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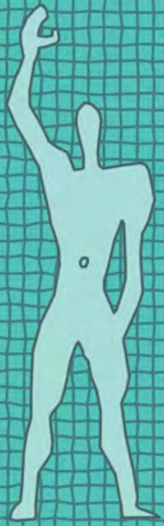

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Spaces Identity Evaluation aNd Assignment - SIENA

A duck typing approach for automatic recognition and semantic enrichment of architectural spaces

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This paper presents the development of SIENA - Space Identity Evaluation aNd Assignment - based on duck typing for automatic recognition and semantic enrichment of the architectural spaces. This method is known in computer science as a form of abductive reasoning and leverages on the observable features of an object in order to establish its recognition. As result, the spatial identity is object-oriented and can be dynamically defined. In this research, the duck typing approach has been achieved with the support of BIM methodology and graph database. The former allows information-based modeling of an architectural project while the latter makes possible the representation of the knowledge along with their relationships. Consequently, this research may have many possible applications, especially as a valid design support tool in the very first design stages. Furthermore, an efficient spatial identity detection could contribute to the development of further human-machine interactions and therefore a possible optimization of the design process.

Keywords: *Semantics, Graph database, Duck typing, Space identification*

INTRODUCTION

So far in architectural design, the room identitification process must be statically and manually defined by designers according to his/her experience and building functional program. This means that the attribution method does not automatically consider its semantical functions and properties and, as consequence, the identity attribution process must be manually updated and upgraded as soon as the project changes. Moreover, it should be considered misunderstandings among involved actors due to different meaning that these people attribute to different symbols, icons, graphic conventions, measure units and terms. Therefore, the knowledge-based analysis and simulations concerning the space identity have a limited level of reliability and objectiveness (Wu & Zhang, 2019).

BIM methodology relies on information of constituent elements and their relationships (Autodesk, 2002). Nevertheless there is still a certain arbitrary

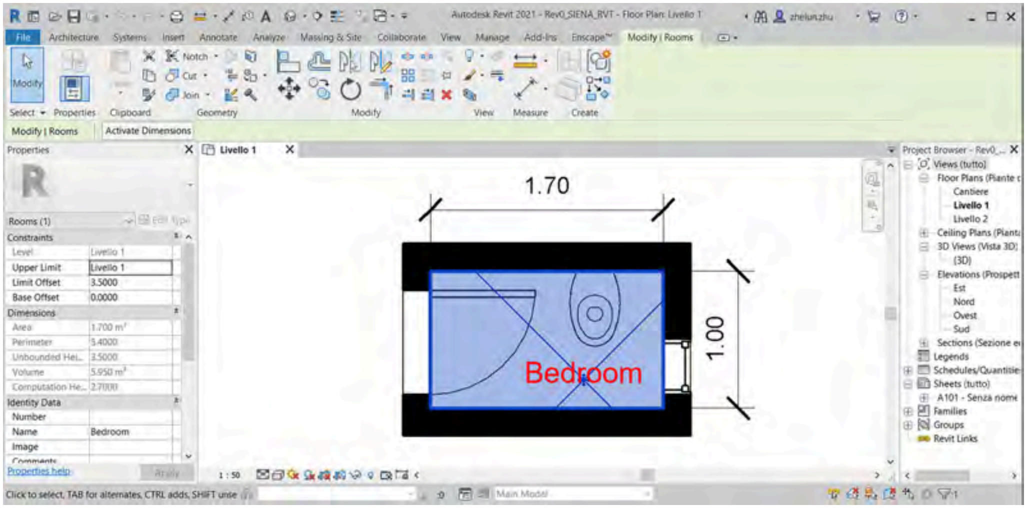


Figure 1
Consequence of designer-dependent attribution of space identity

level related to the spaces identity assignment. As a matter of fact, Figure 1 shows an example of an inconsistent manual definition of a room identity obtained in a BIM software, in this case Revit. As we can see, the name assigned by the designer to this room does not correspond to its function and there would not be enough space for furniture for that scope such as a bed, even in case of future renovation. This means that the semantic attributes of the spatial identity relies on two aspects: its capability and its endowment. The first indicates that a room is characterized by enough dimensions and predispositions for that function. The second aspect, on the other side, indicates that the room is equipped with necessary furniture and devices that allow it to perform that specific use.

