you must first convert the .rvt file to the .gml format.

The **FME Workbench** software³⁶ is used to do this. It is a visual programming platform specialized in converting, sharing and integrating data. It can be used to extract data from a source, transform the data according to your needs and then upload it to the desired

location. FME supports a wide variety of GIS, CAD, Raster formats. It therefore finds wide application to convert data into different formats, so it helps the process to always use compatible data. The project file you create represents an executable file (script), where input data, the Reader, is inserted. Using standard or editable functions called Transformer, you create the sequence of operations that the Reader file must perform to generate the output file, the Writer. The operations are performed in sequence using line connections.

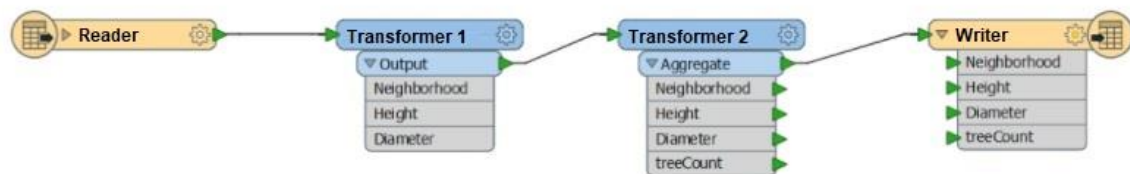


Figure 42 – FME Workbench operation scheme

FME uses standard functions for conversion to Citygml, such as the function *CityGMLGeometrySetter Parameters* which gives two parameters to the output file: one defines the LOD CityGML and the other defines the Function Type that has an object or the whole model in the Writer file.

The conversion of the .rvt file in .gml is realized with a **script** of FME, of which you can see an excerpt in the figure:

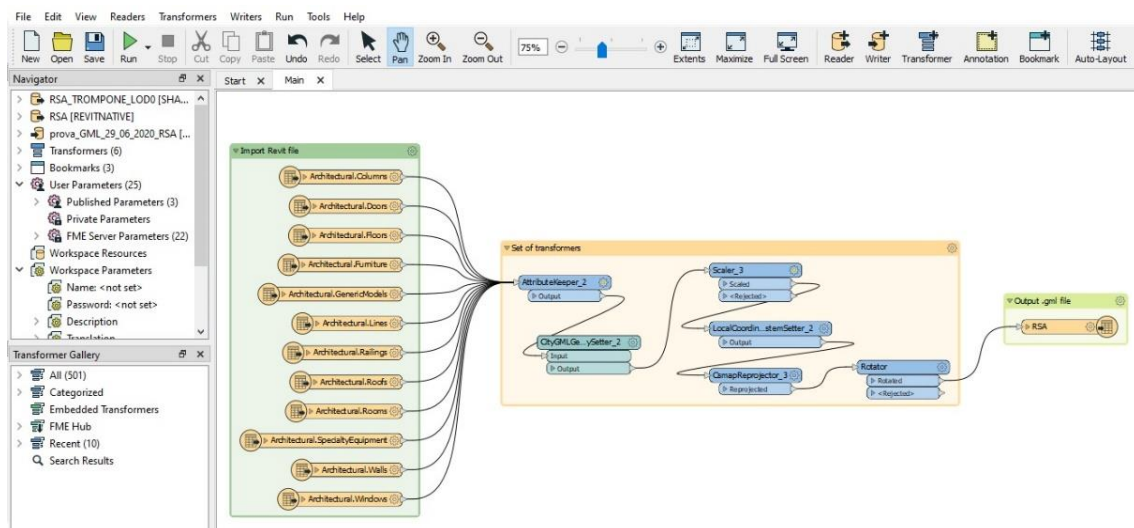


Figure 43 – FME script for conversion of .rvt files to .gml files

In the sequence of operations, filters have been executed to read only some parameters of the Revit categories; they have been assigned a class related to the reachable LOD CityGML. The geolocation is done with the command **LocalCoordinateSystemSetter**, whose N/E coordinate values are those relative to the project base point. Add the CsmapReprojector function to assign a projection to the model. At the end of the functions a

Rotator command is inserted to optimize the orientation of the building; this is a value read from the .rvt file.

The .ifc file is obtained with the Revit export command, where you set the type of format that can be exported and the graphic contents - parameters that the file must have.

For the .ifc and .gml formats it is not possible to proceed with their direct loading in the Project Map. The files are converted to ArcGIS Pro in **Geodatabase file** format (.gdb) with the **Quick Import** tool in the Data Interoperability Tools function folder. The Type of geometry created is a Multipatch.

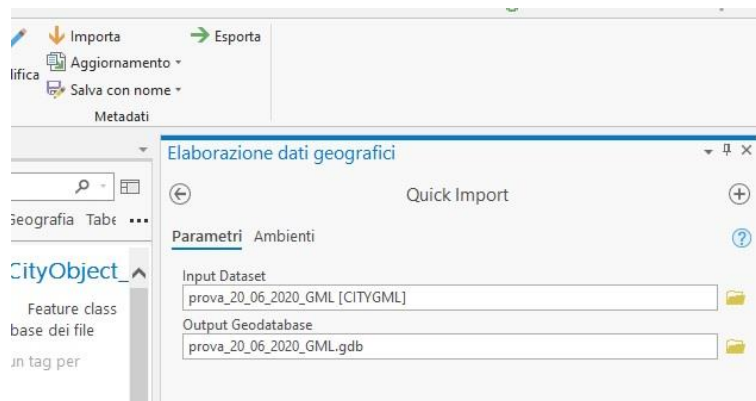


Figure 44 – Import .gml file into ArcGIS Pro

However, if you look at the .gdb file, you will notice that within the ArcGIS Pro space its parameters and information are not easily interrogated, and it has difficulties integrating with other loadable data, such as a shapefile. To use the model from Revit, further convert the Geodatabase file into a shapefile, using the **From feature class to Shapefile** command. The resulting object is a 3D shapefile, as the geometry of the .gdb file was a **multipatch**.

We load the .shp file related to the Data source GIS, a polygon shapefile that materializes the surface of the RSA, at a LOD Citygml equal to LOD0.

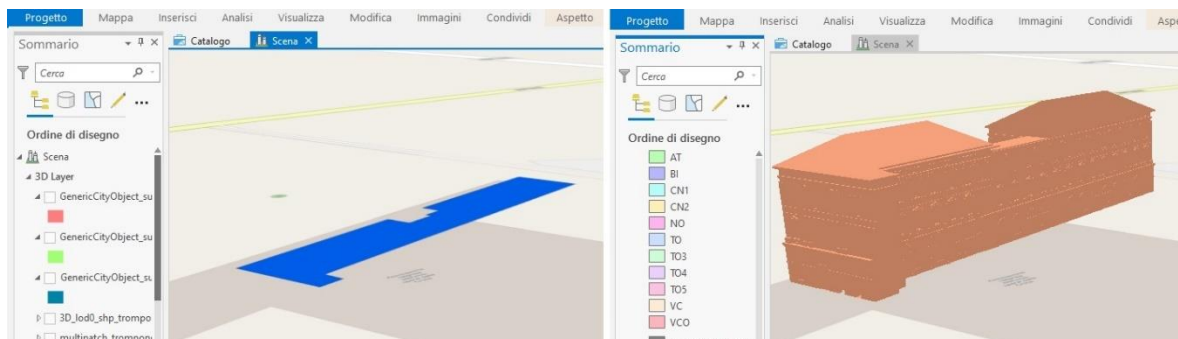


Figure 45 - Shapefile GIS and BIM

At this point, all data from the BIM and GIS sources are entered into the ArcGIS Pro Project; for the two .shp files, you can query individual objects and filter by attributes. As already

mentioned in the paragraph, the two shapefiles have a different geometry, multipatch and polygon. This diversity limits the potential to generate a single DIM database in both geometric and informative form, since it is not possible to use commands such as Merge or Join, which would combine the two sources also geometrically.

However, the main purpose of the DIM is the BIM-GIS integration to obtain a unique database; with this consideration ArcGIS Pro can create an *informative DIM* database. The operation consists of *exporting the attribute tables* of the two original shapefiles, which are then merged with the Merge command. The output table can be exported in Excel format with the command 'From table to Excel'. To make the use of this DIM output more usable, you can filter attributes within the Merge command that are not necessary for DIM database uses.

Progetto

Mappa

Inserisci

Analisi

Visualizza

Modifica

Immagini

Condividi

Dati

Gabriele_Buffa_LearnArcGIS (Learn ArcGIS)

Sommario

Cerca

Ordine di disegno

TO

TO3

TO4

TO5

VC

VCO

Figure 46 - BIM side attributes table

The screenshot shows the ArcGIS Pro interface with a 3D model of a building. The 'Tabella_RSA_CITYgmL_LOD0.shp' table is selected, displaying the following data:

OBJECTID	Id	X	Y	ANGOLO	H_PIANO	NUM_PIANI	H_EDIFICIO	NOME
1	0	420970,591548	5017865,47113	14,21502	5	3	18	RSA VIRGO POTENS

Figure 47 - GIS side attributes table

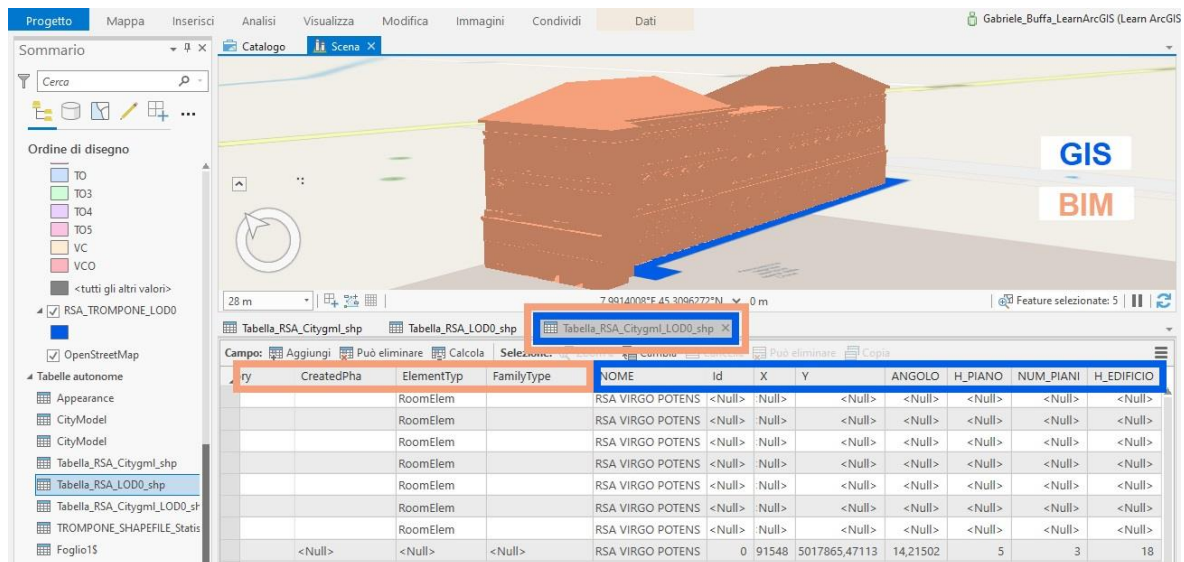


Figure 48 - Integrated attributes table BIM - GIS

FZK Viewer

FZK Viewer is a specialized model visualization software, created by Karlsruhe Institute of Technology (KIT) ³⁷. The potential of this independent open source software is many:

- The ease of managing and controlling small and medium-sized models;
- The software interface allows a walk tool within the model, making it easier to read and query individual objects;
- Many are the data formats that are managed, in particular with regard to file exports there are many formats available (DXF, CityGML, Google Earth);

The main application of data visualization is to read the two standard exchange formats BIM and GIS side, IFC and CityGML.

The following diagram shows a flow of significant steps in the creation of the DIM.

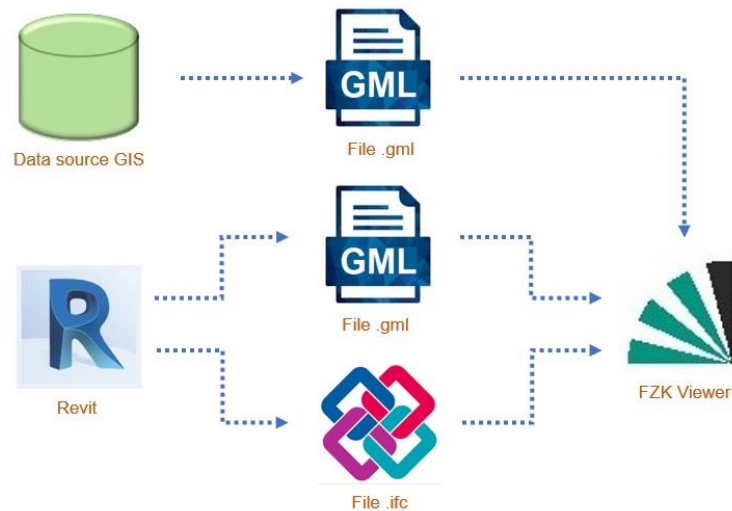


Figure 49 - Operation Flow Interoperability with FZK Viewer

The GIS data source, corresponding to the building's LOD0, is imported into the software interface in the CityGML format. The shapefile conversion is done in the FME Workbench platform using the following script:

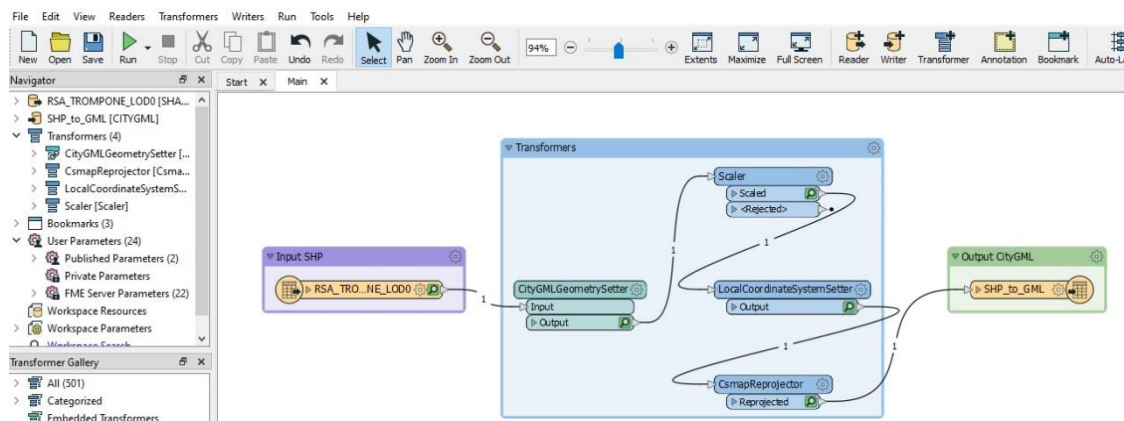


Figure 50 – FME Script Shapefile conversion to .gml

The polygon inserted in the platform retains the attributes of origin and are visible in the Property Toolbar drop-down list by interrogating the object..

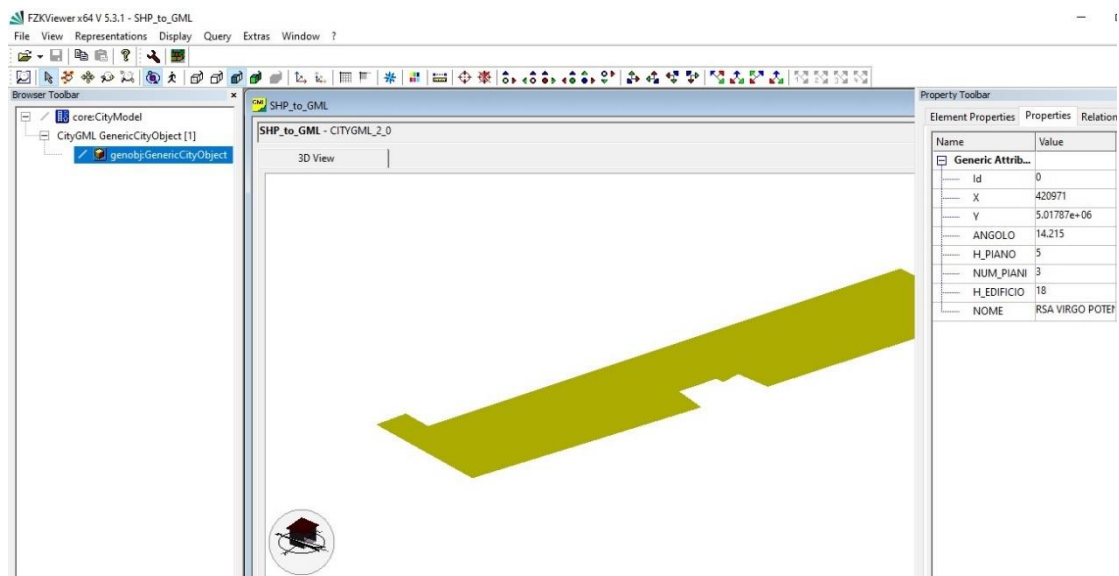


Figure 51 – LOD0 .gml file view in FZK Viewer

The Revit template is inserted into the FZK interface in .ifc and .gml formats.

