A Space in a Space: Connecting Indoor and Outdoor Geography

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Abstract

Spatial phenomena can be encountered in outdoor and indoor geography-related contexts: The description and analysis of indoor environments is an important factor as research on indoor geography has recently gained a certain momentum. To imbue a clear understanding of indoor space, its definition is a crucial issue as the concept of indoor geography is heavily context-based. Therefore, ontologies have the capability to describe such a context-specific indoor space in a semantic manner. It is the aim of this work to analyse the occurrence and the accessibility of different indoor spaces and their connection to the outdoor space. Therefore the paper highlights the possible connections between indoor and indoor space and the connections between outdoor and indoor space. Specific attention is paid to indoor space connections and the fact that indoor spaces can be separated from each other. The analysis will result in models highlighting the connectivity of a common outdoor space and indoor space where the indoor space is connected to another "nested" indoor space not accessible from outdoors. The consistent definition of the connection between different spaces is a basis for navigation or visualization applications in indoor production environments.
Keywords: Indoor Geography, Indoor Space, Ontology, Indoor Production Environment

1 Introduction

Recent years showed higher efforts in research dedicated to outdoor geography than to indoor geography. This is due to the fact that outdoor geography already possesses a high level of structured methods and applications. However, indoor geography-related research is attaining more attention during recent years, as an average person spends almost the entire day inside of buildings [1, 2]. Additionally, the overall size of buildings is increasing, comprising their complexity as well, which in return raises the need for indoor location-based services [3]. Buildings can feature a varying degree of complexity, different sizes, and fulfill different functionalities. Indoor geography-related research has the high potential to evolve transport simulations, the analysis of indoor geography, and its utilisation regarding navigation purposes. The availability of ubiquitous positioning systems such as the global positioning system (GPS) and aerial imagery in the outdoor geography is highlighted by Worboys [1]. Due to the emerging interest of indoor geography-related research also location-based services and applications make the step from outdoor to indoor.

Indoor geography-related research depends on the application domain as well. One possible application domain can be found in indoor navigation within complex buildings. For instance, indoor spatial modelling can be of high potential for indoor production environments. Scholz & Schabus [4] developed an indoor navigation ontology for indoor production environments, including arising navigational tasks. This ontology describes how indoor geography can be applied to a manufacturing site and sets a proper basis for spatial analysis in an indoor environment. Jonietz and Timpf [5] describe an approach where affordances of spatial artefacts are used for routing, which can be used as an alternative approach for spatial analysis and navigation.

Schabus et al. [6] carried out a spatial-temporal analysis by assessing historical data recorded during production processes in an indoor production environment. They employed self-organizing maps (SOMs) in combination with a conceptual modelling approach of movements of production assets. SOMs are one type of artificial neural network algorithms that supports automatic data analysis while providing a visual exploration [7], which is achieved by dimensionality reduction and clustering [8].

In general, ontologies are a powerful methodology to understand complex behavior as it provides a simplified representation [9]. Ontologies have the ability to be a domain or application-specific symbol to represent knowledge throughout different groups and scientific fields [10].

The paper at hand discusses the connection of different indoor geographies under consideration of related outdoor geographical aspects. In particular, indoor spaces are analysed by the example of an indoor geography of a production environment with special peculiarities and affordances.

The remainder of the paper is organised as follows: Section 2 elaborates on a possible characterisation of indoor space including an indoor production environment followed by an indoor navigation ontology and a comparison of outdoor-/ indoor geography. Section 3 focuses on the modelling of possible connections between indoor-/indoor spaces and indoor-/outdoor spaces. Finally, section 4 closes with a conclusion and an outlook regarding potential research directions.

2 Characterisation of Indoor Spaces

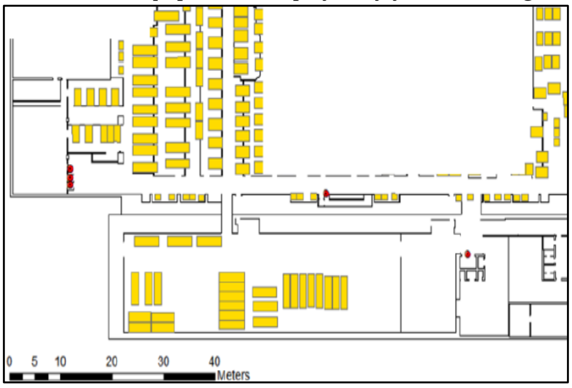
The proper characterisation of indoor space is essential for an accurate modelling and understanding of indoor space. However, the modelling of indoor structures is not straight forward as it is strongly intertwined with the associated application field of the building itself [11, 12]. To give an example of the complexity at hand, Section 2.1 discusses the arising challenges of an indoor production environment. Afterwards, Section 2.2 discusses the concept of nodes used for the transfer between and access of indoor spaces.