This research wants to present an innovative approach, called SIENA - Spaces Identity Evaluation aNd Assignment, based on the implementation of *duck typing* method within graph database formalizing the building, its spaces and its components.

In computer science, *duck typing* is the application of the "duck test" to determine the identity of an object based on its features. It is a form of abductive reasoning and it allows the identification of an object by its observable characteristics (Ramalho, 2015). The "duck test" is defined by this expression "*if I see a bird that quacks like a duck, walks like a duck, has feathers and webbed feet and associates with ducks, I'm certainly going to assume that it is a duck*". The application of this logic in computer science has led to a dynamical establishment of an object's semantic through its very properties (Milojkovic et al., 2017), rather than the type that the object has been manually assigned.

On the other hand, the data structure based on graphs allows the information storage as well as the representation of both *properties* and *relationships* between the elements. This feature embodies the key factor in the proposing methodology together with its characteristic to provide real-time graphical visualization of the relationships. Furthermore, the *duck test* can be obtained by comparing the similarity between two graphs, the project one and the typological one. Consequently, the room's identity can be semantically established and assigned once it satisfies the features of being a typological room such as a kitchen, bedroom or bathroom.

OBJECTIVE

This research inquires about the semantic meaning of buildings' digital entity by its constituent components and functional spaces. Hence, entity semantic attributions are related to the identification of its own features, and relations linked with other entities. This process could lead to an automated spatial semantic identification and enhancement, improving the coherence between the assigned name and its effective essence. Thus the proposed approach could reduce manual room's identity corrections issues in case of frequent changes and then achieve a more efficient design process.

Finally, the knowledge-based identity assignment could be vital for further developments in human-machine interactions. This feature can be achieved in case the system is able to understand the actual meaning and functions assigned to the room and consequently to respond to the designer's requests.

STATE OF ART

This research proposes the application of graph structures for the "duck test", as the enbodyment of the SIENA approach. As defined in the graph theory (Marcus & America, 2011), the structure of a graph G = (V, E) is composed by a set of vertexes V = {V1, V2, ..., Vn} and a set of edges E = {E1, E2, ..., Em}. Each edge E_k is identified with a pair of vertices (Vi, Vj) and the *degree* of a vertex is the number of edges that occurs at that vertex.

A *subgraph* of the graph G is a graph that is contained within G; all vertices and edges of the subgraph are included in G.

A graph is defined *bipartite* if its vertices can be separated into two sets X and Y in such a way that every edge in the graph has one endpoint in each set.

A *path* is a sequence of vertices and edges in a graph such that the sequence alternates between vertices and edges, starting and ending with vertices; each edges in the sequence joins the vertices that occur immediately before and after in the sequence. A path that contains no repetitions is called a *simple path* (Fig. 2).

In graph theory, two structures can be considered *equivalent* even if the shape of an edge or the position of the vertices are different. And this brings to the concept of the *isomorphism* which means that two graphs are *isomorphic* to each other if they can be transformed, by re-organizing vertices, in such a way that they become equivalent graphs. This implies that two isomorphic graphs have the same number of vertices, the same number of edges, the same maximum and minimum degree and the same length of the longest simple path.

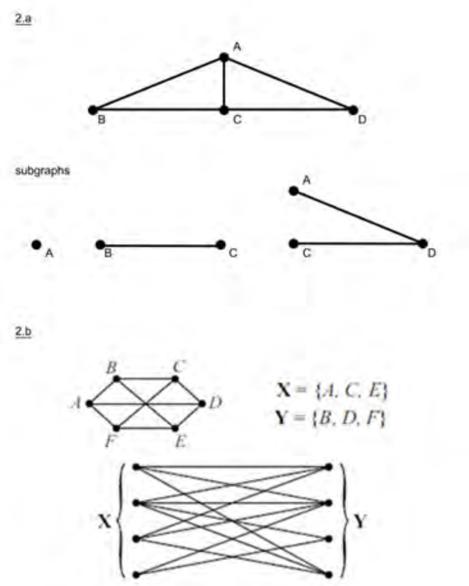


Figure 2
Example of subgraph (2.a) and bipartite graph (2.b). (Marcus & America, 2011)

So far, the application of graph databases in architecture consists in representing and analyzing the relationships between rooms of a building or different areas of the city for design development and evaluation (Dawes & Ostwald, 2013). As a matter of fact, the graph theory has been the vehicle of space syntax analysis which focuses on the spatial configuration and their relationships (S. Bafna, 2013). Fig.