The .rvt file is converted to .gml using a script from the FME Workbench software (see Figure 50).

As with the shapefile, the Revit file retains the project parameters, in particular the Family name and Type of the individual object..

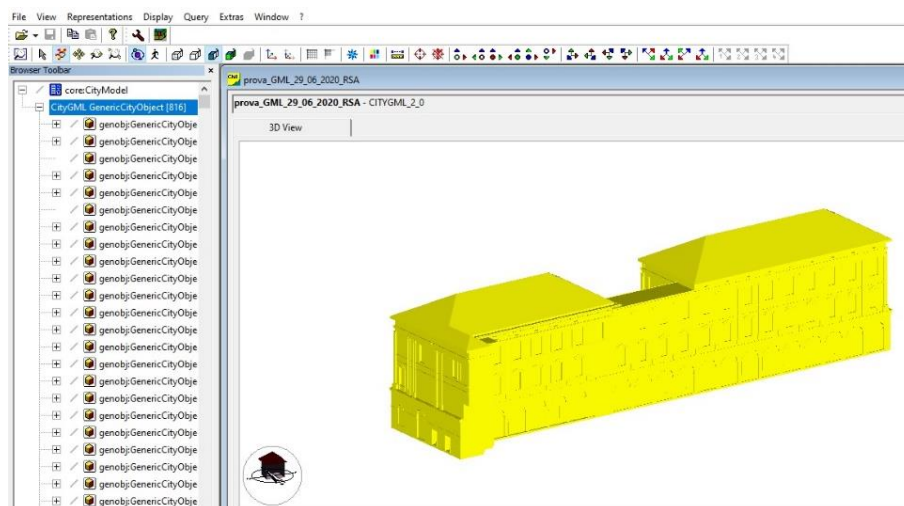


Figure 52 - Viewing BIM Model .gml files in FZK Viewer

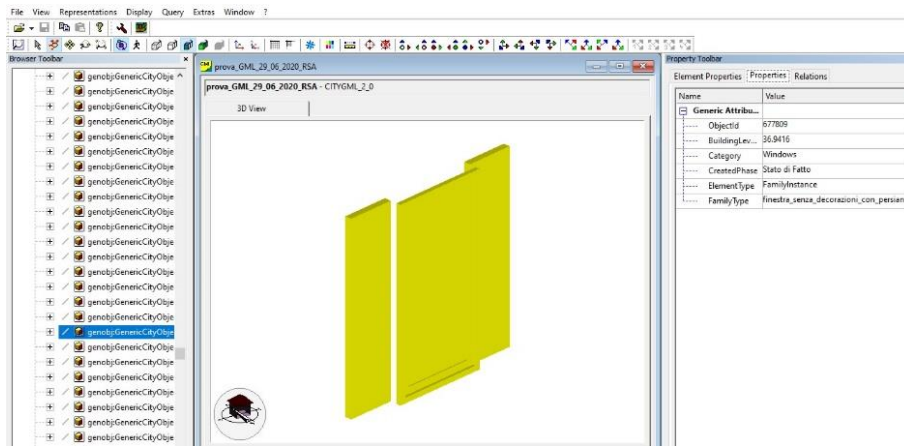


Figure 53 – Viewing object and file parameters .gml from BIM Model

2.3.2. Increasing data source



The improvement of the initial BIM and GIS database is an activity that develops in parallel with the creation of the DIM database. Therefore, in the next steps of the General Workflow, data obtained from both Restitution will be taken for Output operations.

The sequence of operations is contained in the following diagram:

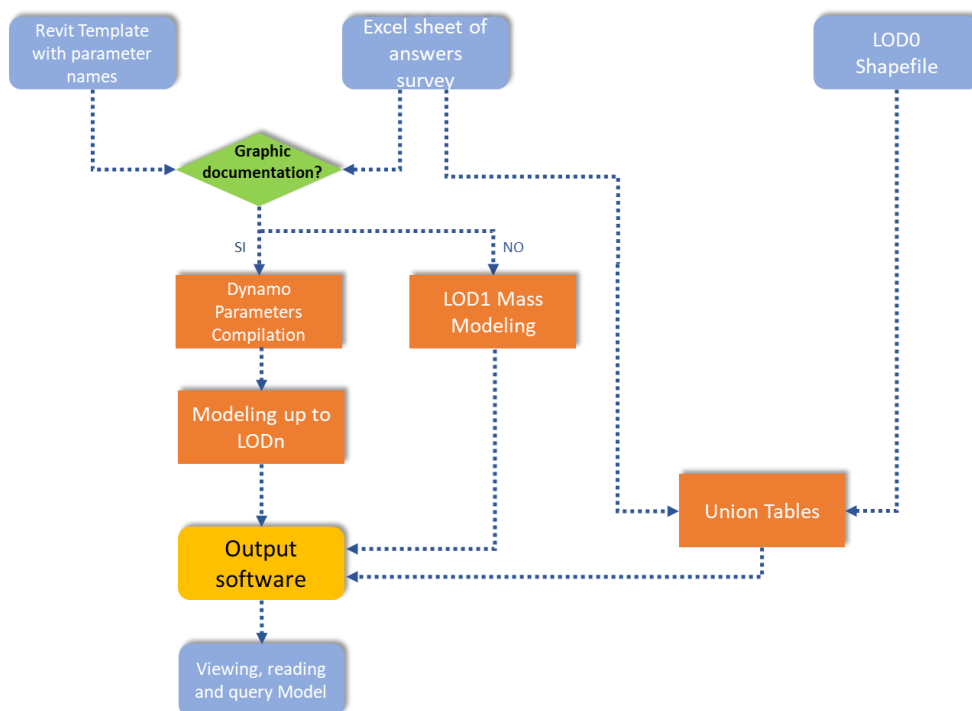


Figure 54 – Flow operation to increase the BIM GIS database

These operations are partly semi-automatic and partly automatic..

answers to the Google Modules questionnaire are saved in the online platform and downloaded to a **Microsoft Excel spreadsheet**.

Here is the link used for the administration of the questionnaire

<https://forms.gle/5L8HeKKjF8J5Ys8T9>

At this point a **semi-automatic** Excel preparation procedure starts, which allows the script to easily read the values of the answers and to automatically fill in the parameters. In the .xlsx file, the Excel answer sheet is organized in a matrix: each row corresponds to a health care facility that filled out the questionnaire, while each column represents a questionnaire question.

Then the Answer Sheet is duplicated, reducing the number of columns to 27, of which 26 columns are related to the chosen parameters and for the first column the values are replaced with the **ID_RESIDENZA** field which is a number that uniquely identifies each Health Residence in Piedmont. This value is obtained from the file " file *“Elenco residenze piemonte 11.05.2020.xlsx”* defined in paragraph 2.2.4.

The first line of the matrix, which contains the text of each question, is replaced by the corresponding name of the Parameter chosen.

Two additional Worksheets are created, each containing 14 BIM parameters and 12 GIS parameters.

	A	C	D	E	F	G
	Informazioni cronologiche	2 - Inserire l'indirizzo della Residenza sanitaria	3 - Indicare la tipologia di struttura della Residenza sanitaria, relativa al tipo di nucleo di ospiti	4 - Indicare il numero complessivo di posti letto residenziale	5 - Indicare il numero complessivo di posti letto diurno	6 - Rispetto al Comune in cui risulta ubicata la Residenza, l'edificio si trova:
1						
2	7/14/2020 10:37:59	LOCALITA' SANTUARIO DEL	1RSA - Residenza Sanitaria Assistenziale	40	0	Circondato da aree verdi
3	7/20/2020 9:11:47	VIA MONDALFORNO SUPERIORE	4RSA - Residenza Sanitaria Assistenziale	36	0	Circondato da aree verdi
4	7/20/2020 12:40:39	VIA CADUTI DELLA PATRIA 4	4RSA - Residenza Sanitaria Assistenziale	40	0	Nel centro cittadino
5	7/27/2020 15:57:08	VIA POZZO AMETIS 4, 13898	RA - Residenza Assistenziale, RAF - Resid	47	0	Circondato da aree verdi
6	7/28/2020 11:34:04	VIA GARIBALDI 20, 13010 CARA	- Residenza Assistenziale, RSA - Resid	58	0	Circondato da aree edificate

Figure 55 – Excel Table Questionnaire Answers

	A	C	D	E	F
	ID_RESIDENZA	INDIRIZZO	NUCLEO	PL_RESIDE	PL_DIURN
1					
2	497	LOCALITA' SANTUARIO DEL TROMPONE, 13040 MONCRIV	1RSA - Residenza Sanitaria Assistenziale	40	0 Circondato
3	1	VIA MONDALFORNO SUPERIORE 4-13831 MEZZANA M.G	4RSA - Residenza Sanitaria Assistenziale	36	0 Circondato
4	162	VIA CADUTI DELLA PATRIA 4, 10010 AZEGLIO	4RSA - Residenza Sanitaria Assistenziale	40	0 Nel centro c
5	691	VIA POZZO AMETIS 4, 13898 OCCHIEPPO SUPERIORE	(BRA - Residenza Assistenziale, RAF - Resid	47	0 Circondato
6	76	VIA GARIBALDI 20, 13010 CARESANA VC	RA - Residenza Assistenziale, RSA - Resid	58	0 Circondato

Figure 56 - Excel Table Questionnaire Answers - editing sheet for the automatic compilation

In parallel to the preparation of the Excel file, in a **Revit template file (.rte)** we proceed to the definition of the **Shared Parameters** that will be applied to the different categories of the model.

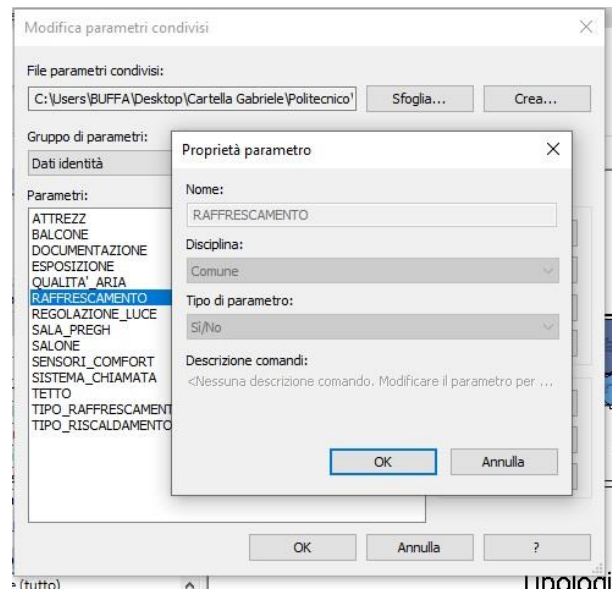


Figure 57 – Creating Shared Parameters in Revit

The double choice to create shared parameters and use a Template file derives from the results of the initial research of the thesis material, where no models of health residences available as free sources were identified. Therefore, a question related to the provision of a *precise technical documentation* (Plans, sections, prospectuses) was included in the questionnaire; with it it would be possible to create templates with a precise level of detail and fill in all 26 parameters, of which 12 are filled in a GIS platform..

In the Template you create the **Project Parameters** that can be used by the template, choosing the parameter from the list of Shared Parameters. You complete the operation by adding the Grouping and Application Categories for each one.

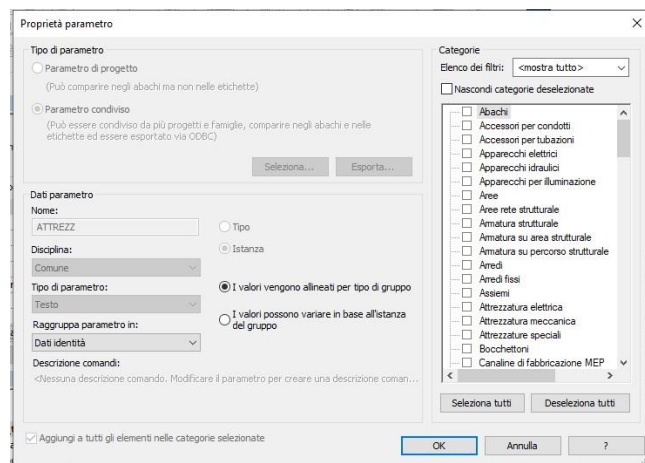


Figure 58 - Creating Project Parameters in Revit

Once the Residence to be analyzed has been chosen, its project file is created, compiling in Revit the unique Parameter ID_RESIDENCE.

We proceed to model the building inside the Revit interface, an operation mediated by the response to the **Documentation** parameter:

- **SI** Response: modeling to a LOD 'n' that is a Level of detail equal to the degree of completeness of the provided graphic works and according to the LOD range established in Table 3;
- Response **NO**: since no documentation is provided, we proceed to a simplified modeling equal to a LOD '1', where a Building **Mass Model** is developed.

The compilation of the parameters is part of the **automatic procedure**. **Autodesk Dynamo** software has been used for this activity. This software is an interface that uses a visual programming language to manage the workflow related to building information, dialoguing directly with Revit. It is possible to manage parametric modeling of BIM objects, but above all to manage data using different formats.

In the interface a script has been created that contains a sequence of functions (Nodes) linked together that define the steps that the file must do to automatically compile the parameters. It should be noted that some of the 14 BIM parameters are not applied to the project, but to individual categories of objects as Instances, so their correct compilation is **manual**.

The logic of the script is as follows. From the Revit software, you can find a list of all the names of the Project Parameters in the file, which are catalogued in a list. From the Excel file you can find the Response Sheet and read two lines in it: the first line that corresponds to the **Parameter Names** and the n-th line that corresponds to the Healthcare Structure whose parameters you want to compile. The values of the parameters are catalogued in a list. For the two lists just mentioned each data corresponds to a number. For each parameter the next operation is common. A number is read from the list that corresponds to the Parameter name and a number is read from the list that corresponds to the Parameter value. The **Parameter.SetValue node** proceeds to compile the desired parameter.

