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A common-sense based system for Geo-IoT

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Abstract

This paper presents an architecture for smart buildings based on common-sense reasoning using the IndoorGML standard. The main objective is the construction of a knowledge model that allows inferring information that is not explicitly defined in that model. The main challenges addressed are: 1) the modeling of the concepts presented by the standard in the knowledge base used, known as Scone; 2) the automation of the introduction of knowledge in Scone with the proposed model; and 3) the implementation of a service-oriented architecture that makes possible to introduce knowledge in a transparent way. The semantic knowledge we present here, which shows more advanced and flexible capabilities, will make it possible in the future to carry out reasonings that not only depend on the structure of a building, but on many other aspects of the IoT such as sensors or actuators that are difficult to contemplate if a common sense approach is not followed.

Keywords: Common sense; Smart building; Indoor spatial data models; OGC IndoorGML; Mapping; Modelling; IoT; Geo-IoT; Multi-Sensor Information System.

1. Introduction

The deployment of interconnected devices that is currently taking place in buildings is turning into a reality the envisioned paradigm of Smart Buildings. This paradigm is intended to maximize technical performance, operating cost savings and tenant comfort in the building among other aspects [9]. To this end, this approach relies on an Internet of Things (IoT) complex system in charge of monitoring and controlling multiple spaces, tenants, human-machine interfaces, distributed systems and sensors.

With the emerging and continuing advances in Ambient Intelligent systems, the location-based services (LBS) are gaining attention. Different location techniques have been proposed to support context-aware services to exploit

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contextual dimensions such as user-centered dimensions, environmental context and temporal context. Examples of such services include, but are not limited to, human wayfinding and navigation in built environments, evacuation routes for people stuck in a building in case of an emergency [5], and real-time collaborative activities [1].

Geospatial IoT (Geo-IoT) technology has been proposed to support the acquisition, storage management, analysis and visualisation of data generated in IoT environments. However, most approaches lack mechanisms for incorporating context dimensions into the query processing as well as dynamic spatial models that provide appropriate services to users acting in the environment.

In this paper we propose a common-sense reasoning system for modelling buildings using semantic relationships and context management. Among the main contributions of this paper are the transfer of the principles proposed by the IndoorGML standard to a common-sense knowledge base, obtaining as a result a knowledge model that supports the aforementioned reasoning techniques; the automation of the acquisition of knowledge in a knowledge base such as Scone with the proposed model; and a service-oriented architecture that supports the process of acquiring and consulting new knowledge.

This paper will be organized as follows. First, the State of the art and Background section reviews the main standards, works and Geo-IoT commercial solutions oriented to the design, management and modeling of indoor spaces, paying special attention to those that enable context-aware processes. There is also a brief introduction of the standard that will be taken as reference in this paper and the knowledge base that has been used to achieve the proposed objectives. The next section describes the knowledge model that we present and the proposed architecture for the automatic acquisition of knowledge of indoor spaces. The Evaluation section describes a small example that helps to strengthen and evaluate the bases of the proposed model. It also describes the process followed for the mapping of a real building in order to validate the proposed architecture. Finally, the Conclusions and Future Work section summarizes the main ideas withdrawn from this work.

2. State of the art and Background

The current state of the art in the design of spatial environments mostly focuses on supporting the specification of physical layouts and structural elements using Building Information Modeling (BIM) technology. Works as [31] identified the need for providing static and dynamic semantics for BIM through modeling formalism that captures the topology of cyberphysical space in order to enable automated analysis on a variety of properties such as safety, reliability or security.

Industry Foundation Classes (IFC) [20] and City Geography Markup Language (CityGML) [16] standards have emerged as a neutrals, non-proprietary or open standard for sharing BIM data. However, these standards are more oriented to model and represent geometrical and structural features than to capture the semantics of the elements and entities that make up a building [13]. It is in this point where the work presented at [1] introduces the preliminary requirements for the development of indoor spatial models for enabling LBS through context-aware system perspective. Following this approach, the integration of an indoor spatial model into a context-aware system implies a consideration of the environment as a dynamic system that should represent: 1) the features that populate the environment: a feature can refer to either a person or an object of interest; 2) their spatial properties (i.e., locations of the objects of interest and the spatial relationships that relate them) and; 3) the actions that emerge from them (i.e., physical interactions and communications).