3 shows an example of graph visualization of habitation's organization in "Architect's Data" by Ernest Neufert (1980).

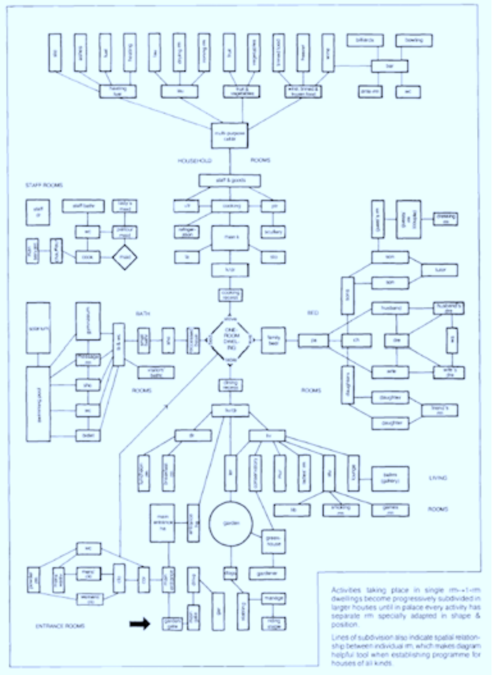


Figure 3
Graph representation of an habitation, Architect's Data by Ernest Neufert

However, the space syntax theory *describes* the spatial features and configuration of buildings or urban areas but does not *recognizes* their identities by means of a semantic attribution. Therefore this paper presents an implementation of the graph database in the automatic assignment of the spatial identification process. The exploitation of the graphs in this process provides graphical visualization of the relationships between rooms and their semantic attributions. Furthermore, a graph database allows queries and logical operations which could provide needed functionalities in the SIENA process.

METHODOLOGY

The basic idea is that if there is a sufficient level of similarities between a typological room's graph (duck) and a specific project room's graph, which identity is still unknown, thereby it is possible to assign the identity of the typological room to the project room. This process can be synthesized with Fig. 4.

In this research the adopted graph database is NEO4J which is an open source software.

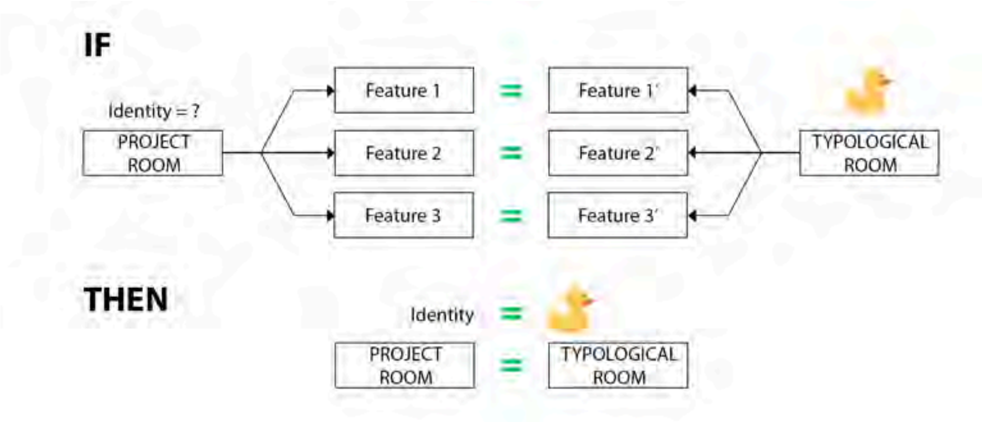
The first step is the individuation of meaningful properties of "ducks", which in this case have been considered as typological rooms: a kitchen, a single bedroom, a double bedroom, a WC and a bathroom. Therefore, features, and consequently their value, like spatial dimensions, minimum quantities of openings, required devices and equipment have been analysed.

The adopted typological room standards are taken from the *Building Code* of Rome, Italy, which provide quantified requirements needed for the obtainment of the habitability licence (Regolamento Generale Edilizio Del Comune Di Roma, 1934) [1].

Then the requirements of the considered typological rooms have been extrapolated from the Building Code and therefore transferred into the graph database. As pointed out in the Introduction chapter, there are two kinds of requirements: capability and endowment. Hereby this aspect has been taken in consideration during the creation of the relationships. In order to facilitate data comparison and exportation in the next phases, these features are defined according to the Revit classes nomenclature and the corresponding graphs that have been created in NEO4J. The Fig. 5 shows in particular the requirements of a bathroom, according to the building standards of the City of Rome.