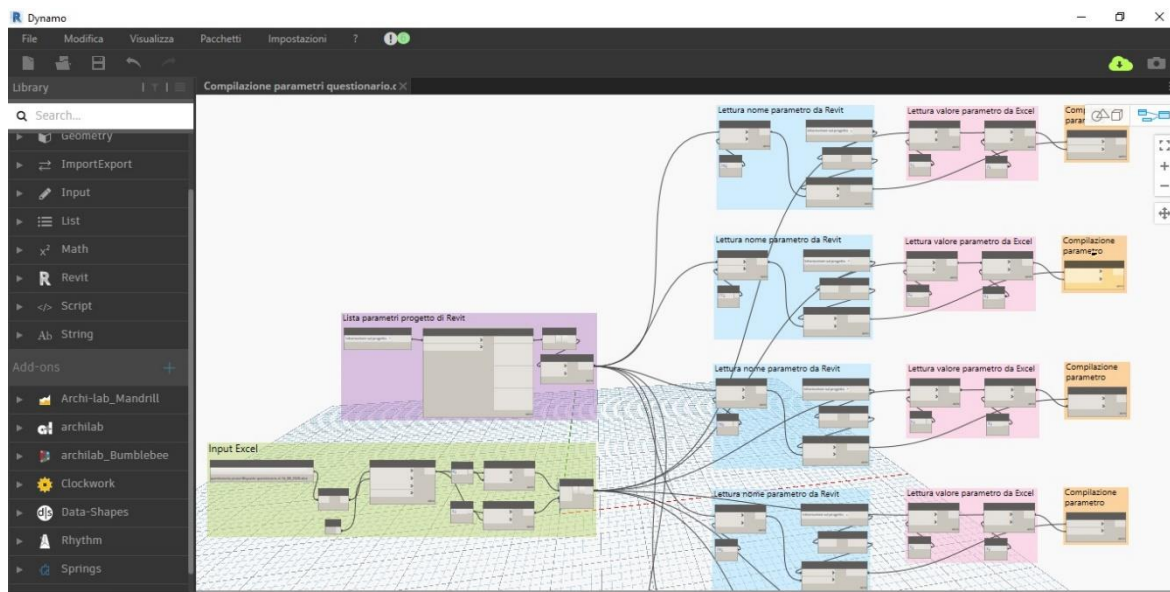


Figure 59 – Dynamo script for the automatic compilation of BIM parameters

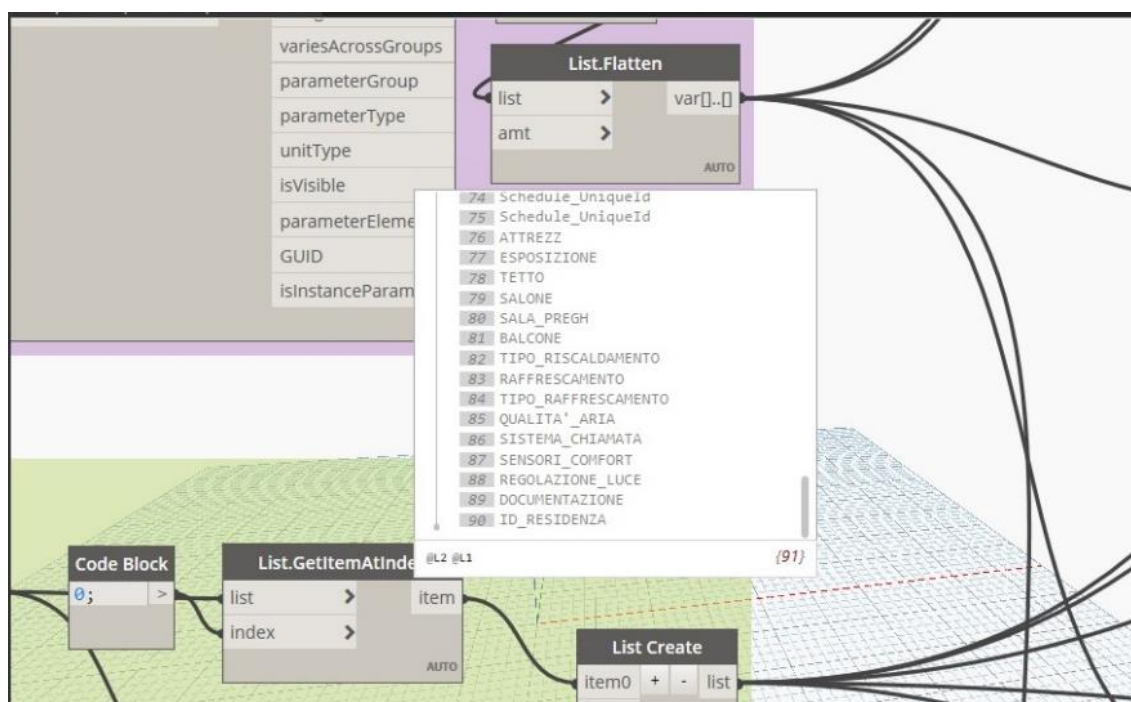


Figure 60 – Parameter name and corresponding number in the list

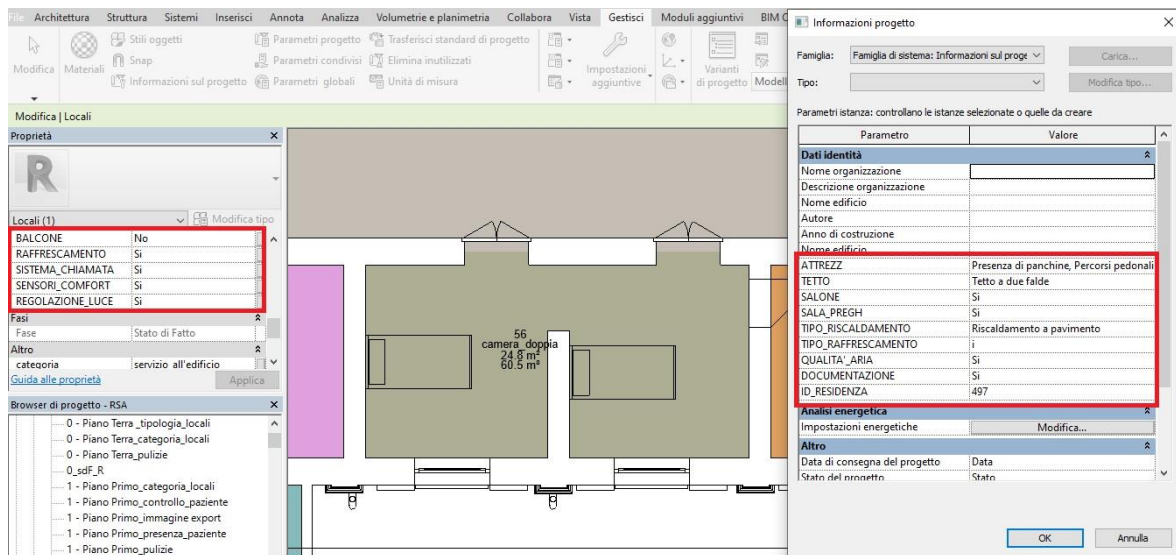


Figure 61 – Example of BIM parameters compiled by Dynamo

As mentioned before, the script aims to compile the parameters; however, in the absence of a high LOD model, it is not possible to associate the parameters to the Rooms and Windows, as they are not modeled. In these cases it is still essential to be able to use the answers provided by the questionnaire, as they are additional information that complete and improve the knowledge of the Healthcare Facilities. Therefore it is decided that these parameters can also be displayed in a **LOD 0**. The operation takes place in the output software, where the Excel Sheet of answers is imported. The Attributes Table of the *building's LOD 0 shapefile is merged with the Excel sheet* to obtain a single table. In this way you get both BIM parameters and GIS data enrichment, where the shapefile attributes are completed by the GIS Parameters of the questionnaire.

2.4. Output

Before introducing the different tools it is necessary to define the role that the **user** has. The achievement of a certain level of quality and reliability of the data is only one of the objectives to be set when working with databases. It is necessary to create conditions for a certain data to be easily usable, minimizing the possibility of interpretation of the same to avoid duplication, misunderstandings. Basically the three filters that must be applied to the visualization - data usage are:

- the **user** to whom the data is directed;
- the **use** for which the data is organized;
- the **interface software** in which the data is contained;

Surely it should be stressed that the *software* is very influential in the output result; the goal is to try to overcome this technological limit by proposing solutions with more user-friendly software.

The user's appearance is undoubtedly the most influential variable in the output. Each user interfaces with data and information according to his level of knowledge and interest. Given the complexity of solving the high number of cases, **typical users** are identified, who have well-defined characteristics and skills.

Three types of output are proposed below, each of which is designed for a certain type of user.

2.4.1. DIM tools



DIM tools are operations that are performed within the software previously described for interoperability and DIM. The operations consist of using or viewing data through the commands and functions of the software itself.

Often there is an intermediate sequence of operations to achieve the desired information. For this reason it is assumed that the DIM tools are intended for *users who have a **high level of skill in using software and data*** in the industry. In these cases, the software type variable is added, since they are rarely user friendly or licensed free of charge; this fact limits their use by administrations and managers of health care facilities.

2.4.1.1. Query

A query using part of the data processed in this thesis is proposed. It consists in obtaining from the ArcGis Pro platform information about the glass surfaces of all or part of the building. For the search of the information is used the source BIM, updated with the compilation of the parameters of the questionnaire. Within the Revit software, the model has the Exposure project parameter applied to the windows. There is no design parameter that identifies the window surface. This value, however, is obtained by preparing a window Abacus, as this screen allows the geometric properties of the windows and create **calculated Values**. The *superficie_vetrata* field that combines the dimensional values of the windows is created.

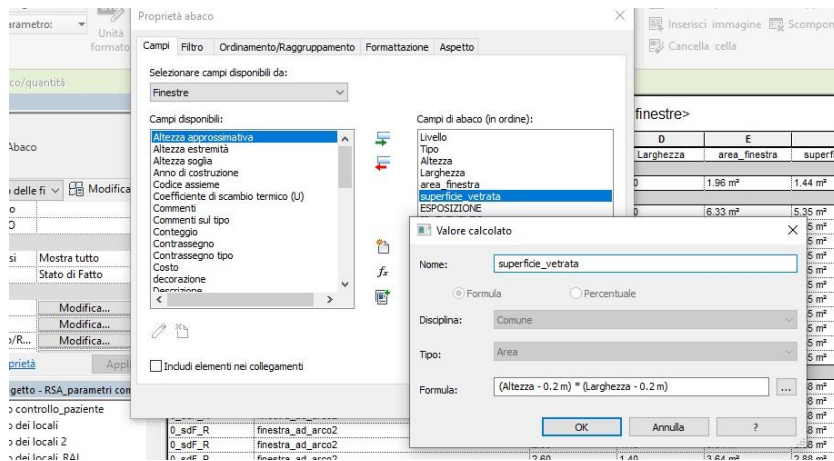


Figure 62 – Values calculated in Revit Windows Schedule

The .rvt file is imported into the ArcGIS Pro project file according to the procedure listed in paragraph 2.3.1.1. A value calculated in the Abacus cannot be treated as a Project parameter; to make the query it must be read in the GIS software.

The strategy is as follows: the data is obtained through a **Join by attribute** between the RSA shapefile and the Revit window abacus. The abacus is exported in .txt format and then opened in an Excel file. The Excel file is imported into ArcGIS Pro, of which the worksheet is read.

Before proceeding with the import it is necessary to identify the attribute that allows the Join between the two sources. In Revit the Project Parameter **ID_ELEMENTO** is created. It represents the unique ID code that Revit assigns to all the Instances of the .rvt model.

Since it is a data not directly extractable from the software, it is compiled in the parameter ID_ELEMENTO through a script created with Dynamo.

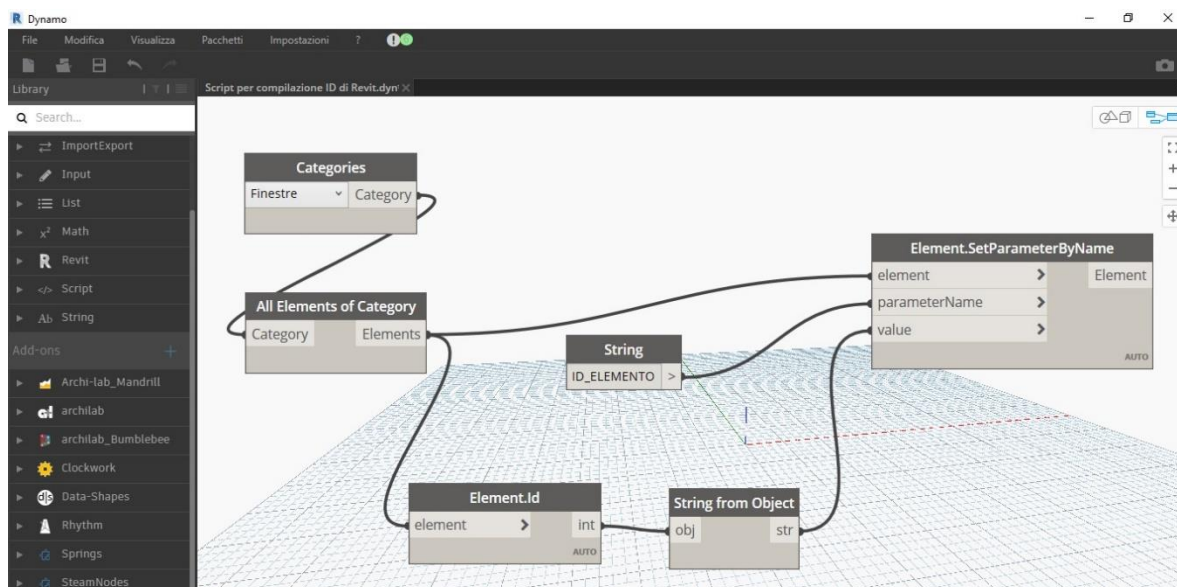


Figure 63 – Compilation ID in the project parameter ID_ELEMENTO

Once the parameter is compiled, the Schedule is exported from Revit and imported into the GIS platform.

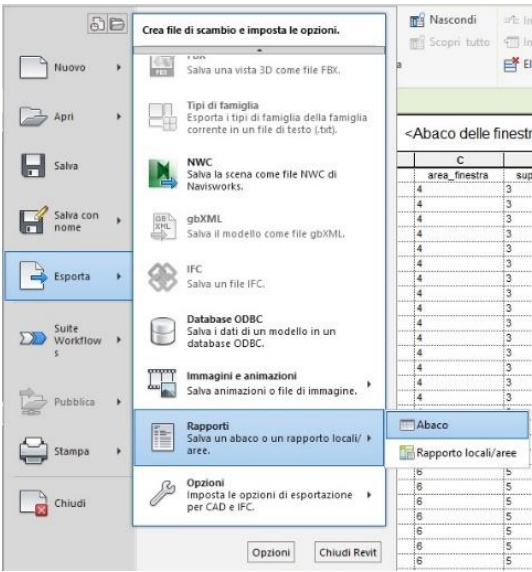


Figure 64 – Export Windows Schedule in .txt format from Revit

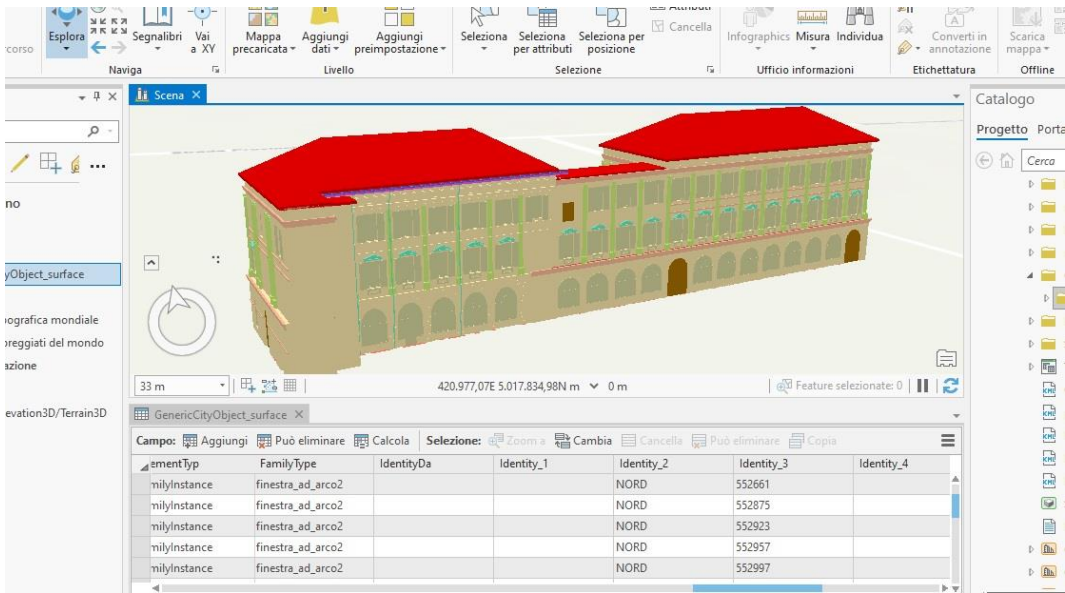


Figure 65 – BIM model shapefile display in ArcGIS Pro

Once the Join is completed, you proceed to a **selection by attributes** of window, applying the search filter to windows with SUD Exposure. Selecting only the features to be searched for, the attributes table is reduced. Selecting the attribute AREA_VET, which corresponds to the glass area in square meters, under **Statistics** a table summarizing the main numerical properties of the attribute is generated. In this way it is possible to identify the total number of square meters of the glazing of only windows exposed to SUD.