A wide range of location-aware services can be applied to indoor environments but the most commonly services provided by software vendors are focused to indoor mapping and wayfinding for Smart Buildings. Some of the most well-known platforms as Mapwize [27], Indoorway [12] or MapsIndoors [23] are focus in modeling and representing geometrically the building structure with the purpose of provide a indoor navigation service only employing location as context parameter.

There are some works as [32] [10] [30] that expose different architectures and techniques with which determining the location of the people using a devices/sensor network. But what is really interesting is taking advantage of context-aware information sources for adapting services accordingly to people preferences and contextual information. Works as [22] [2] [34] [9] address indoor navigation services taking into consideration dynamic properties and interactions of moving objects with their physical surroundings trough the use of ontology-based models and context-aware systems.

On the commercial side the application of that systems has been evolved through Geo-IoT platforms as GISinc [29] or Ubisense [33] but, as it was already stated in the introduction, this platforms are more centered in the acquisition, storage management, analysis and visualization of data generated in IoT environments than in enabling context-aware processes.

It soon becomes evident that most of the research and commercial platforms are limited, in the best case, to support context-aware indoor services for a specific task as the navigation and wayfinding problem. However, a new approach is required that not only support 3D geometric modeling of environments and buildings, but also capable of describing how the environment evolves, based on the interaction of the entities that are in it and to enable more sophisticated reasoning processes. Another major shortcoming shown by the mentioned proposals is the lack of semantics. In [14] [3] [4] the consequences and problems for this lack are analyzed in such heterogeneous environments as the IoT. However, it is also important to note that semantics are not enough by themself, since it is necessary to have approximations that allow to extract knowledge and make inferences that are not explicitly described or codified by the developers, characteristic that the existing approaches also lack.

2.1. IndoorGML

Some of the most popular standards for modeling 3D building geometry are IFC [20], KML (Keyhole Markup Language) [26] and CityGML [16]. However, these standards are more oriented to model and represent geometrical and structural features overlooking the semantics of the elements and entities that comprise the building and that go beyond the typical structural elements. These concepts and semantic relationships can be very varied, for example from relations of connectivity or accessibility between rooms, to relationships that allow modeling more complex relations such as the coverage of a certain set of sensors or the navigability within the building.

As the knowledge pursued in this work goes beyond the purely geometric, we decided to use IndoorGML [19], which is a more flexible standard that would support more advanced semantic relationships such as the ones discussed above. As specified in the definition of the standard, IndoorGML propose "*a data model and XML schema for indoor spatial information which aims to provide a common framework of representation and exchange of indoor spatial information*". The standard proposes to model the space as cellular spaces, that is, a set of cells which are defined as the smallest organizational structural unit of indoor space. Each of these cells can represent different types of spaces such as stairwells or elevators and are characterized by not overlapping other cells and having common boundaries and a unique identifier. Thus, a cellular space S is defined as follows:

$$S = c_1, c_2, c_3, ..., c_n \tag{1}$$

where c_i is the c^{th} cell [19].

One of the main advantages of IndoorGML is that it is not necessary to explicitly express the relationships between the different spaces that make up the building. It allows to represent topological relationships, e.g., adjacency and connectivity, among the different indoor entities through the Node-Relation Graph (NRG). In this way, NRG allows abstracting, simplifying, and representing topological relationships among 3D spaces in indoor environments, such as rooms within a building [17]. Other of the main advantages of using IndoorGML as a data model is that it allows to represent the same space from different semantic points of view through the mechanism of Multi-Layered Representation. In this Multi-Layered Representation each semantic interpretation layer results in a different decomposition of the same indoor space, where each decomposition forms a separate layer of cellular space. This way of representing the different entities, relationships and their semantics will establish the basis for a modeling of knowledge that makes possible the common sense reasoning about the structure of a building.