2.1 Indoor Production Environments

An indoor production environment is a challenging indoor space due to its high complexity. One example of a production line is represented by a semi-conductor fab. This indoor production environment features a high variability of production assets with different degrees of completion present at the same point in time. Additionally, the processing time of production assets varies from several days to a couple of weeks and each production asset requires a high number of production steps from beginning until the end. Each production step may necessitate capacity of several pieces of equipment, which can be geographically distributed over the entire indoor production environment [4]. Additionally, aspects of cognition of indoor spaces and indoor landmarks have to be taken into account [13]. This circumstance is specifically challenging, as indoor production environment landmarks are difficult to define due to their changing characteristics over time.

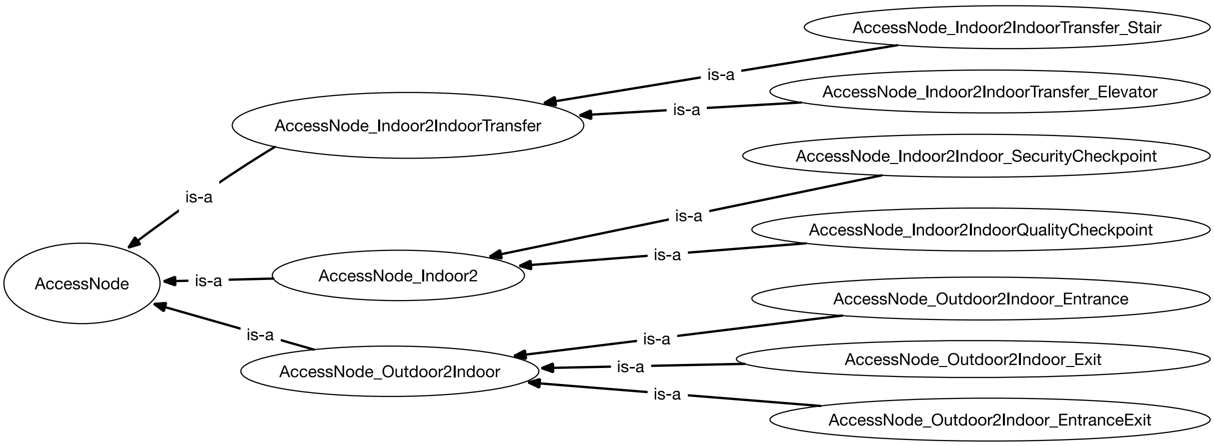
which have to be transported. Figure 1 shows such an indoor environment.

Figure 1: Layout of the Indoor space of production environment - equipment is displayed by yellow rectangles.



The layout of a production hall is different than classical production environments, due to the cleanroom conditions and restrictions. Furthermore, it differs from public office buildings or residential buildings as, e.g. rooms are hardly present. Fig. 1 depicts an extract of such an indoor production environment, which is separated into long corridors with fairly distributed equipment, which can be identified by yellow polygons.

Figure 2: *AccessNode* example of how to access or transfer between spaces indoors and outdoors [4].



One way to tackle these issues is found within graph-based methods. This approach enables an affordance-based navigation similar to Jonietz & Timpf [5], as nodes could serve as bridge between indoor spaces and outdoor space.

Due to personal experience, the work of Geng [14] and Osswald et al. [15] it can be stated that the production of microchips is a complex process chain, which has to be carried out under special cleanroom restrictions. As cleanroom space is expensive to construct and maintain, production halls cannot be extended too easy. Hence, cleanroom space is a limited property. To justify the complex production process, production assets move several kilometres within the indoor environment, while the movement exhibits a multi-faceted structure due to different microchip types,

2.2 Nodes as a Way to Access Indoor Space

As mentioned in Section 2.1, graph-based methods are a promising way to model indoor space and to manage transfers between spaces in general. Such an approach is applied by Scholz & Schabus [4] as they employed a so-called *AccessNode* to represent either transfer between building levels, indoor spaces, or even between outdoor and indoor spaces and vice versa. Figure 2 represents the corresponding class hierarchy associated to the *AccessNode*.