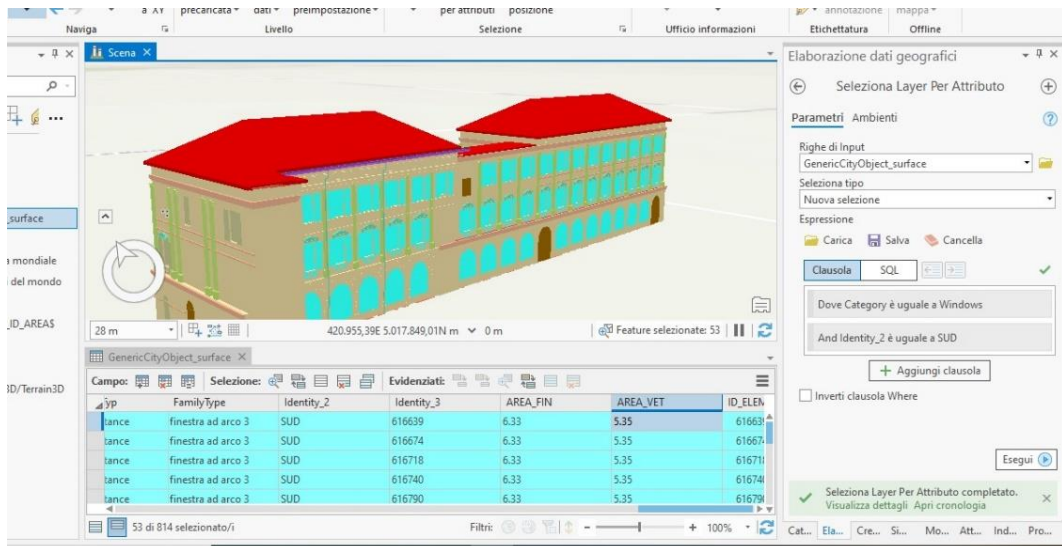


Figure 66 – Selection by attributes in ArcGIS Pro

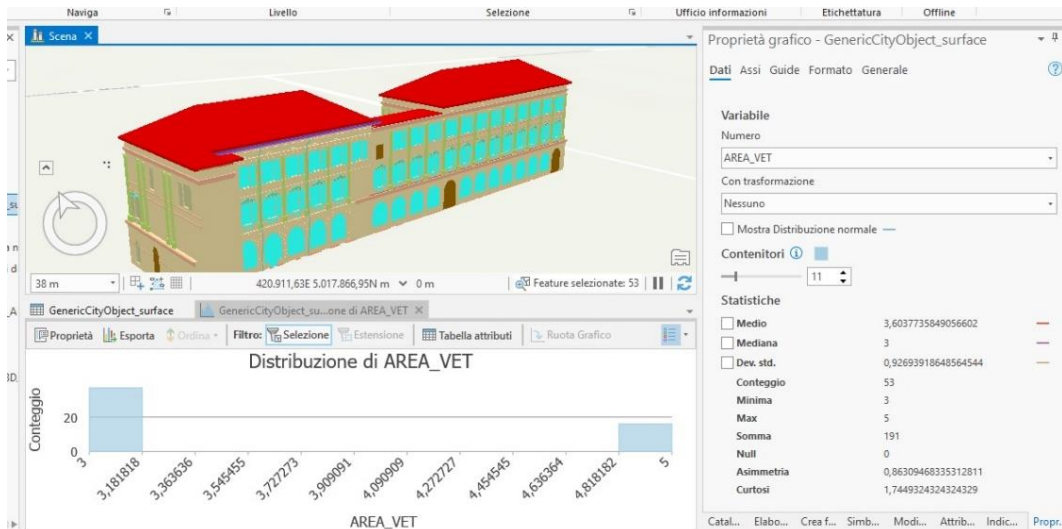


Figure 67 – Statistics and Glass Area Windows in ArcGIS Pro

2.4.1.2. Network Analyst

Network Analyst is an extension of ArcGIS Pro that includes a number of tools dedicated to managing connections within a road network. Specifically, you can calculate the shortest routes that connect two points, or alternative roads in the presence of barriers or obstacles, calculate routes based on the type of vehicle (car, walking, bike). In order to use these commands, ArcGIS Pro's interface needs a **Network**, which is a connection system made up of **Arcs** and **Nodes** that represent possible routes from one place to another.

A Network is created from a *Shapefile of Lines*. From GIS sources we use the Shape *Grafo road*, which materializes the main road and highway networks in Piedmont.

With the graph available the tools of the Network are activated. Now it is necessary to define the two points of departure and arrival on which to carry out the calculation of the **shortest route**. We suppose the departure near Vercelli and the arrival at RSA Virgo Potens in Moncrivello. The two points are materialized in a Shapefile of Points. Now the tool has all the data to create the route. In the drop-down list you can set the shortest route and the driving.

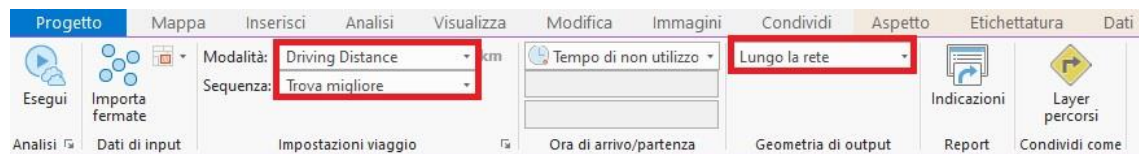


Figure 68 - Network Analyst Tool Specifications

Once the route is generated, the tool creates a Report where the travel time and the names of the road sections followed in the route are reported.

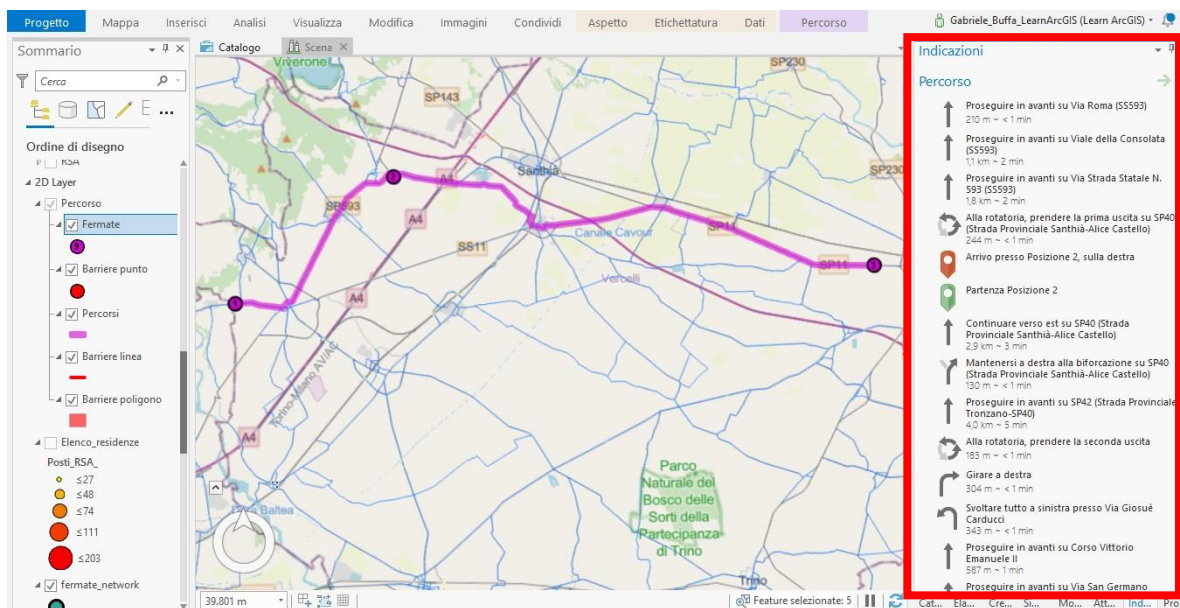


Figure 69 - Shortest route and directions

2.4.1.3. Coordination model

From the perspective of a Smart City, the importance of managing multiple buildings in a single platform is essential to achieve a high level of quality BIM - GIS integration. To achieve this, we rely on two key points: the BIM process and a Revit model management methodology: the **Coordination Model**.

Conceptually we can define this Model as a set of single models, which are displayed inside an empty file and which will be spatially and functionally connected with a geolocation logic. The choice to manage buildings or parts of it in different .rvt files is to be found in the *size of the files* and in the application areas; in the first case the complete modeling of an entire building/s involves too large a file size that makes it unmanageable; in the second case it is preferable to model single parts in different files, where only single *Disciplines* (.rvt files of the electrical system, .rvt files of the structural model) or for specific categories (single model of all the windows of a skyscraper) are modeled.

Among the advantages of the coordination model there are:

- complete visualization of all areas of the building or set of buildings;
- Interactive management of the building and modeling process, as coordination is the starting point for debates to correct errors or oversights during the design phase or as a decision support to *propose variants* during construction;

The first advantage allows the experienced user of the software to take advantage of the BIM capabilities to generate parameters common to all coordination files, allowing quick visualization of the filtered data for a specific use.

Given the merits of coordination, it is proposed to recreate such a graphic-informative visualization outside the Revit software. In order to have a good functioning of the coordination it is initially necessary to set some parameters directly in the Revit platform..

Autodesk Revit

In light of the BIM sources, it is generated in an empty .rvt file that coordinates the RSA_Trompone, Convento and Parco files. To be coordinated with each other, they must be correctly geolocated. Each model in its own file is located according to its own coordinate values, reported in the **Project Base Point** command. For all three files the coordinate values of the Project Base Point of the RSA_Trompone file are used. The numerical values of the map coordinates of the RSA_Trompone file have been obtained according to the procedure in paragraph 2.3.1.2, see Figure 39.

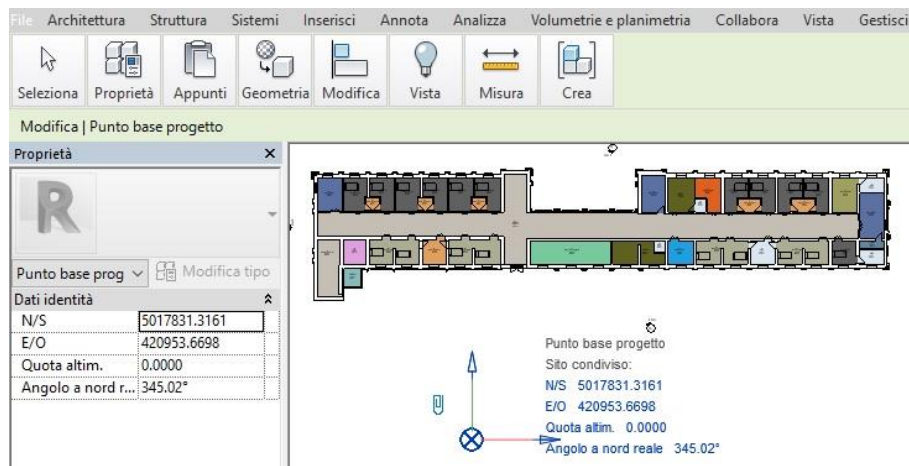


Figure 70 – Map coordinates Project base point

Once the models are imported into an empty .rvt file to verify coordination, they are correctly located and adjacent.

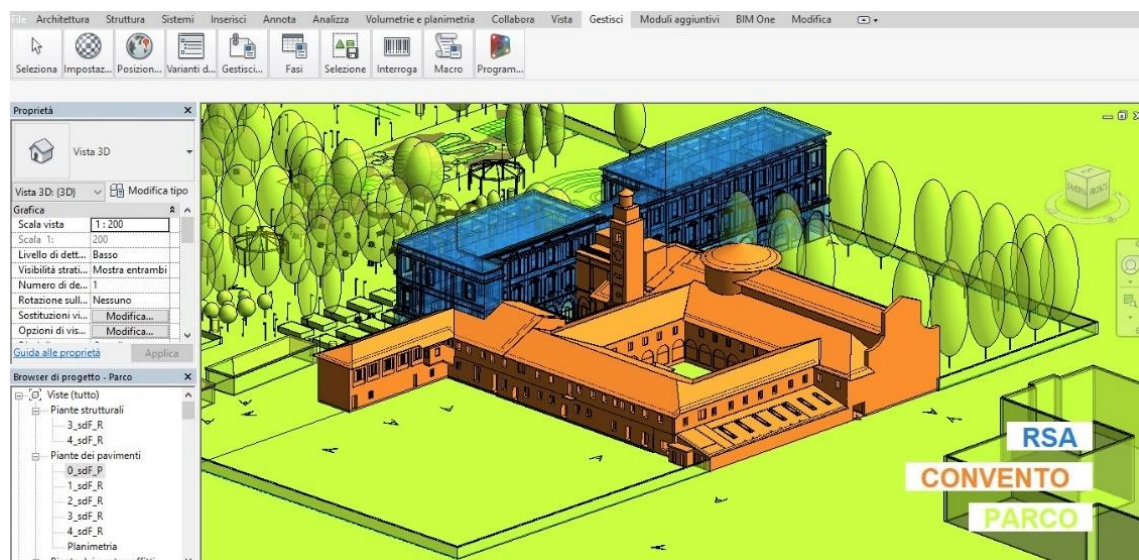


Figure 71 – Coordination Model into Revit

Now the files are ready to be used in the output software to create a coordination. We propose integrations of the models in Autodesk Infraworks and ArcGis Pro software.

Below we analyze the realization of coordination in Autodesk Infraworks and ArcGis Pro software.

Autodesk Infraworks

Within the Infraworks project file you can link .rvt models (see chapter 2.3.1.2. in the paragraph *Autodesk Infraworks*). The procedure for inserting each .rvt model on the 3D terrain is done in **manual mode**. Once the position on the ground surface has been selected with the interactive positioning command, the x-y coordinate values are modified by inserting those reported in the *Revit Project Base Point* of the RSA_Trompone file; repeated the procedure for all three .rvt models, they are correctly geolocated in the ground but manageable at database level only as single building blocks.



Figure 72 - Coordination Model into Infraworks

Arcgis Pro

Within the ArcGIS Pro project file it is possible to directly import an .rvt file. However, by evaluating the purpose of the coordination model, which aims to integrate multiple models, we propose an interaction not only geometric and geographical but also informative. Therefore, other data formats are used to coordinate the three files in the GIS platform. The procedure is as described in Chapter 2.3.1.2. in ArcGIS Pro, applicable to all three .rvt files and is simplified as follows:

- .rvt files converted to .gml format using **FME Workbench**;
- conversione da file .gml a file .gdb;

At this point a correct coordination model has been obtained, but it can only be used at a geometric level.

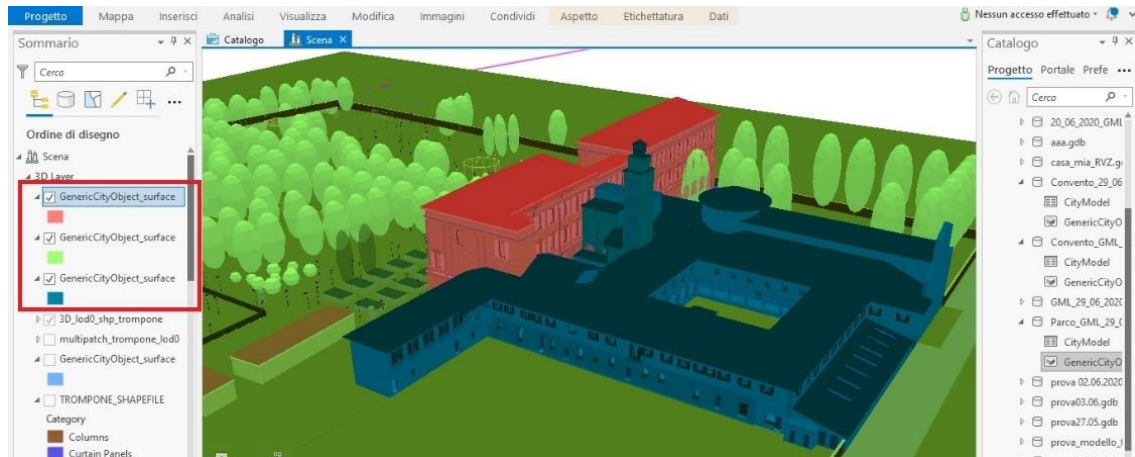


Figure 73 - Geodatabase Files into ArcGis Pro

The next step is to use it on the information plan. To do this, you need to convert all three geodatabase files **into one shapefile** using **From feature class to shapefile** tool. You get a single all-inclusive model of the original three, in *Multipatch* Shapefile format. Now you can easily use the attributes table complete with all the information from the Revit software. In the import the Categories of objects are recognized, as well as the Families and Types. The data is filtered and queried, e.g. a graphical grouping by Object Categories.

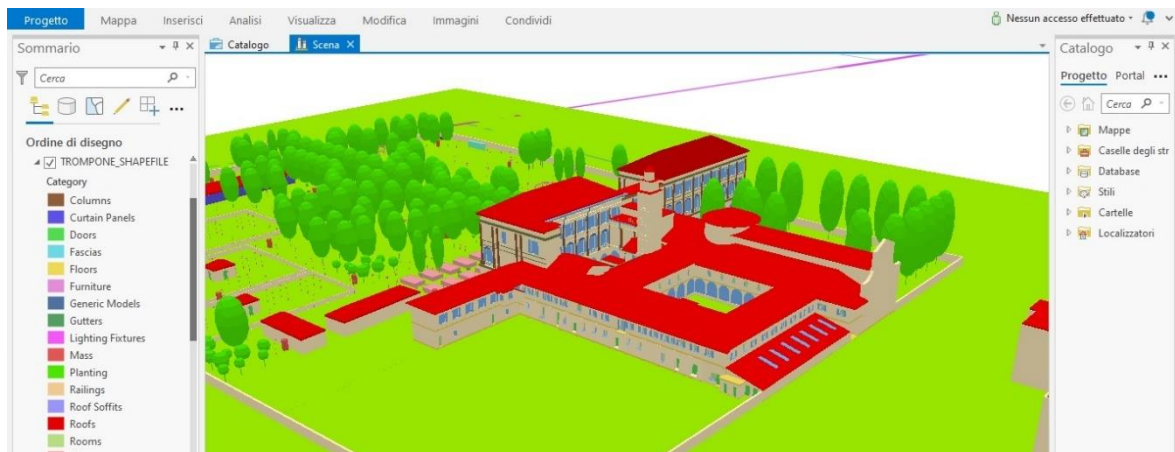


Figure 74 - Coordination Model into ArcGis Pro

2.4.2. 3D visualization – Multi LOD



In this thesis work, the BIM and GIS capabilities are used to produce a multi-LOD 3D model. The case in examination of the source data BIM **RSA Virgo potens** is used. The generation of a single output environment follows the idea of a BIM-GIS data integration, proposing **a multi-scale model** that has a common database, pursuing the aims of *District Information Modeling (DIM)*, in which the visualization of building models is the result of data from both the BIM and GIS world. A Multi LOD model enhances the geometric component of the DIM without forgetting its non-graphic content.