On the other hand, many testers have been created to be compared with the "ducks" in order to verify their identity. In this research, these rooms have been modelled in Revit and the data extrapolation achieved through Dynamo. With the support of the adopted visual programming language, values of above individuated features of testers, have been

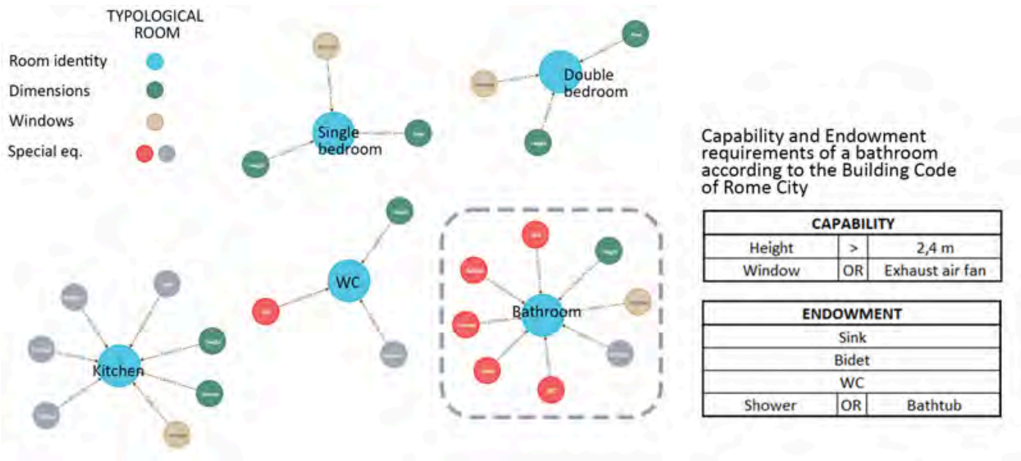
Figure 4
Schematical reasoning of the duck test in SIENA



organized and then transformed into CSV - Comma Separated Value - file and thus imported into the graph database. This research has considered as significant tester three different rooms, shown in Figure 6. The result of the comparison process will be presented in the next paragraph, followed by discussions.

In order to facilitate the data extrapolation, this work has adopted a BIM objects management regarding the constituent elements' identity, which is not the focus of the present research. The simplification consists in the manual assignment of the name of objects under the "Comment" parameter, in the "Data Identity" section. This process is a common practise among design teams in order to coordinate and uniform parameters of BIM objects coming from different origins, in the same project.

Figure 5
Graph representation of the "ducks" (Typological Rooms)



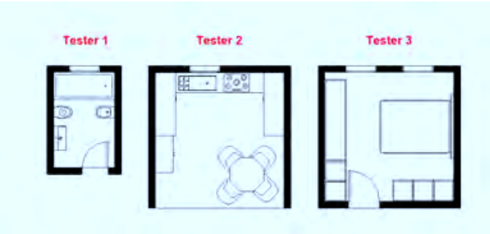


Figure 6
Utilized testers in this research

Thereafter, these labels have been summoned in Dynamo by their parameter's name and therefore organized into a list of lists. The sorting process considers the CSV file's format and the order needed for the Cypher Statement, essential in afterward data importation in NEO4J. In this work the creation of the graph database has been subdivided into many steps, corresponding distinct Cypher operation:

Starting with the creation of the nodes (Fig. 7, step 1), this process involves information from the project room. As a matter of fact, nodes contain necessary data in order to provide a *knowledge-based* database. Then, each project room's graph can be created by connecting the room identity's node with the feature ones (Fig. 7, step 2). Consequently, graphs of the project rooms are ready to be compared with the typological rooms ones.

However, in order to avoid useless cartesian products during the comparison process between nodes, which would lead to a consistent computational effort, a conditional matching method has been adopted (Fig. 7, step3). Even though all requirement-fulfilled relationships are wanted.