Basically, the class *AccessNode* is split into three sub-classes, namely "Outdoor2Indoor", "Indoor2IndoorTransfer", and "Indoor2Indoor". The detail description is as follows [4]:

- "AccessNode_Indoor2IndoorTransfer" represents the connection within the same indoor space, thus it is connecting for instance different building levels. The sub-classes are "Elevator" and "Stair", whereas the transport over a stair is used for the transfer between different building levels in the same indoor space with special restrictions. These restrictions have to be defined, as it is dangerous to transport valuable production assets over a stair. In order to change the building level with a production asset the elevator has to be considered including a time constraint.
- "AccessNode_Indoor2Indoor" enables a transfer between different indoor spaces. The sub-classes are Quality-Checkpoint and Security-Checkpoint". A quality check can be an example for an air lock, as in a semiconductor production environment special air conditions have to be considered. The security checkpoint highlights access restrictions.
- "AccessNode_Outdoor2Indoor" represents the connection from outdoor geography into the indoor environment. Therefore, the subclasses "Entrance", "Exit" and "EntranceExit" are necessary. The "Entrance" sub-class enables the movement from outdoor into the indoor space. The "Exit" defines designated doors for leaving a production environment such as a cleanroom. The "EntranceExit" both ways from outdoor to indoor and vice versa.

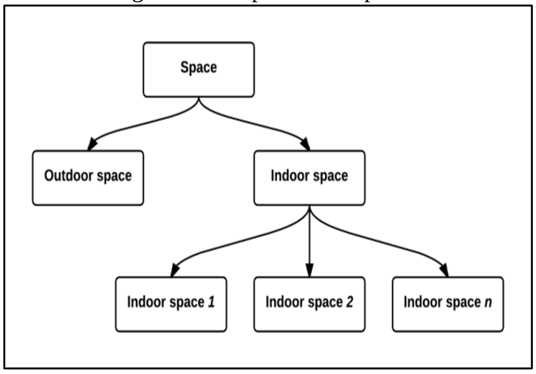
This example of a defined node demonstrates a transfer opportunity between different indoor and outdoor spaces. Therefore, a graph is a good starting point as it is also enabling navigation within a building, and especially in a production environment. The graph structure can be modified and adjusted to create access and transfer points between spaces.

2.3 Comparison of Spaces

In order to be able to compare spaces accordingly, a tree is set up listing the outdoor space and indoor space relationships. Figure 3 illustrates the comparison of spaces. In a first step, space is split up into outdoor space and indoor space – based on the same level of detail similar to Yang & Worboys [16]. In this abstract example the outdoor space represents the world outside a building. At the same level of detail the "opposite" of the outdoor space is the indoor space, which represents the world inside a building.

If we go one step further, indoor space can be subdivided into different indoor spaces. Therefore, Fig. 3 shows that the indoor space is divided into *indoor space 1*, *indoor space 2*, and the opportunity for other indoor spaces. *Indoor space 1* can be an example for a public building or a residential building. *Indoor space 2* can be a production environment with constraints regarding air quality and thus an installed air lock to enter the building. Another opportunity for an indoor space could be a separate environment where security clothes are necessary in case of chemicals. Additionally, a fine-grained subdivision of an indoor space could take place, which is described in Section 3.2. For spatial analysis this would require to look at indoor spaces with different scales depending on the question to be answered (i.e., is a person inside a building vs. is a person inside a room?)

Figure 3: Comparison of spaces.



3 Modelling of Indoor-/Outdoor Connections

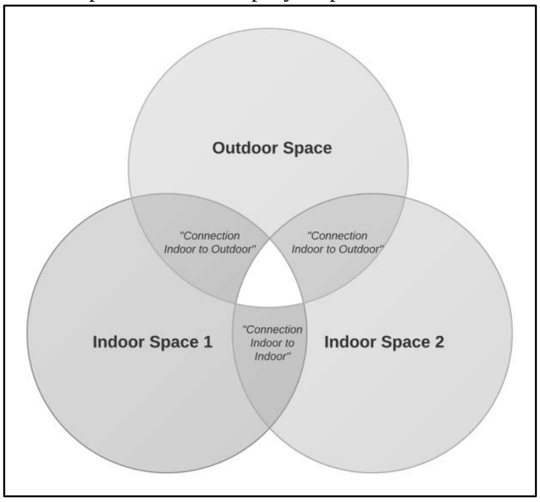
Modelling of indoor space or outdoor space is essential for the development of new applications. It is a challenge to develop an application connecting several spaces, as this process requires considerable modelling effort to represent reality in an accurate manner. This section describes on one hand the opportunity of *co-existence of spaces* and on the other hand a clear separation of spaces defined here as a *space in a space.*