Analyzing the purposes of multiLOD, it is assumed that the use of this output is required by a user with intermediate skills, that is an *user who does not obtain data through a sequence of pre-commands of a software, but uses a file on a user-friendly platform* that does not assume reworkings of the data avoiding duplication or possible misunderstandings. The output that is produced represents the merging of the two BIM and GIS data sources described in the previous chapters.

The input data are chosen according to the different levels of detail and their contents. This fact is fundamental for a consistent *graphics* of the individual elements. From the BIM and GIS sources there are standards for BIM and GIS LODs. When data integration takes place, the two languages must communicate. That is why the LOD DIM concept is needed. These LOD levels are a hybrid of the initial LODs, which means that certain **DIM LODs** will display more details of the BIM world, which also applies to the GIS world.

By analyzing the urban scale of the detail in which the data can be visible, the LOD GIS, the LOD of the CityGML standard, plays an important role in generating comparisons between different building models and is taken as the driving range for filtering graphic - informative content..

The creation of the multiscale model is done in the **FME Workbench** interface, where a script is compiled.

The output data is provided in the form of a 3D model, in .kml format, which can be interrogated in its individual parts with regard to the data provided and can be viewed on the **Google Earth Pro platform**. It is a software that generates virtual images of the Earth using satellite images obtained from remote sensing, aerial photographs and topographic data stored in a GIS platform ³⁸. In addition to the free exploration of places, this service allows you to move between the streets in three dimensions.

One.rvt file and two .shp shapefiles are used as input data. There are five levels of details in which to filter the contents of the model, which will be five subgroups (**feature type**) of the .kml file. Now we introduce the geometric attributes that make-up the individual subgroups. From the CityGML standard are reported the thematic dimensions of the models that can be displayed in a LOD.

	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city, city districts, projects	city districts, architectural models (exterior), landmark	architectural models (interior), landmark
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	no	no	yes	representative exterior features	real object form
Roof structure/representation	yes	flat	differentiated roof structures	real object form	real object form
Roof overhanging parts	yes	no	yes, if known	yes	yes
CityFurniture	no	important objects	prototypes, generalized objects	real object form	real object form
SolitaryVegetationObject	no	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	no	>50*50m	>5*5m	< LOD2	<LOD2
...to be continued for the other feature themes					

Figure 75 – LOD table and their accuracy requirements (Source: Albert et al. 2003)

The next step is to define the DIM and how it can be achieved, because the multiscale approach defines the concept of single, multi-level output, but does not specify from which source the data in these LOD levels comes from, i.e., whether there is data in a layer that comes from BIM or GIS.

A list of object categories is proposed, relative to the case of a building, which generally defines the increase in LOD and the corresponding geometric content. Compared to the object categories contained in the CityGML LOD layers, some changes are made for these LOD DIMs. For the LOD1 we propose a GIS source, however, obtained from a BIM data source (*Revit Mass* category). For **LOD2**, we also insert the floors, so you can categorize the building by number of floors and identify its architectural features (**Simplified Floor**). In addition, the data on the number of floors is already simplified in the mass at **LOD1**.

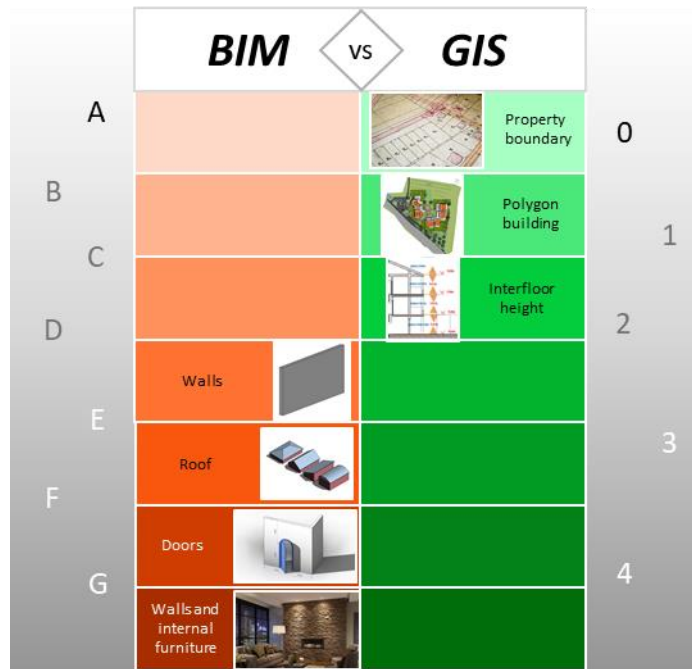


Figure 76 – Categories objects from BIM and GIS

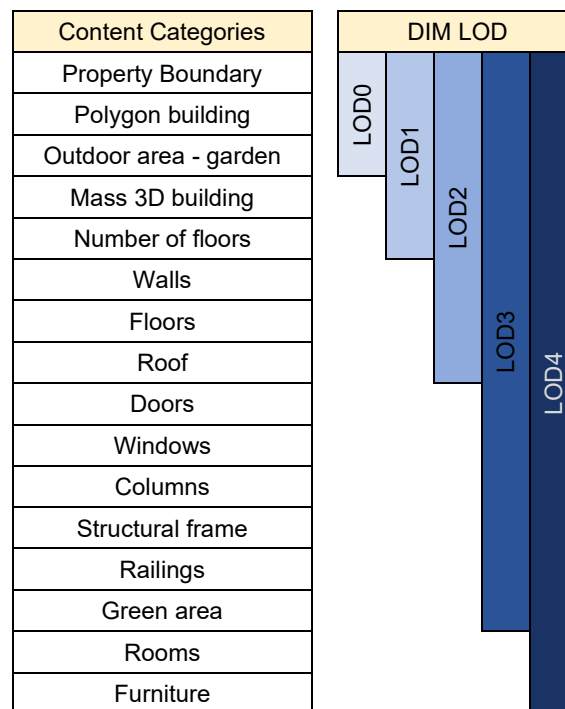


Figure 77 - Content categories DIM LOD

LOD0 feature realization

The geometry proposed for this LOD corresponds, as indicated by the CityGML standard, to a 2.5D surface of the building. It materializes using a GIS-derived datum, i.e. a polygon shapefile, formed by the floor plan of the building. Bringing the data in FME, with the command **CityGMLGeometrySetter Parameters** you attribute the text value "lod0Geometry" to the attribute *CityGML Lod Name*. As for the geolocation of the feature, the shapefile is derived from the BDTRE database and has the map reference system UTM-WGS84 32N

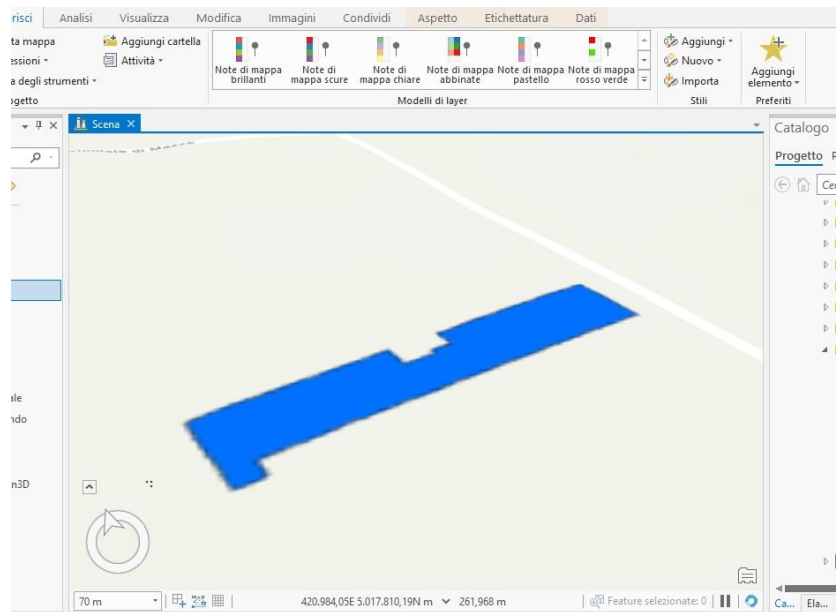


Figure 78 – Feature LOD0 from Shapefile

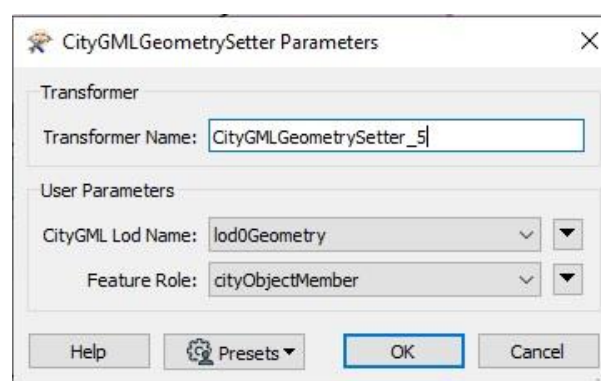


Figure 79 – Command CityGMLGeometrySetter Parameters of FME Workbench

LOD1 feature realization

The geometry proposed for this LOD provides for the creation of a 3D Territorial Information System, that is a *block model* that simplifies in height the volume given by the number of planes, but without indicating the roof. The initial data is derived from GIS and corresponds to a **Multipatch** shapefile (i.e. a 3D feature), formed by a simplified volumetric mass that represents the extrusion of the footprint in plan, which has a height equal to the value of the attribute *Altezza interpiano* and number of floors of the building.

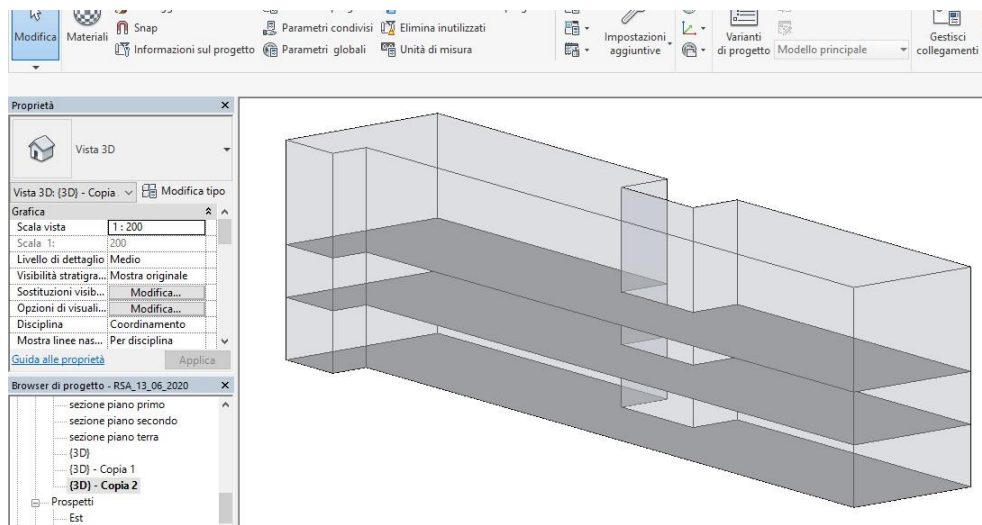


Figure 80 - Feature LOD1 from Shapefile - Revit Mass

It should be noted that the mass was first made in the Revit environment and converted with FME Workbench into a Multipatch shapefile format. This step was necessary in order to keep the data source at low LOD all in GIS environment. We attribute the text value *"lod1Geometry"* to the CityGML Lod Name attribute. For geolocation, given the initial nature of BIM geometry, a transformer is needed to define the shapefile's map coordinates. The values correspond to the N/E values of the *Basic Design Point*.

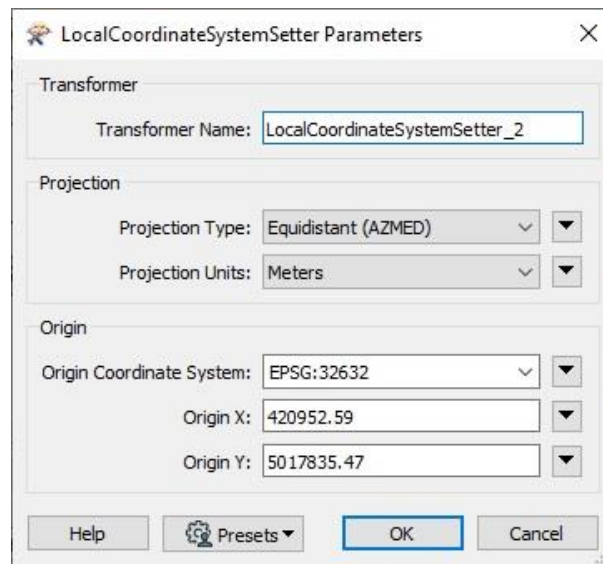


Figure 81 – Command LocalCoordinateSystemSetter Parametri di FME Workbench

LOD2 feature realization

The geometry proposed for this LOD involves the realization of a textured 3D model where the roofs are structured. The initial data is derived from BIM and corresponds to a 3D provided with geometric content related to walls, roof and floors. The text value "lod2Geometry" is attributed to the attribute *CityGML Lod Name*. For geolocation, given the initial nature of BIM geometry, you need a transformer to define the shapefile's map coordinates. The values correspond to the values N/E of the Base Project Point of the .rvt file.

Both LOD2 and the remaining LOD3 and LOD4 are BIM derived. It is necessary to define inside the file.rvt which are the categories of objects that are visualized in a certain LOD. The objective is to obtain a single file with multiple LODs, where however each object is not duplicated (in Revit environment it would mean that the same wall would be duplicated, therefore having two different IDs) between one LOD feature and another. This would only create an overlay of patterns and the initial data would no longer be unique..

An object grouping strategy is used on Revit. This method involves the use of **Phases** commands. Although this command is suitable for a site management use of the Revit model, it still finds a good application for grouping objects. Four Work Steps corresponding to the Layers that interface with the BIM are created: "LOD1, LOD2 LOD3, LOD4". Each category of objects modeled in the.rvt file is associated with that *Creation step*.

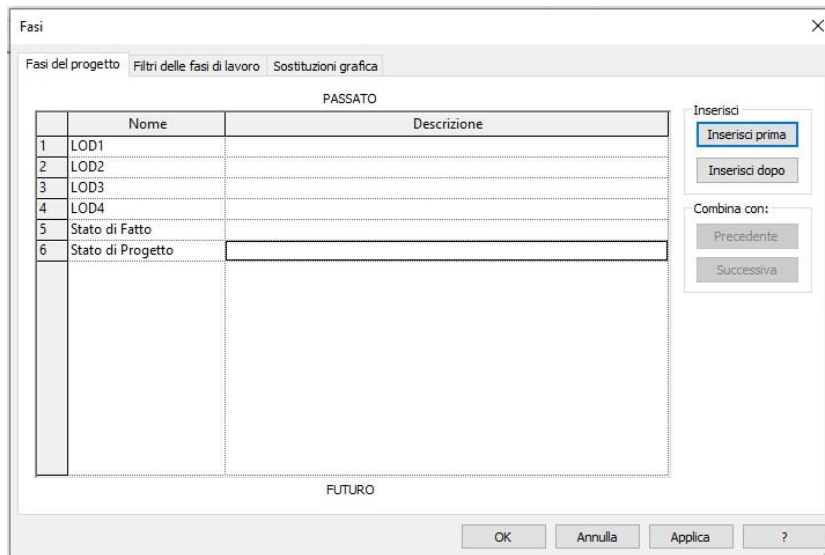


Figure 82 – Creating Work Phases in Revit

The procedure is essential to avoid duplication of objects, but it is also important to make the output in Google Earth Pro look plausible, solving a critical issue in Revit: *managing Window objects inside a Wall*. The perimeter wall of the building can be viewed in LOD2, while Windows only from LOD3. If a "Phases" Project parameter had been used to diversify the two categories, the objects would still be in the same Work Phase and the visible Wall LOD2 would already have the openings given by Windows and Doors. This would not be correct because in LOD2 we have not yet introduced the additional detail information of Windows. The use of the Phases completely diversifies the categories, which in LOD2 only graphicize the completely solid wall.