In synthesis, the adopted workflow can be described by the process diagram in Figure 8.

```
STEP 1:
CREATE (N: ' Node_Class ' { ID: ' Node_ID ', Name: ' Node_Name ',
Value: ' Node_Value ' });

STEP 2:
MATCH (x: ' Room_Identity ' ), (y: ' Room_Features ')
CREATE (x) - [: CAPACITY/ENDOWMENT ]-> (y);

STEP 3:
MATCH (a: ' a.Node_Name '), (b: ' b.Node_Name ') WHERE
' b.Node_Value ' = ' Condition ' CREATE (a) - [:SATISFY ]-> (b);
```

Figure 7
Cypher statements to create graph nodes and their relationships

RESULTS:

About the graphs structure:

The resulting graphs, both from typological rooms and project ones, are *bipartite* and endowed with the same length of the longest *simple path*. Furthermore, if the project's graph G can be matched with the graph of its "duck" D, the latter is *subgraph* and *isomorphic* to G.

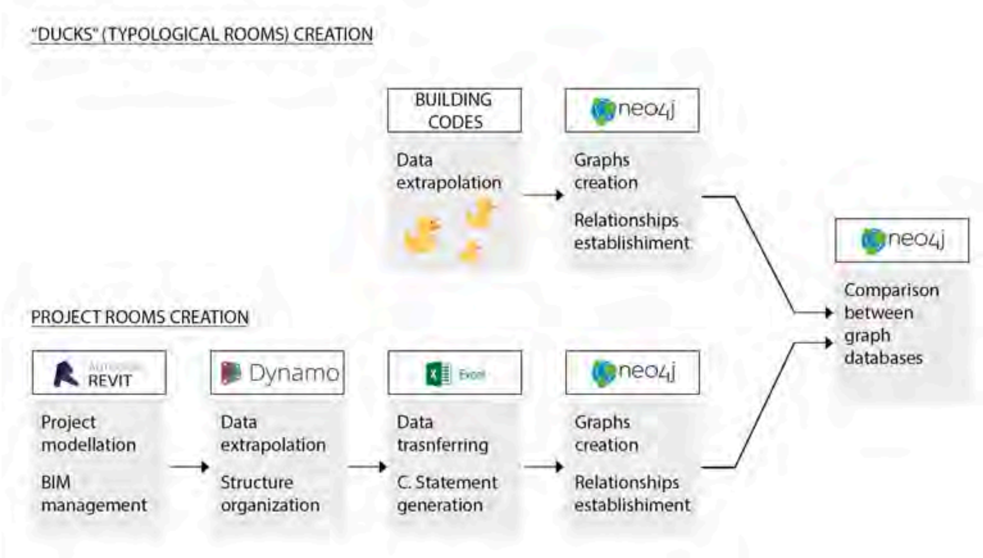
During the data extrapolation process from Dynamo of this work, no sorting process has been done except for the walls. Hence the degree of G corresponds to the number of elements exported from the project's model minus one, which is the vertex representing Family_Rooms. This is the reason why the degree of G is higher to D's, and there are unmatched vertexes within the G. These are furniture like tables, chairs and other furniture that don't contribute to the satisfaction of the Building Code, but are present in the project model.

About the comparison:

The graph representation offers a visual and immediate solution for the SIENA problem. As can be observed in the Figure 9, where a room's identity vertex of G is coloured with blue and the D ones are lighter blue, the satisfaction of the *duck test* can be easily verified. The dashed line distinguishes the G graph from the D ones and the correspondence between project nodes and the typological ones are highlighted by orange-color link. The result of this comparison can be exported through a matrix via CSV file and thereby analyzed in other software, including Dynamo. Thereby it is possible to establish a reverse data flow from the graph database, with the results from this process.

Moreover, the comparison process in the graph database allows the representation of relationships among all requirement-fulfilled vertexes. The evaluation of these similitudes, in space capabilities and device equipment, could provide the flexibility of the comparing room to change its functional destination in the future and thereby offer solutions for renovation, with least operations.

Figure 8
Workflow of the adopted SIENA approach



Hereafter there are been reported the result of the comparison process of the testers (Fig. 9). In particular, there are going to be discussed in detail.

Result of the tester 1: As can be observed, all requirements to be a bathroom have been satisfied, the P_Room1 is therefore a Bathroom, even though it could be a WC at the same time. This is because the graph of WC is the *subgraph* to the Bathroom's one. Moreover, it is endowed with more equipment rather than a WC like a Sink, a Bidet as well as a Bathtub. In particular, this element can fulfill the requirement of the Building Code which requires the endowment of a Bathtub *OR* a Shower in the bathroom (as mentioned in Fig 5). On the other hand, its surface area, as well as its windows area, doesn't satisfy all requirements to be a bedroom. As a matter of fact, the Building Code of Rome establishes that the minimum surface of the bedroom must be at least 9mq in case of single bed use and 14mq in case of 2 beds. At the same time, the area of the window of bedrooms, in order to provide a good air/light refurnishing, must be at least 1/8 of the room's surface. This means that the opening must be at least 1.125mq. In the case of the P_Room1 the room surface is about 5mq and its windows area is 1.05mq therefore does not fulfill the required standard for bedrooms.