2.2. Scone

The common sense knowledge automation is a task that requires a sufficiently expressive language, a knowledge base that allows to store large amounts of knowledge and a set of mechanisms that are able to manipulate this knowledge, as well as to infer new information from it. Taking into account these characteristics, some of the most successful approaches found in the literature are Cyc [18], ConceptNet [21], Scone [6] and WordNet [24]. However, to support the work proposed in this article, the chosen alternative must cover three basic needs: mechanisms that support inconsistent information in the knowledge base, a higher order logic language and an effective and efficient management of resources. An analysis of common-sense reasoning systems are out of the scope of this paper but Scone cover all the needs mentioned before.

Scone is an open source knowledge base written in Common Lisp language developed at Carnegie Mellon University by Scott E. Fahlman [6]. It is important to note that one of the main differences with respect to the aforementioned approaches reside in the mechanisms that it integrates to carry out the search and inference processes. Thus, Scone adopts a marker step algorithm [8] originally devised to be executed on a NETL machine [7]. Although these types of algorithms can not be compared with the general theorems, they have very interesting characteristics such as their speed and the support to most of the inference operations that are involved in the reasoning common sense: inheritance of properties, roles, relationships in a hierarchy of multiple inheritance types, default reasoning with exceptions, detection of type violations, search based on the intersection of sets, maintenance of several points of view simultaneously in the same knowledge base, etc.

3. Spatial reasoning with common sense

3.1. Mapping IndoorGML concepts to Scone

The main objective of this approach is to combine the power and advantages offered by a three-dimensional space management approach, such as that proposed by the IndoorGML standard, with the possibilities and flexibility of knowledge-based techniques based on common sense. For this reason, the first step in our work was to study how we could apply the IndoorGML standard to achieve this goal. In this way, it is important to highlight that all the knowledge presented in this subsection has been manually identified and codified, obtaining as a result the knowledge model that serves as basis for the process of automatic knowledge collection through the architecture proposed in this work.

The first step to introduce the model of a building based on the standard IndoorGML in the knowledge base was to identify and model the necessary entities, together with their roles and their relationships. As already mentioned in Section 2.1, IndoorGML is composed of five key elements: cells, boundaries, states, transitions and the NRG graph. In the first lines of the next listing (Fig. 1) we show how the key elements of IndoorGML mentioned above are modeled in Scone: {`CellSpace`}, {`CellSpaceBuundary`}, {`StateSpace`} and {`TransitionSpace`}. Immediately afterwards with the sentence `new-split` it is indicated that an IndoorGML entity can only belong to one of these four categories. Finally some of the different properties of these entities are modeled, such as ({`id`}, {`duality`} and {`usage`}) as well as some of the different types of uses that a cell can have ({`Room`} and {`Door`}).

```
(new-type {indoorGML entity} {intangible})
(new-type {CellSpace} {indoorGML entity})
(new-type {CellSpaceBoundary} {indoorGML
    ↪ entity})
(new-type {StateSpace} {indoorGML entity})
(new-type {TransitionSpace} {indoorGML entity
    ↪ })
(new-split
  '({CellSpace}
    {CellSpaceBoundary}
    {StateSpace}
    {TransitionSpace}))
(new-type {id} {intangible})
(new-type {duality} {intangible})
(new-type {usage} {intangible})
(new-type {Room} {usage})
(new-type {Door} {usage})
```

Fig. 1. Defining the key elements of IndoorGML and some of its properties in the base knowledge model.

Although in the proposed model the number of properties has been limited to those presented by the IndoorGML standard, Scone allows defining and specializing these attributes in the way that is necessary. This ability to specialize the concepts together with the powerful inheritance mechanisms provided by Scone offers important benefits in terms of scalability and flexibility. This will allow describing indoor spaces with any type of characteristics, even if these have not been previously defined in the model. The next listing (Fig. 2) shows an example of how to perform this process, specializing each one of the attributes defined in the previous listing. For example, in the first line it is indicated that the concept {`CellSpace id`} inherits the properties of the concept {`id`} and its owner will be the entity {`CellSpace`}. As you can see in that listing, in the following lines this specialization process is repeated for the concepts {`CellSpaceBoundary Geometry`}, {`StateSpace name`} and {`TransitionSpace weight`}. At the end are defined the geometrical entities that will allow to describe the geometry of the cells of the building that will be modeled. The most complex of them is the entity {`Point`} that will have three roles associated to represent the different coordinates that make up a three-dimensional geometric point.

```
(new-type-role {CellSpace id} {CellSpace} {id })
(new-type-role {CellSpaceBoundary Geometry} {CellSpaceBoundary} {Geometry})
(new-type-role {StateSpace name} {StateSpace} {name})
(new-type-role {TransitionSpace weight} {TransitionSpace} {weight})
(new-type-role {Surface} {Geometry} {thing})
(new-type {Point} {thing})
(new-type {coordinate} {thing})
(new-type-role {x-coordinate} {Point} {coordinate})
(new-type-role {y-coordinate} {Point} {coordinate})
(new-type-role {z-coordinate} {Point} {coordinate})
```