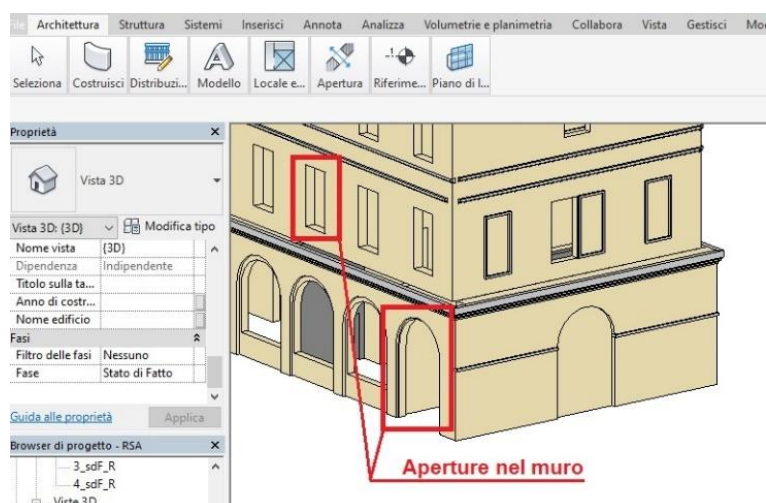


Figure 83 – Unresolved issues between LOD Walls and Windows

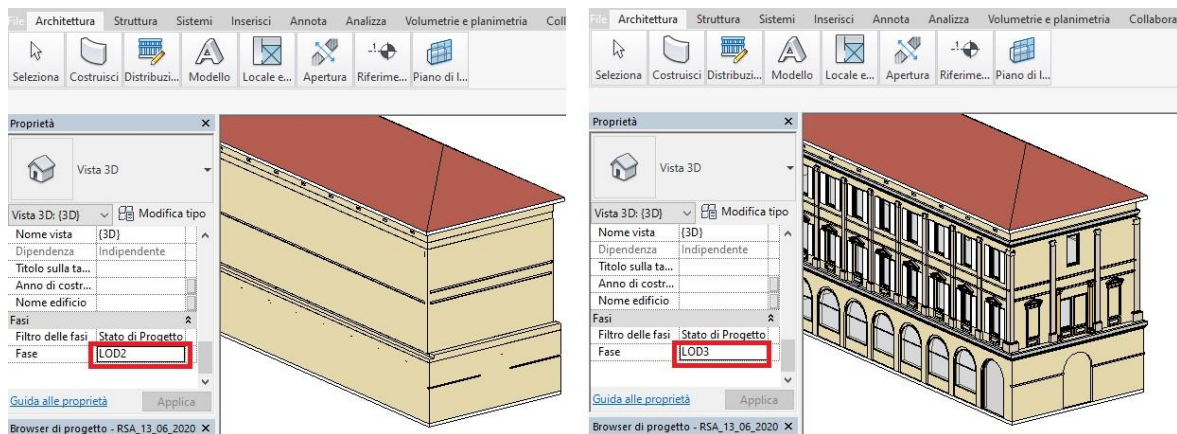


Figure 84 – Criticality solved between LOD Walls and Windows

LOD 3 feature realization

The geometry proposed for this LOD provides for the realization of a detailed architectural 3D model of the exterior and surface of the building. In this Level there are doors, windows and all external finishes such as columns, railings. The Doors category is divided into two LODs, where only external doors appear in LOD2. To help their selection and filtering, a *Funzione Project parameter* is assigned, with the value "ESTERNO".

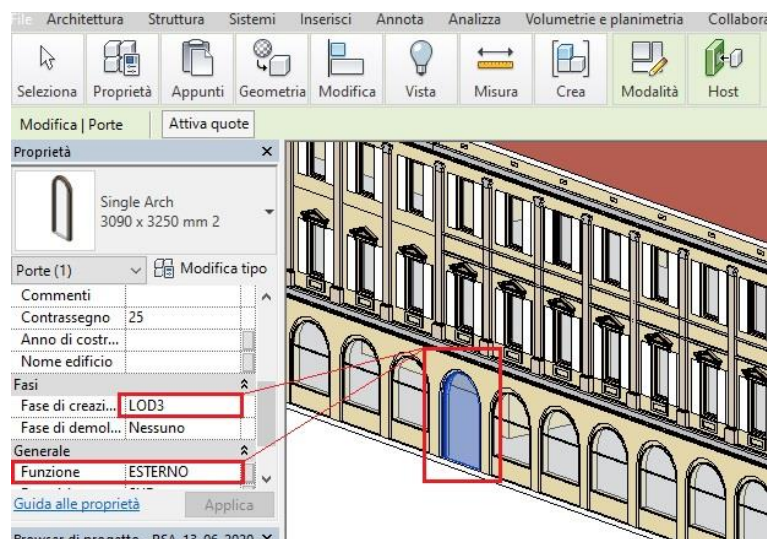


Figure 85 – Parameter display Windows in LOD3

LOD 4 feature realization

The geometry proposed for this LOD includes the realization of a complete Architectural 3D model, in which the interior walls and the various rooms are also visible. In order to distinguish between external and internal perimeter walls, the same procedure is used for

the Doors. Internal walls are given the value "INTERNO" for the Project Parameter *Funzione*.

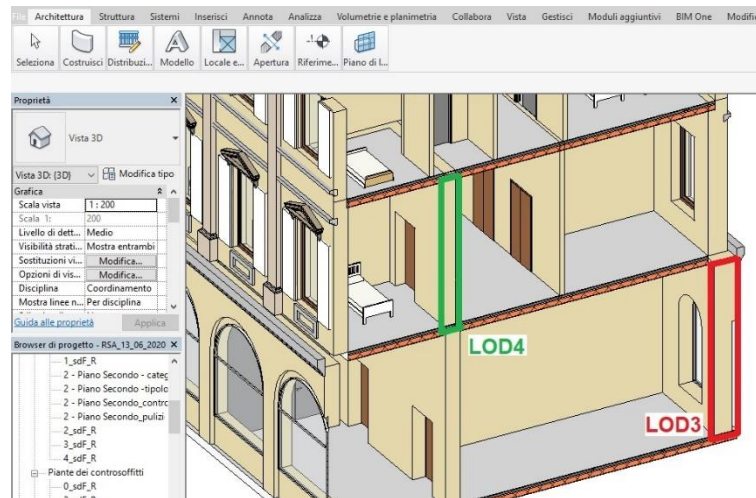


Figure 86 – Viewing Walls LOD3 - LOD4

FME script details

To complete the script in the FME Workbench platform, all the feature types that define the different objects in the LOD are grouped in **Bookmarks**; the indication of the work phase is recognized by an *AttributeFilter* transformer, which filters only the elements of a category that have a precise Revit Creation Phase value. For better geolocalization of features derived from objects in the BIM world, you need a *Rotator* transformer, which allows objects to be rotated perpendicular to the feature's reference plane. The value in sexagesimal degrees is obtained from a LOD0 shapefile *ROTAZIONE* attribute.

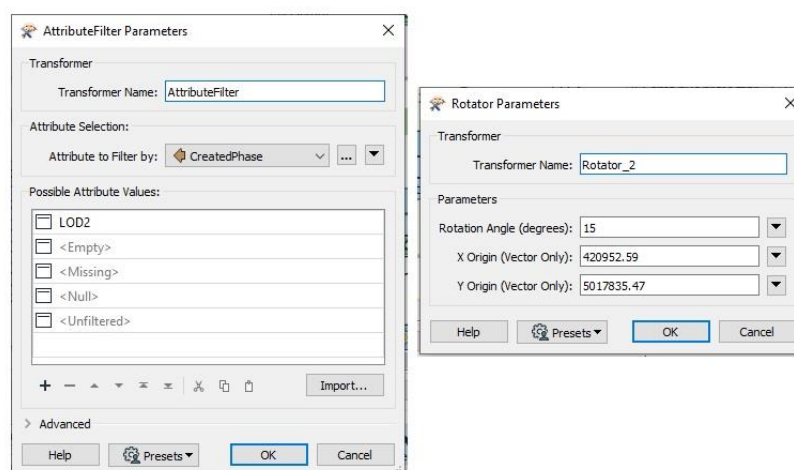


Figure 87 – Transformers of FME Workbench

Google Earth Pro

Once the whole sequence of Transformers on FME is completed, the script for the creation of the RSA Virgo Potens **.kml file** is launched. Inside the Google Earth Pro platform the file is loaded, which is perfectly divided into FME prepared Type features. They are individually selectable, recreating the conditions of a LOD DIM. The 3D model can be selected in its individual objects and the values of those parameters that have been selected in FME to be displayed appear.

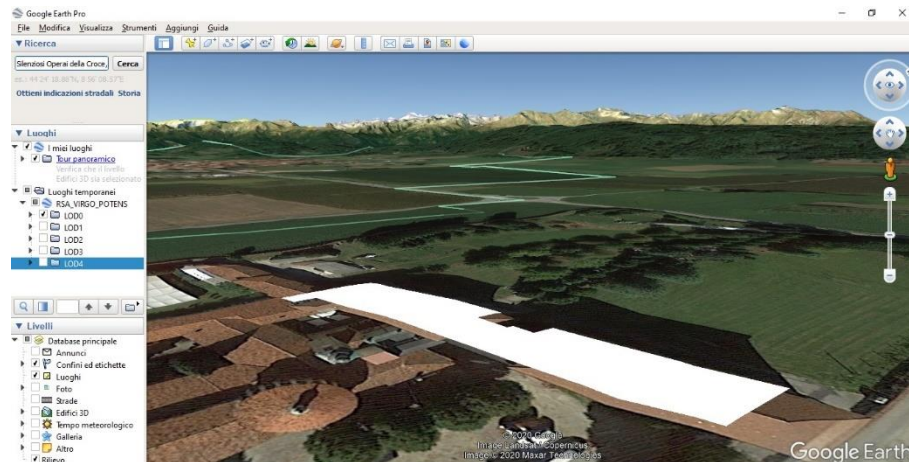


Figure 88 - Google Earth Pro_multilod_LOD0

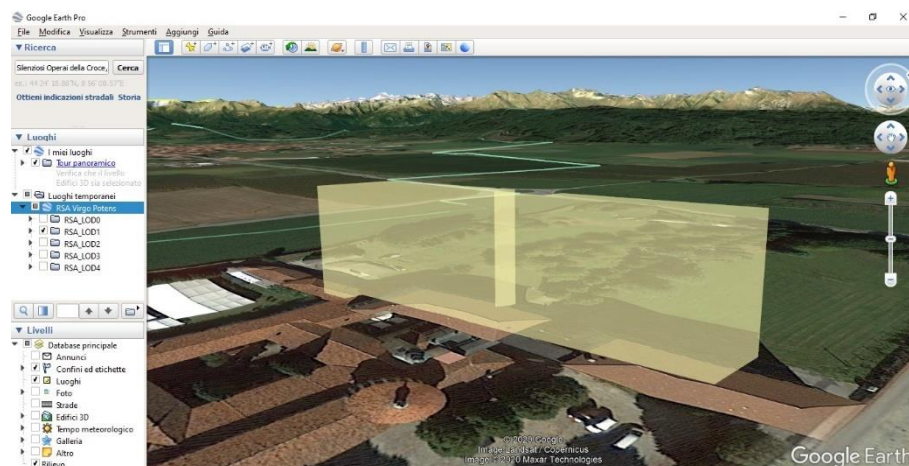


Figure 89 - Google Earth Pro_multilod_LOD1

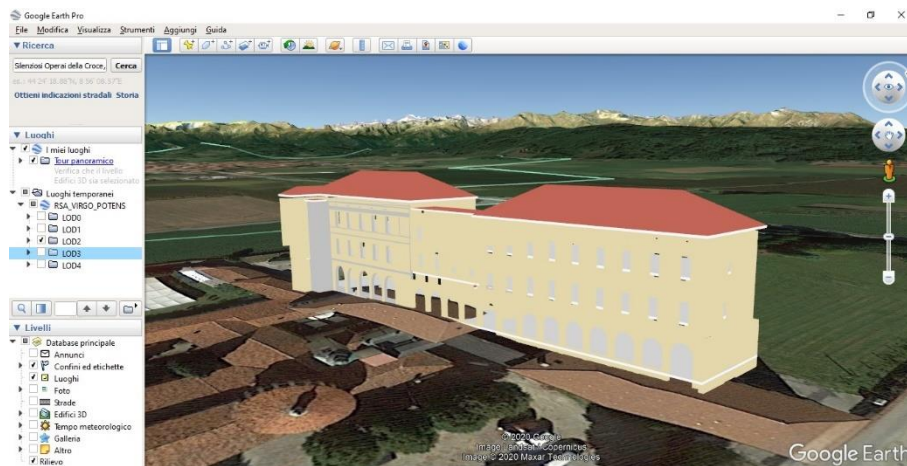


Figure 90 - Google Earth Pro_multilod_LOD2

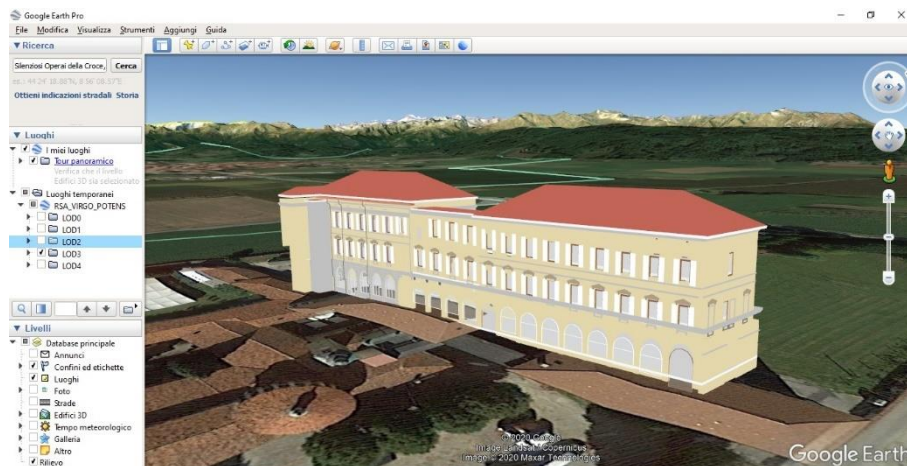


Figure 91 - Google Earth Pro_multilod_LOD3

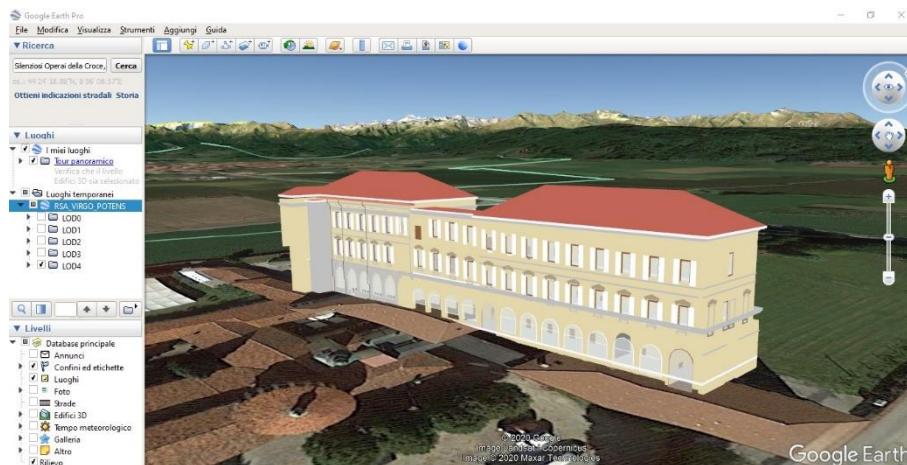


Figure 92 - Google Earth Pro_multilod_LOD4

2.4.3. Dashboard



The word *Dashboard* is used to define a set of graphic objects that, structured and displayed in a certain way, allow to make accessible at a glance in real time a lot of information of different nature and complexity ³⁹.

Solitamente la dashboard si presenta come una schermata, una pagina dove vengono aggiunte delle visualizzazioni chiamate *Riquadri*, che contengono delle *info-grafiche* di diversa forma come diagrammi, grafici, tabelle, immagini. Usually the dashboard looks like a screen, a page where views called **Panels** are added, which contain **infographics** of different shapes such as diagrams, graphs, tables, images.

The potential of using a dashboard is molteplice:

- visual immediacy
- customization of the graphic interface
- can be grouped and filtered as needed
- simultaneous display of information from different sources

Views in a dashboard may come from one or more data sets and reports, offering a consolidated view regardless of the location of the input data. The ability to view different data of the same process at the same time, make the dashboard a powerful **decision support** tool, especially in business and management in general. This faculty derives from a property of the dashboards, that is the **interactive navigation**: in the screen it is possible to select the chosen data inside a box and the navigation is updated **in real time**, filtering the data inside all the boxes..