Result of the tester 2: All requirements of a Kitchen have been satisfied, then P_Room2 is a Kitchen. On the other hand, the tester 2 differs from the bedroom because the ventilation and the lighting requirements needed for a bedroom's window are not satisfied (1/8 of the room's area) while it is endowed with many special equipments like Refrigerator, Chimney, Cooktop and Sink. Another interpretation of this result is that in case of functional changes, the P_Room2 can be transformed into a bedroom working only on the window's properties rather than other functions which would require more operations.

Result of the tester 3: P_Room3 satisfies all requirements for being both a single and double bedroom. These are *isomorphic* to each other. According to the Building Code, bedrooms have the same, but more restrictive requirements in case of a double bed use (area single bedroom must be at least 9 mq while area double bedroom must be minimum 14mq in order to provide enough breathable air for 2 people). It is also possible to observe, that the tester satisfies the capacity requirements to be a kitchen, but it is not equipped with the necessary devices (Endowment). This means that the P_Room3 can be potentially transformed into a Kitchen in case of a future renovation, as long as endowed with all necessary devices and therefore their system connections (gas, plumbing, water and so on).

DISCUSSION

This work has considered many typological models, obtaining its semantic definition by essential requirements from the *Building Code* of Rome. Nevertheless, there can be many additional functional and dimensional features to be take into consideration. For example, the accessibility of a room which absence compromises its functionality. The question here is that the entrance into a space can be achieved both from a vertical opening as well as thorough stairs or elevators. From an operative point of view, those elements should be considered within the same semantic class while so far they belong to different classes in Revit (they are called "Families"). On the other hand, the adopted area and volume requirements doesn't consider the proportions between dimensions which could affect the comfort of internal spaces. These particular cases require a deeper analysis of this approach.

Moreover, in order to focus on the final objectives of this research, and imagining what happens in the actual design process, this methodology has considered only terminal equipment (like cooktop, sink, chimney) but not the actual ducts and/or plugs (like gas connection, water supply and draining, chimney pipe). This feature could be solved only in a very detailed model creation which is rare in a common design process, especially during its very first stages. Nevertheless, it could be inquired in the future progress of this approach in order to improve knowledge-based spatial recognition processes.