Fig. 2. Definition and specialization of some IndoorGML attributes in the base knowledge model.

The next step was to define in the knowledge model the different relationships that establish the way in which different entities of IndoorGML interact, which can be seen in the next listing (Fig. 3). On the one hand, the relationship {`is in`} attempts to capture the knowledge implicit in the relationship between a point and a surface to which that point belongs. The relation {`dual`} models the concept of Poincaré duality [25] and that, as established in the standard IndoorGML, provides a theoretical background for mapping indoor space to NRG representing topological relationships. As can be seen, the types of the instances that can take part in this relationship have been left open, stating that both should be of type {`indoorGML entity`}. This flexibility provided by inheritance and supertypes will allow to cover the different combinations of duality that are contemplated in the standard: cell-state, boundary-transition, etc. On the other hand, the relation {`is-bounded-by`} allows to model that a cell ({`CellSpace`} is surrounded by a certain boundary ({`CellSpaceBoundary`}). Finally, with the relation {`connected`} it is possible to model change from one state to another through the transition that connects them.

```
(new-relation {is in}
  :a-inst-of {Point}
  :b-inst-of {Surface})
(new-relation {dual}
  :a-inst-of {indoorGML entity}
  :b-inst-of {indoorGML entity}
  :transitive t)
(new-relation {is-bounded-by}
  :a-inst-of {CellSpace}
  :b-inst-of {CellSpaceBoundary})
(new-relation {connected}
  :a-inst-of {StateSpace}
  :b-inst-of {StateSpace}
  :c-inst-of {TransitionSpace}
  :transitive t)
```

Fig. 3. Definition of the relationships between the different types of IndoorGML entities in the base knowledge model.

To conclude, it remains to represent in the knowledge base one of the most powerful aspects of those introduced by the standard IndoorGML: the Multi-Layered Space Model (MLSM). According to IndoorGML, the MLSM provides an approach for combining multiple space structures for different interpretations and decomposition layers to support full indoor information services. This will allow us to have different interpretations of the same interior space depending on the requirements of the application. This results in different decompositions of a same indoor space, and each decomposition results in a specific NRG.

To introduce this concept proposed by the standard on the Scone's knowledge base we have used the paradigm of multiple contexts. A context is seen in Scone as a node in the knowledge base that represents a different world model within the general knowledge base. Within the Scone system there may be many contexts in which most of the knowledge will be common, but each of them having a specific part. It is important to highlight that knowledge inheritance is handled efficiently by the marker-passing algorithms presented by Scone. With the paradigm of multiple contexts, existing knowledge adapts similar situations, activating a different context each time to avoid inconsistencies. Scone, through the paradigm of multiple contexts, takes into account the situations that a priori may be considered inconsistent with each other, but since there will only be one active context at each moment this will not be a problem. In this way one of the most important restrictions established by the standard is handled, and that is that each cell may have a common boundary with other cells but does not overlap with any other cell. This allows that different cells can be defined for the same indoor space in separate contexts and that they represent distinct aspects such as topology or sensor coverage.