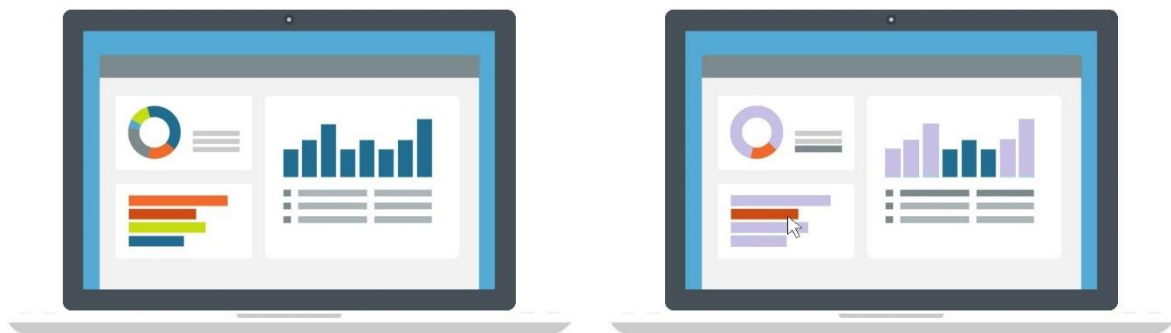


Figure 93 – Selective dashboard filter operation

The dashboard is not born as a database but is a tool that contains only the data necessary to obtain specific information. Therefore, dashboards are created for a **purpose** and contain only the data necessary to fulfill the purpose.

In decision making the dashboard is also applied in the construction world, in the management of real estate assets and to evaluate some info of the sector.

For this reason the use of the dashboard is dedicated to a user such as a nursing home administrator or a patient or relative of the same. He does not have to have a necessary technical preparation, as he can satisfy his research by comparing himself with interactive data presented in different forms; the *clicks* on the filters allow to get to the information sought in a simple way.

Two Dashboards are proposed, each of which has been designed to meet a specific purpose. The objective is to obtain the dashboards by creating them as a Web page that can be consulted online. The dashboards are made with the **Power BI Desktop** application and the Web **Operation Dashboard** application.

Power BI Desktop

Power BI Desktop is a free application that is part of **Power BI**, a collection of software services, apps and connectors that interact to transform unrelated data sources into a coherent, visually appealing and interactive set of information.⁴⁰

With Power BI Desktop you can connect to many different data sources and combine them (modeling) into a data model that allows you to create visual objects and collections of visual objects that can be shared as reports⁴¹.

Within the interface you can create the dashboard screen and enter all the necessary boxes to present and make the data attractive. With Power BI you have created an interactive dashboard that has the following purpose:

"Use a dashboard to analyze data related to the cooling of the interior spaces of a healthcare facility"

In order to obtain a dashboard that meets the above mentioned purpose, the activities were carried out and the necessary data were defined, as developed below.

The input data is the BIM source for the *RSA Virgo Potens*, specifically the building's .rvt file. Being a model with a high LOD, the Rooms are also included. This category has a series of dedicated Project Parameters. In addition, by integrating the results of the questionnaire (see paragraph 2.3.2.) additional parameters have been added to the Rooms.

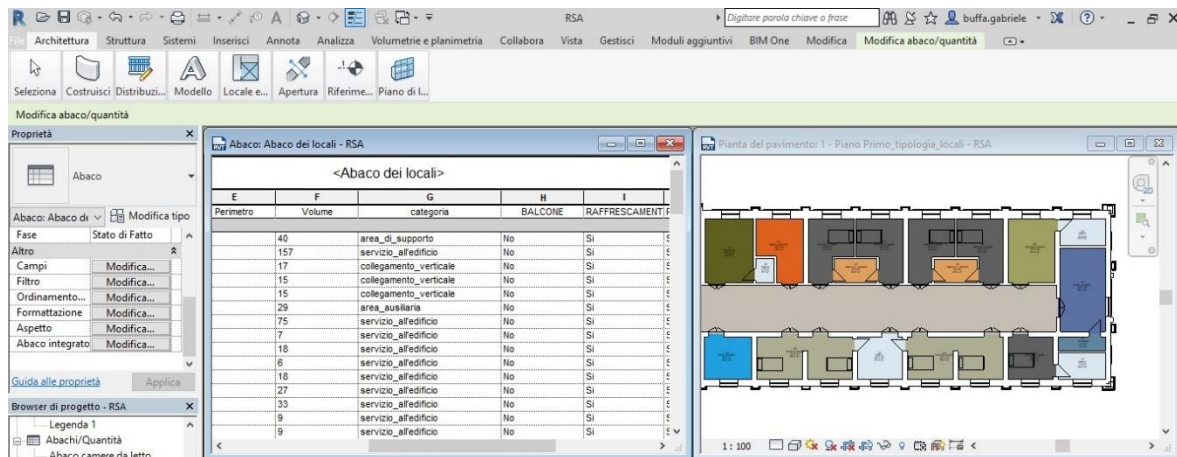


Figure 94 – Rooms Parameters from Revit Schedule

To view the graphical content of the Revit file in the application, assume a pane in the dashboard relating to a 2D building plan. The procedure for inserting the plan on Power BI is **semi-automatic**.

A .jpeg image of the building plan is extracted from Revit. This image is modified in **Synoptic Designer for Power BI**. It is a web application that highlights areas of the map in an easy to use way ⁴². By inserting the image in the app you can create closed polygons; the app identifies walls as perimeters and draws the closed polygon corresponding to the room. Two data are assigned to the drawn area: Name and Number. Once you have drawn and compiled the polygons of all the rooms in the plan, you export an SVG file ⁴³.

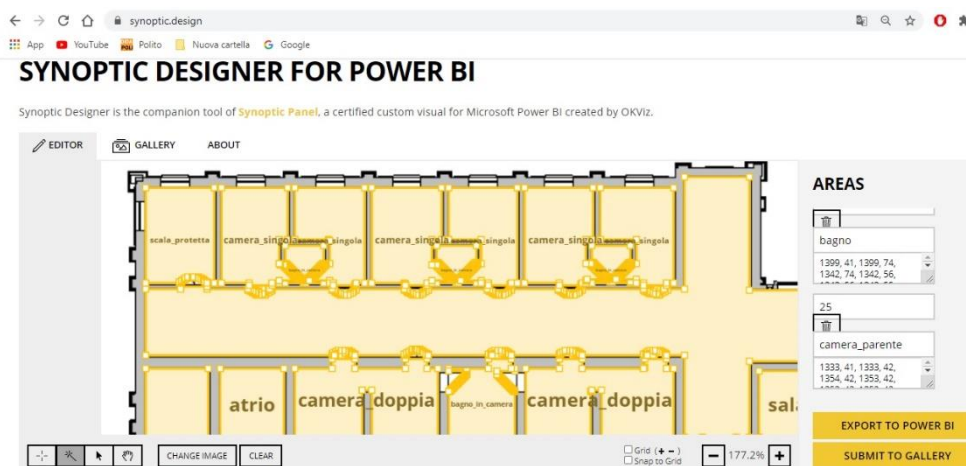


Figure 95 – Creation Area in Synoptic Designer for Power BI

The SVG file is the image format obtained and loaded in Power BI. The dedicated tool to manage this data is **Synoptic Panel**, a visual plug-in that connects areas of a custom image with attributes present in the data model of the Power BI file; the areas are colored with a color or saturation of a color related to a data model value. The correlation is made possible because the Revit Rooms are assigned Parameters related to an ID number and a unique

Name. These values are the same as those compiled in the online App. The operation is repeated for all three floors of the facility. These plans are the first three boxes inserted in the dashboard.

In order to use the Design Parameters applied to the Rooms, which are necessary to make the dashboard logic work (such as the Parameter on the volumetry, the Room category and the Yes/No condition of the cooling), an import of the Room abacus is required. First exported from Revit as a .txt file, an Excel file is created. Power BI has a tool dedicated to the direct import of many files including Excel sheets. In these cases a Query page is activated to modify the data specification before using it in the dashboard. The project parameters are classified according to type, i.e. whether Entire numbers or Text. The Excel table is the fourth pane of the Dashboard.

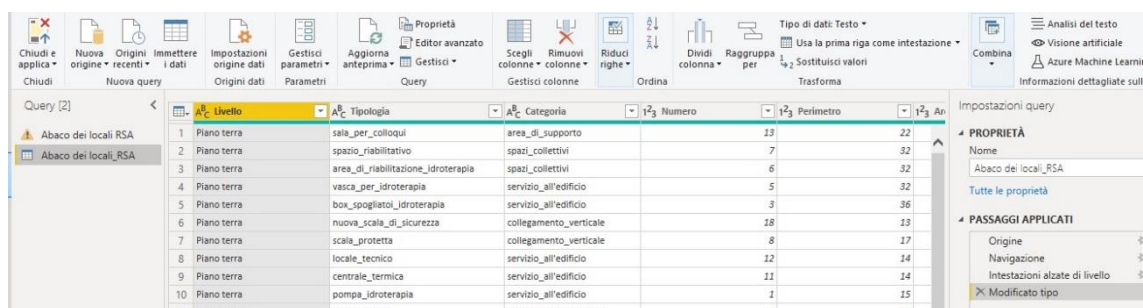


Figure 96 - Editor Query of Power BI

The external data is now ready to be reported in the dashboard using the following screen infographics:

- The fifth Pane is a **pie chart** that shows all the types of Rooms in the building;
- The sixth pane is a filter command, which uses the **Level** Parameter to visually filter the affected rooms;
- The seventh pane is a **filter** command, which uses the **Category** Parameter to visually filter rooms that have the same function;
- The eighth pane is a filter command, which uses the **RAFFRESCAMENTO** Parameter to visually filter rooms that have or do not have a cooling system;
- The ninth pane is an **indicator**, which graphically materializes the total **Volume** of the analyzed rooms with an exact number;
- The tenth pane is an indicator, which graphically materializes with an exact number the number of rooms analyzed by **Tipology**.

The Power BI project file is saved and uploaded online to create the dashboard **Web App**. Logging in with credentials and the link opens the dashboard screen.

Now you can search and query the data. For example, if you select a single room in the dashboard, all the boxes are filtered to that object's specifications. You can then see in the table if that room is cooled or not and the **Technical Volume** of use.

The data on the volumetry of the cooled rooms can be observed at wider search radii; using directly the curtains in the filters narrows the search radius of the data, which is always controllable in the partial total of the two indicators.

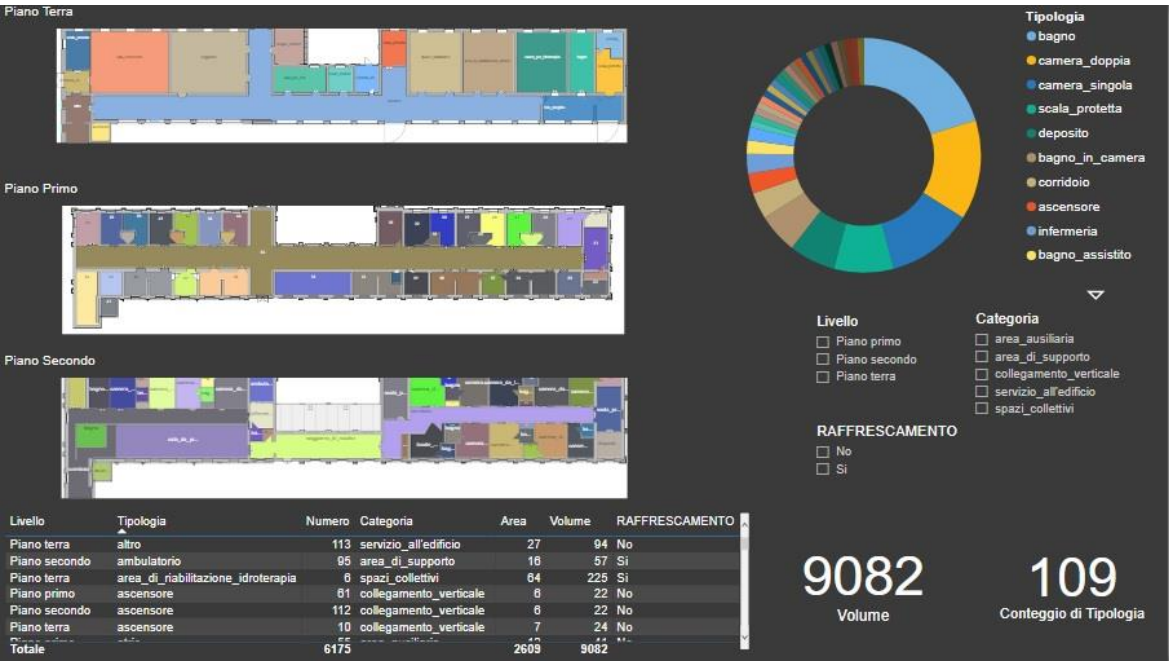


Figure 97 - Power BI complete full screen Dashboard

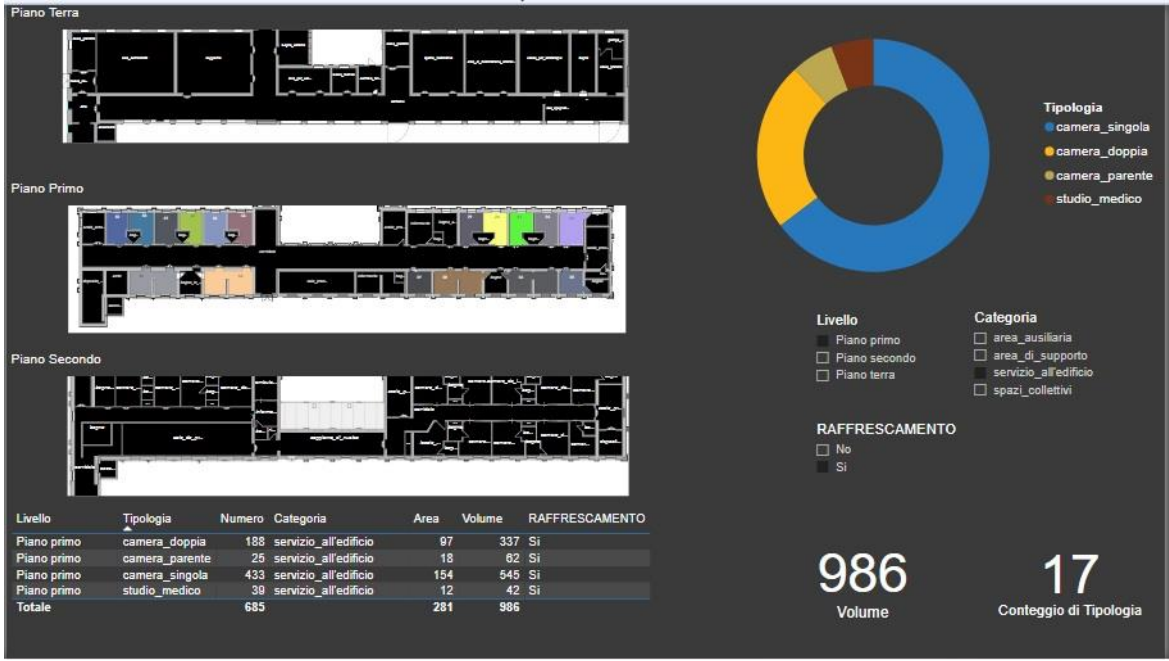


Figure 98 - Power BI screen Dashboard filtered

Operation Dashboard

Operations Dashboard for ArcGIS is a fully configurable application that allows you to use charts, indicators, maps and other visual elements to show the status of static or real-time objects, services and events. It is suitable to provide end users with dynamic interactive visualization and navigation between maps, charts, indicators and other visual elements ⁴⁴. The online version, managed in the **ArcGIS Online cloud**, is used in this thesis. The data that can be entered in an Operation Dashboard are GIS-derived and this is well suited to the management of real estate assets on an urban and territorial scale. Therefore, you use this application to generate an interactive dashboard that has the following purpose:

"Use a dashboard to analyze the data related to the types of Residenza sanitaria present in the Piedmont Region, identifying the beds active in the health care azzonamenti"

In order to obtain a dashboard that meets the above mentioned purpose, the activities were carried out and the necessary data were defined, as developed below.

Two Shapefiles are used as GIS input data: one identifies the municipal limits, the other identifies all the health facilities of the Piedmont Region.

Once the necessary Shapefiles have been identified, a **Web Layer** must be created in order to use them in the Online platform. You create the Web Layers of the three Shapefiles mentioned above.