FUTURE DEVELOPMENTS

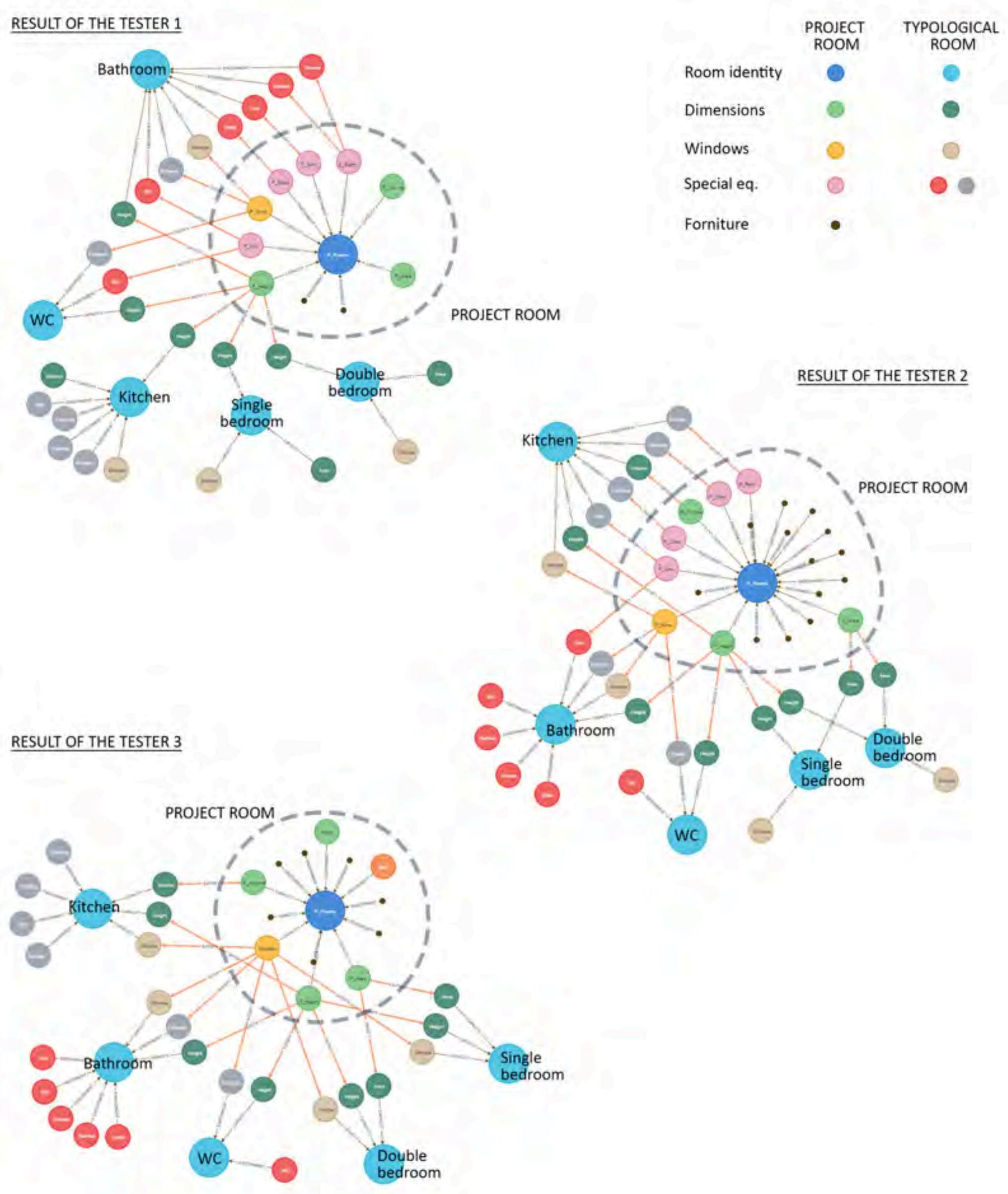
For instance, this research could be extended from "space identity" to "building identity", which means an upper hierarchy of organization. It is possible therefore, changing the scale of the graph database, to define the semantic meaning of entire buildings. The emerging challenge represents the establishment of the relationships between spaces which is vital for the correct performance of activities.

Moreover, the referencing "ducks", which in this work belong to the *Building Code* of the city of Rome, can be any other technical standards like hygiene requirements of special facilities in hospitals or building's fire prevention and protection regulations as well as building programme with stakeholders' needs. Thereby, it is possible to automatically evaluate the conformity of a design to the required standards.

As mentioned during the results' discussion, another potential application of the SIENA approach is finding out similar functions in the case of renovation and functional conversion process. The similitudes analysis could provide valid design support pointing out those functions achievable with minimum operations and therefore most affordable ones. As result, the proposed approach could bring to time and energy, therefore cost saving, during the design process for the restoration of an existing room.

On the other hand, further development of this work is its reversed side. The idea is to take advantage of the synthesized semantical features of spaces which can be defined by designer's creativity as well as through technical requirements (dimensional, functional, structural, fire prevention and so on), and import them into the project. Consequently, the resulting design is naturally endowed with semantic meanings and it can satisfy *a priori* all necessary requirements. This achievement can provide valid design support in answer to the intertwisted technical requirements and allow the management of complexities in modern projects.

Figure 9
Result from the comparison



CONCLUSION

The SIENA approach based on the "duck test", could represent an innovative tool to support design, especially in the very initial stages of the design process. Through this strategy, the spatial identity can be established by its semantic attributions taking into consideration its dimensional capabilities and device endowment. Therefore the SIENA approach can configure, in the meanwhile, as a useful checklist of technical requirements as well as design purposes. Eventually, human designers may be relieved to verify the compliance of their project with the building standards, and therefore focus on more creative activities.

The proposing strategy aims to the automatised and objective mode of the spatial recognition which could provide remarkable improvements in further human-machine interactions. As a matter of fact, establishing the semantic meanings of spaces could be the further step of KAAD, Knowledge-based Assistant for Architectural Design.

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