This can be easily understood with the example shown in Fig. 4, where different cells have been defined for the same space representing different layers of information: topology, camcorder coverage and Radio Frequency Identification (RFID) transmitters coverage. Thus, cells `R1` and `R2` represent the topology and geometry of the building, cells `V1` and `V2` the coverage of the surveillance camcorders and cells `C1` and `C2` coverage of RFID transmitters. Thanks to the semantic expressiveness that Scone offers, the example presented here can be extended to any type of information layer. It is very important to emphasize that this approach provides extremely useful tools to describe environments characterized by their enormous heterogeneity such as the IoT and where everything is closely related (sensors, actuators, people, architecture of buildings, etc.). An example to understand the advantages implied by this approach would be to consider an IoT scenario where it is required to infer new knowledge resulting from combining information from different types of sensors. It could be necessary to study the real vision field of a video camera taking into account the obstruction of the walls, or even the combination of the signal strength of several sensors such as Wi-Fi and RFID to, for example, calculate an approximate position of a person when there are no specific sensors deployed.

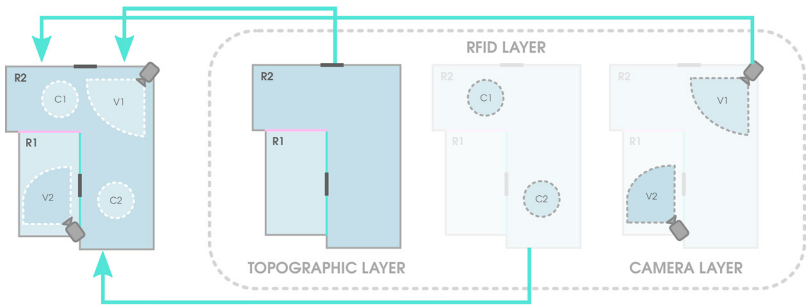

Fig. 4. Example of topology, camcorder coverage, and RFID coverage layer of the same building.

The following listing (Fig. 5) shows how this process that has just been described would be carried out for the example above. In the first line the new context {`topology layer`} is created, which inherits all the contents of the context {`general`} and contains the general knowledge of the model. Then the same process is followed with the {`Camcorder coverage layer`} and {`RFID coverage layer`}. In the fourth line it is indicated to Scone that from that moment all the queries and the new knowledge that is introduced will be done in the context that represents the topology layer, such as creating the cell {`R1`} in the line 5. After that, we move to the context {`Camcorder coverage layer`} and {`RFID coverage layer`} so that we could proceed to introduce information about the coverage of the sensors that is being modeled and query about them.

```
1 (new-context {topology layer} {general})
2 (new-context {Camcorder coverage layer} {
     ↪ general})
3 (new-context {RFID coverage layer} {general})
4 (in-context {topology layer})
5 (new-indv {R1} {CellSpace})
6 (in-context {Camcorder coverage layer})
7 (new-indv {V1} {CellSpace})
8 (in-context {RFID coverage layer})
9 (new-indv {C1} {CellSpace})
```

Fig. 5. Example of how to define different layers in Scone.

3.2. Proposed architecture

The proposed architecture is completely service-oriented and it uses, at the middleware layer, a general-purpose object-oriented middleware as it is ZeroC Ice [11]. ZeroC Ice is a remote-procedure-call-based middleware developed by the company ZeroC. The interfaces of any service developed in ZeroC Ice have to be defined in the interface definition language, known as slice. After the slice definition, the developer can generate bindings for different languages. Inter-operation among clients and servers is supported independently of the underlying language or the platform, thanks to the Ice protocol (IceP).

In Fig. 6 a general scheme of the architecture proposed in the present work is shown. It consists of a total of two services, `UrbanModelService` and `parserurbanModel-to-scone`, which will be described in more detail during the next paragraphs.

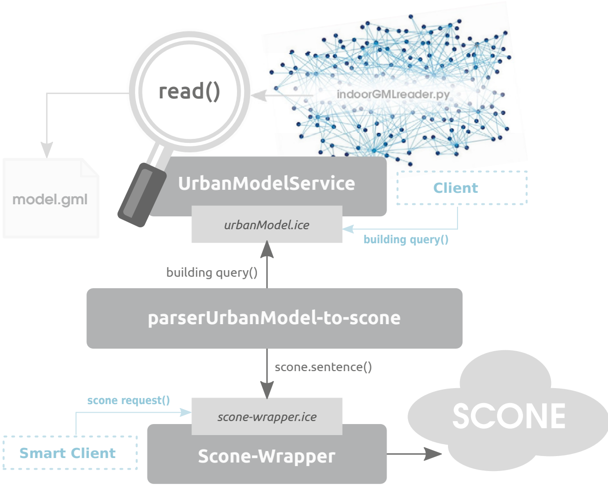

Fig. 6. Scheme of the proposed architecture.