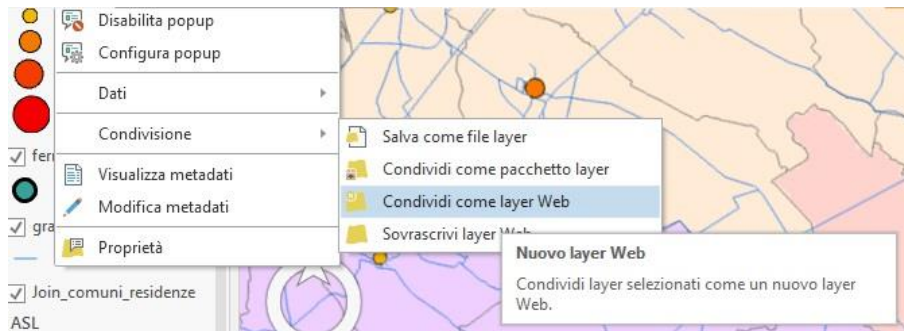


Figure 99 - Creation Layer Web

Inside the ArcGIS Online Cloud, in the personal page of your Account is stored the list of Web Layers that can be used to create **Web Maps**. These Maps are the cartographic format manageable in the Dashboard *Panes*.

The Dashboard screen consists of the following seven Panes:

- **Map** of the Residences of Piedmont;
- Map of the Health Reservations of the Municipalities of Piedmont;
- Map of the shortest route between two points;

- **Pie chart** that shows a grouping of the most numerous types of health facilities in Piedmont;
- Pie chart that shows a grouping of the most numerous types of health facilities in the Province of Vercelli;
- Pie chart that shows the list of the health care facilities of the municipalities of Piedmont;
- **Indicator** that shows the number of active beds in Piedmont;

Using these boxes you can filter the data search. Typing on a field of the pie chart reduces the fields of the municipalities that host these structures; typing on the pie chart of the resets the active beds in the resets are updated in real time, compared to the total number.

The online dashboard is available, after filling in the Account data, at the following link:

<https://learnigis2.maps.arcgis.com/apps/opsdashboard/index.html#/59026127ac8f42fe925941f69e2dd302>

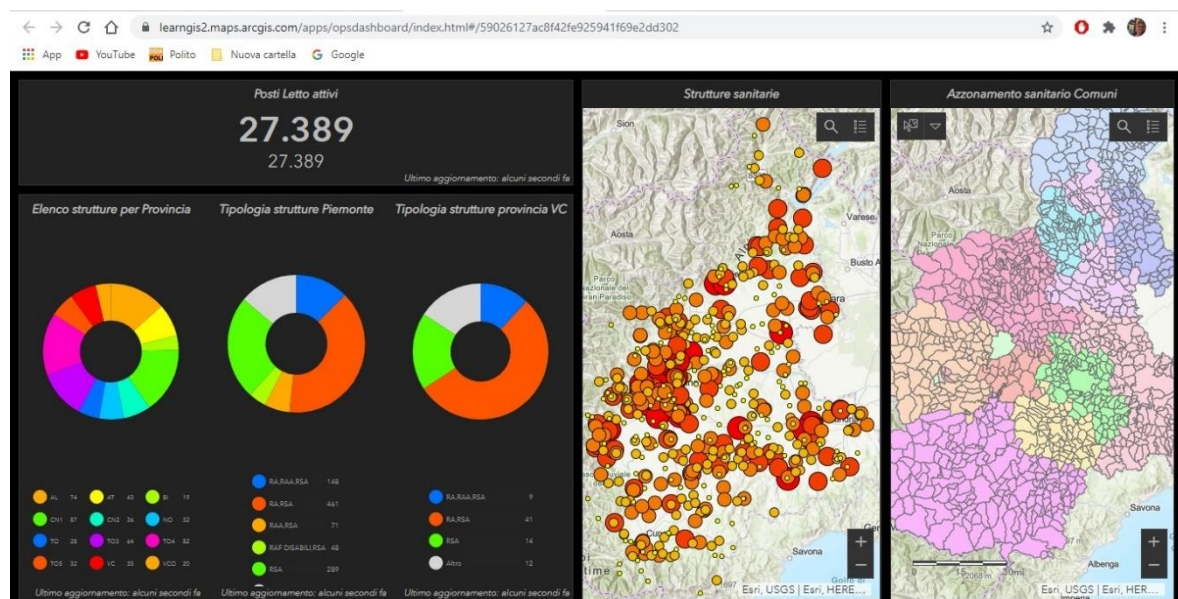


Figure 100 - Full Dashboard screenshot

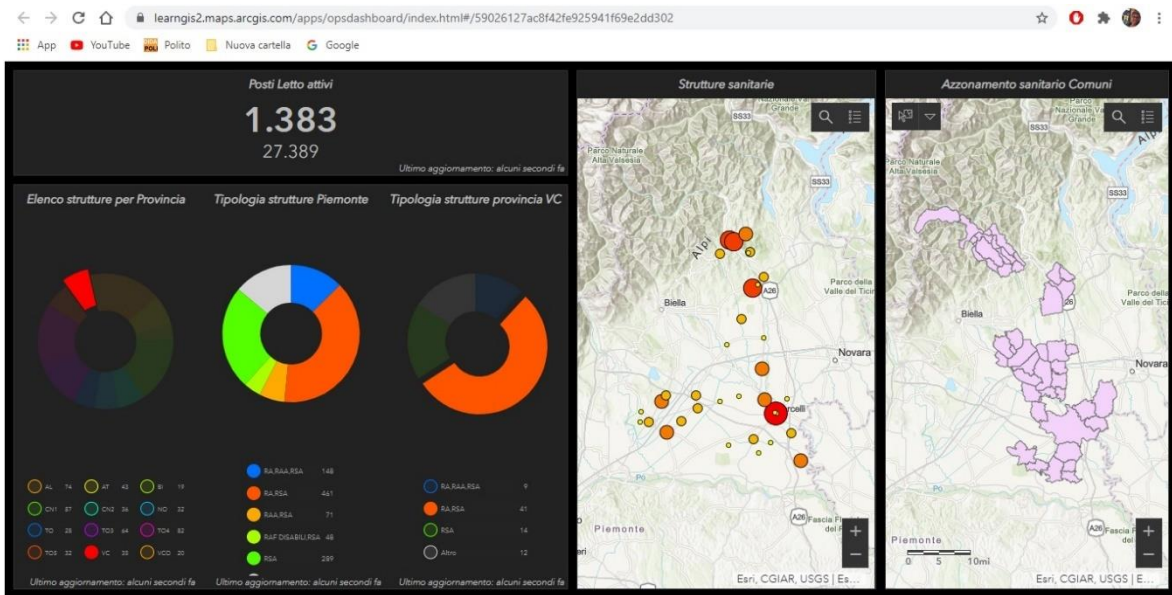


Figure 101 - Dashboard screen with search filter

3. RESULTS

The thesis work dealt with the management of the real estate assets of retirement homes through the analysis of two very distinct realities, BIM and GIS, evaluating the strengths of individuals to seek process optimization. The interaction of the two databases has produced different output results, according to the needs of different users hypothesized. Given the heterogeneity of the data and software used, it is necessary to distinguish and categorize the results of this thesis work, in order to make them scalable from general to particular.

We propose a more general analysis of the results that evaluates the *method* and *interoperability* of data, to arrive at more particular results, related to the *use of software* and *data visualization*.

For the results related to the **method**, the DIM concept was an important objective because it allowed to optimize the BIM - GIS integration analysis and to propose effective outputs. In the ideal case proposed in the methodology, the DIM is a fully integrated and successful unit, with all the databases integrated both in terms of graphics and information. With the BIM and GIS interaction the idea of the DIM has already been reached, but several factors have limited its capabilities and completeness. There is therefore a distinction between the ideal DIM and the achieved DIM where the latter is fully configured but is not a single entity, since the initial databases are still identified and a third entity keeps them linked, which represents the capabilities and ability to manage the **relationships** and **connections** between heterogeneous data.

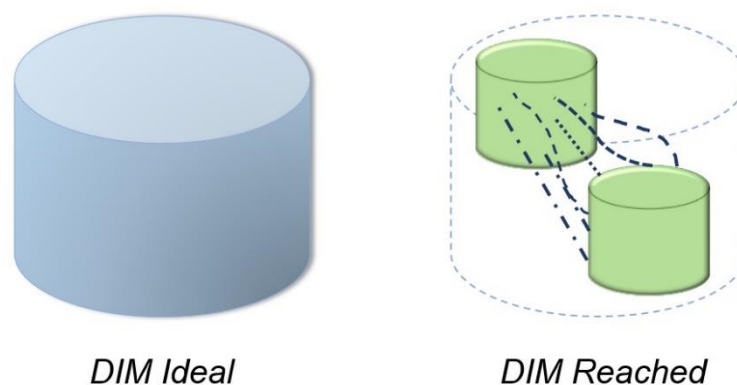


Figure 102 - Methodology result

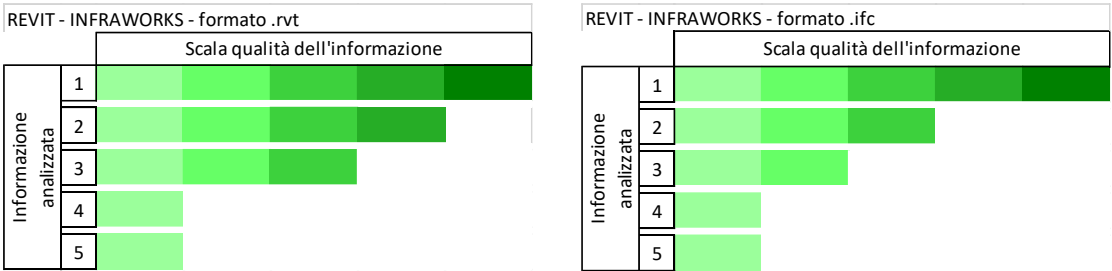
Always in the results related to the method, the implementation of the initial database has been able to become effective, as demonstrated by the tools implemented in the ArcGIS Pro platform. However, the discreet interaction of the administrations of the nursing homes has not allowed to better implement the BIM source, necessary to increase the informative LOI during the management of the models.

In evaluating the results related to **interoperability**, a key role was played by the software, as the analysis brought to light heterogeneous results on the potential of the software in managing the *connections* between the data that makeup the DIM. Below are the results of interoperability testing on some of the key information.

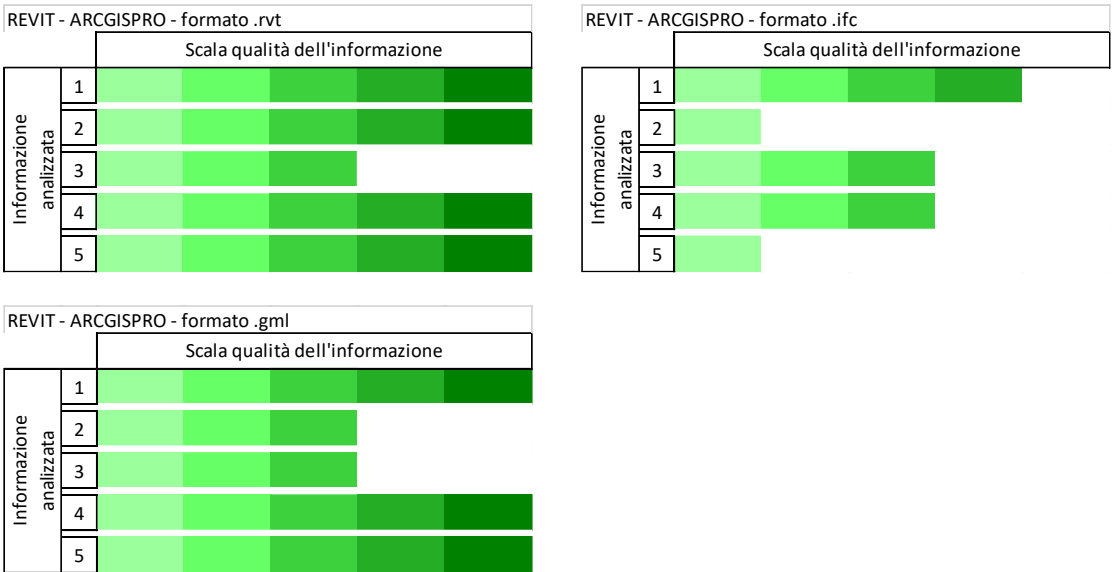
Analyzed information:	1 - Geometry and shape
	2 - Geolocalization
	3 - Display, color of individual objects
	4 - Object name
	5 - Custom Parameters

Information quality scale:	Insufficient
	Discreet
	Good
	Very good
	Excellent

Infraworks



ArcGis Pro



FZK Viewer

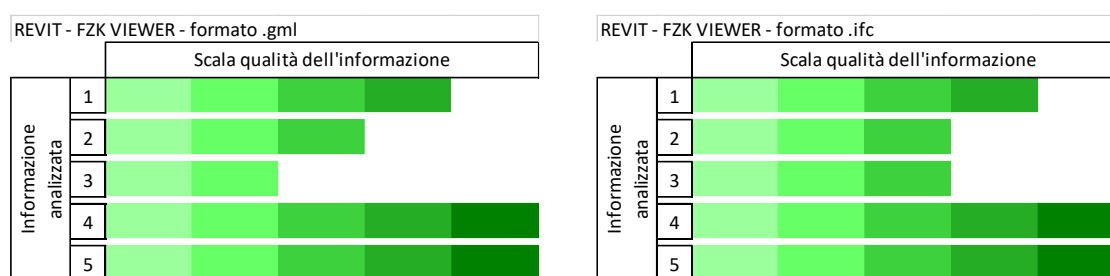


Figure 103 - Interoperability Test Results Tables

The values of the tests confirm the above mentioned difficulties to manage different data even for the same software. The Arcgis Pro software, which is able to offer the best information management of the BIM - GIS interaction, is a winner among all.

About the potential for the **use of the software**, much has been filtered by the needs of the user. Queries made in ArcGIS Pro environment do not use data source interaction. Similar situation for the Dashboard, whose nature of the creation software leads to use is data from a source. Also in ArcGIS Pro, good DIM interaction has been achieved only at the information level, combining the Shapefile tables on the BIM and GIS side. The output that best integrated the data, achieving a high level of completeness and knowledge of the connections that govern the DIM, was the Multi LOD model managed in the Google Earth Pro environment. In a single file, the features of the LOD DIM, of both BIM and GIS derivations, have been enclosed in a single file. If necessary, the.kml file responds fully to the performance of a DIM. If you need spatial information, you query the GIS feature, the opposite is true for the BIM feature. However, there are also output defects related to visualization, as the model adapts too much to the topography of the 3D terrain and deforms the initial shape.

Going down to the scale of detail of the results, as mentioned in the case of Google Earth Pro, the **visualization** is also a result that deserves observation, since it is the first degree of appreciation of a DIM user, who could turn to other outputs if the visual component does not satisfy his search. In this analysis, the Dashboard is the output that best recreates a clear and immediate display based on the purposes for which it was designed.

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

In the face of the more general results regarding the methodology, it can be said that the DIM is an effective tool for the management of a real estate asset such as retirement homes. The successes obtained in the output of the *Coordination Model* exalt this methodology. For a simple structure three models have been joined, dependent on a series of parameters and preset specifications. Their peculiarity was to have common parameters that allowed to filter and collect information, usable for each building. With the advent of the technological era increasingly impacting the building, Smart Cities will become an increasingly effective strategy in the management of services to citizens. Having a platform or software that performs the coordination of urban assets certainly helps the quality of services offered to the community.

It is for this reason that ***the greater involvement of administrations*** can increase the quality of services offered to patients. If a good interaction was created with these agencies (see the administration of the questionnaire), they would be the bearers of a considerable amount of data, which would allow the BIM database to be implemented in a significant way, not only in terms of information but also in the modeling of health residences.

The data would have the same source and format and this would be ideal because it would allow all assets models to be used for industry comparisons, rankings and statistics. This would facilitate the inclusion of models in a real urban and territorial scale, making it easier to manage an entire real estate asset.

The idea is that each property in the urban-scale database should have as many, if not all, of the common parameters available. This would facilitate the choice of stakeholders and technical and administrative managers, reducing the time needed to read and interpret the data in order to dedicate themselves fully to the activities.

As for the more particular results, the potential of the software is evaluated. Many of the software used in this thesis work allowed the realization of effective outputs. However, it is not enough to analyze the result of a software but also the path to the result. Analyzing the ideal methodological scheme of this thesis work, it is clear that the process is simple. In reality the achievement and creation of one of the proposed outputs required a considerable number of operations. In this real point of view of complex operations in which the software are protagonists, it is important that ***more research is carried out to transform semi-automatic operations into automatic ones***. The streamlining of the procedure will give advantages, both on the administrators' side that will concentrate more their skills in the outputs, and on the user's side because it would improve the quality of the data inserted in the outputs.

Looking again at the process of obtaining output and DIM in the broadest sense, it is clear that a considerable number of data formats have been used. The standard IFC and CityGML formats were not enough to allow the integration and use of the DIM; often proprietary software data formats were used. The heterogeneity of the formats negatively affects the process, limiting its performance and sometimes preventing its subsequent operation. For this reason a development in the ***search for a universal exchange format between the different domains*** that come into contact with the building world should be evaluated, obtaining a high performance in terms of data interoperability.

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