The service `UrbanModelService` is oriented so that it provides basic information about the model of a given building to other services. One of the main advantages of this approach is that it eliminates the need for those who require information about a particular building to know in depth how the IndoorGML standard works or how to read and process an XML file. To this end, an interface has been designed to communicate with this service and make the necessary queries. The resulting interface `TopologyLayer` is shown in the following listing (Fig. 7). Although only the interface of the topology is shown in this example, it is important to mention that this interface can be directly extended to any other type of information layer: Wi-Fi coverage, range of vision of surveillance cameras, or what is the same, to any type of information related to IoT that wants to be represented.

```
interface TopologyLayer{
  bool isConnectedCell(string referenceCellID, string cellToCheqID);
  bool isAdjacentCell(string referenceCellID, string cellToCheqID);

  CellSequenceID getConnectedCells(string referenceCellID);
  CellSequenceID getAdjacentCells(string referenceCellID);
  CellSequence getCells();
  CellSpaceBoundarySequence getCellSpaceBoundarys();

  StateSequence getStates();
  TransitionSequence getTransitions();

  string getCellofPosition(position3D position);
  string getUsage(string referenceCellID);
  string getName(string referenceCellID);
  float getHeight(string referenceCellID);

  SurfaceSequenceID getExits(string referenceCellID);
  BoundarySequenceID getEntrances();
};
```

Fig. 7. `TopologyLayer` interface of the `UrbanModelService` service.

Through this interface, any service can make queries that range from direct consults of the type "What are the cells adjacent to cell X?" whose answers can be directly extracted from the model, to more elaborate questions of the type "To which cell does the position with coordinates (x, y, z) belong to?" based on searches in auxiliary structures (graphs, kd-tree, etc). Besides being able to make the model available to other services, this service has another main objective: to serve as a reference to be able to validate the advantages offered by having the model in a knowledge base based on common sense.

On the other hand, there is the service `parserurbanModel-to-scone`. The main objective of this service is the introduction of the entire model in the Scone's knowledge base. For this purpose, through the interface described above, different queries are carried out to recover all the necessary information about the model. At the same time, making use of the mechanisms provided by Scone and the entities that have been previously modeled at the beginning of the section (see 3.1) the information provided by the `UrbanModelService` service is transformed into richer and more flexible knowledge so that it can be processed to extract inherent information through the methods of inference provided by Scone.

4. Evaluation

For the evaluation of the knowledge model resulting from mapping the concepts of the IndoorGML standard to Scone's knowledge base, a small example is proposed in first place. In this example we try to model the architecture of a small single-floor building composed of two rooms connected through a door, where one of them is connected to the outside through another door. Fig. 8 illustrates the topology of the proposed example. As you can see, the example model tries to represent the topology of a small building. Both rooms are represented with two cells, named as `R1` and `R2`, and they also have associated their corresponding states `S1` and `S2` respectively according to the established in Poincaré duality. Both states are connected through the transition `T1`, which is the dual representation of the `D1` gate. Finally, you can also see how both rooms share three boundaries: `D1`, `CB11` and `CB12`.

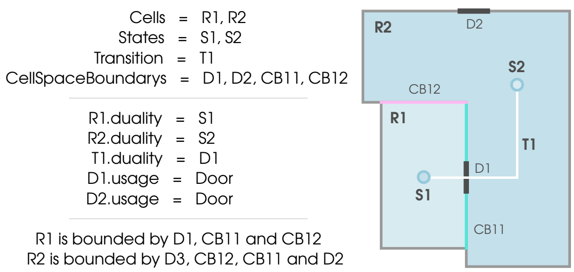

Fig. 8. Example of small building.

The following listing (Fig. 9) presents a summary of the knowledge automatically generated from the example just introduced. As it can be seen, the first necessary step is to create a new context in which all the knowledge related to the topology layer of the modeled building will be introduced. After indicating in the second line that a change of context is made to {`topology layer`}, we proceed to introduce the corresponding cell {`R1`} and its {`id`} into the knowledge base. In the fifth line, through the role association mechanism provided by Scone, the fact that the individual {`R1-id`} is a {`CellSpace id`} of the cell {`R1`} is said. After creating the entities {`R2`} and {`D1`}, the next step is to define the concept {`Door`} as a new type of {`usage`} on line 8 and indicate that this is the use of {`D1`} on line 9. The next step is to define the states {`S1`} and {`S2`} on lines 10 and 11. Next, through the relation {`dual`} it is defined in the knowledge base that the states {`S1`} and {`S2`} are the dual correspondence of the cells {`R1`} and {`R2`}, respectively. The transition {`T1`} defines its duality, the {`D1`} door, and it is established by the relation {`connected`} that the state {`S1`} is connected to the state {`S2`} through the transition {`T1`}, or what is the same, that the cells {`R1`} and {`R2`} are connected through the door {`D1`}.

In addition to this small example, the mapping of a real building through the proposed architecture was carried out. This would allow demonstrating the real advantages of carrying out an automatic process in which all the implicit knowledge is carried in a model according to the IndoorGML standard to the Scone knowledge base. For this we decided to model the Institute of Information Technology and Systems of Ciudad Real (Spain) to have a base model to start experimenting. To do this, the tools JInedit [28] and InfoorGML-Viewer [15] of the Spatio-Temporal Databases Laboratory (STEAMLab) were used to edit and visualize our model, respectively. In Fig. 10 the result obtained from this process is shown.

```
(new-context {topology layer} {general})
(in-context {topology layer})
(new-indv {R1} {CellSpace})
(new-indv {R1-id} {id})
(x-is-the-y-of-z {R1-id} {CellSpace id} {R1})
(new-indv {R2} {CellSpace})
(new-indv {D1} {CellSpaceBoundary})
(new-type {Door} {usage})
(x-is-the-y-of-z {Door} {CellSpaceBoundary usage} {D1})
(new-indv {S1} {StateSpace})
(new-indv {S2} {StateSpace})
(new-statement {S1} {dual} {R1})
(new-statement {S2} {dual} {R2})
(new-indv {T1} {TransitionSpace})
(new-statement {T1} {dual} {D1})
(new-statement {S1} {connected} {S2} :c {T1})
```

Fig. 9. Scone code of the example of the small building.

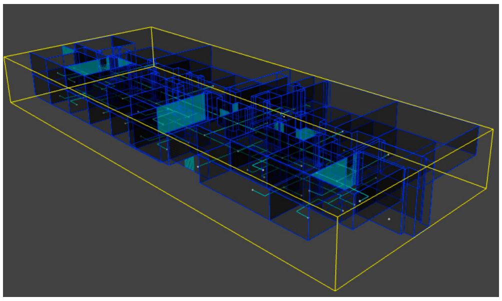

Fig. 10. IndooGML model of the Institute of Information Technology and Systems of Ciudad Real (Spain).

5. Conclusions and Future Work

This work presents a common-sense knowledge model for spatial reasoning. This model captures both the topological information of an indoor space, using to this end the IndoorGML standard, and the semantics implicit in topological relations. This model therefore poses the basis for more advanced inference in which spatio-temporal reasoning mechanisms are to be supported. For example, if a camera needs more lighting in order to properly record and there is a lamp nearby, the topology and geometry of the building should be used to decide if the camera will receive enough light when you turn on that lamp. If, despite being close to each other, there is a wall between the two, turning on the lamp will be useless. However, if the wall is made of glass, it would work. This is the type of reasoning our model uphold. This differs greatly from how other approaches face the same challenge, closely coupled to data structure used to represent the knowledge (graphs, trees or other similar structures). This mainly limit the type of search and inferences that can be carried out. Our approach, for being more flexible and general based on how information is modeled, can support advanced reasoning mechanisms (default reasoning with exceptions, intersections, multiple contexts, etc.)

Finally, we also propose a system for automating the process of asserting topological information into the knowledge base. Any building described according to the IndoorGML standard can be automatically input into the knowledge base.

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