3.1 Co-Existence of Spaces

There is a "*co-existence of spaces*" next to each other. This implies that all spaces are connected via some type of node (and edge) or, in real world, an entrance of a building connecting outdoor space and indoor space. An abstract model of this co-existence is illustrated in Fig. 4 with a modified Venn diagram. This diagram points out three different spaces, which are i) *the outdoor space*, ii) *indoor space 1*, and iii) *an indoor space 2*. The main essence is the possibility to establish connections between each space separately, but not to connect all spaces into one.

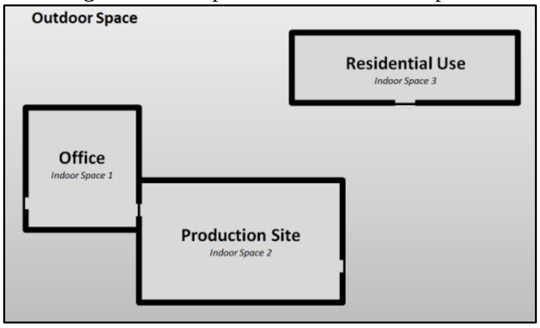
Figure 4 clearly shows that there exists a connection from *the outdoor space* to *indoor space 1* and to *indoor space 2*. However, there is no way to connect *the outdoor space*, *indoor space 1*, and *indoor space 2* all three in one way if the boundaries of each space are crisp. Then it is only possible to transit from one space to another space, step-by-step wise.

Figure 4: Modified Venn-diagram showing the co-existence of spaces and the step-by-step connection.



A real-world instance of the concept is depicted in Fig. 5. The example describes the co-existence of spaces. The example shows that the outdoor geography wraps-around the indoor spaces.

Figure 5: Example of co-existence of spaces.

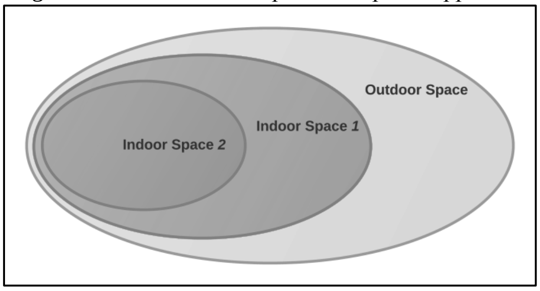


The indoor spaces are separated into one office building as *indoor space 1*, a production site as *indoor space 2*, and a building for residential use as *indoor space 3*. The office and the production site are one building but separate indoor spaces due to security reasons. For instance, not every employee of the production site is allowed to enter the office building. *Indoor space 3* is only accessible for residents.

3.2 A Space in a Space

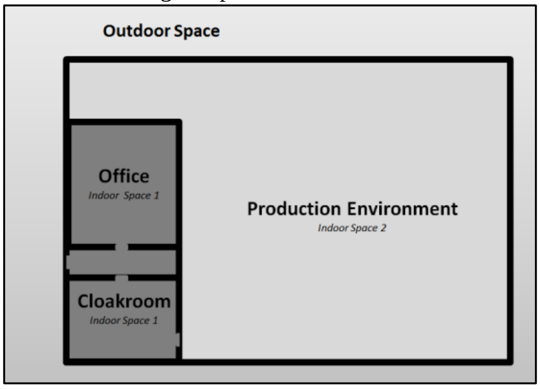
To model the characteristics of disjoint spaces, the "*a space in a space"* concept is introduced. This concept enables the modelling of special conditions, for example, as imposed by an indoor production environment. Figure 6 depicts the existence of a space in a space. The outdoor space wraps around all indoor spaces as does is in real world. Within *the outdoor space, indoor space 1* is located. *Indoor space 1* completely contains another *indoor space 2*. This *indoor space 2* is disjoint with the *outdoor geography* and cannot be accessed directly from outdoors.

Figure 6: Model of the "a space in a space" approach.



To illustrate the "*space in space*" concept, the reader is referred to Fig. 7. Again, the example of an indoor production facility is chosen. One building includes two separate indoor spaces. The production hall itself contains offices, a cloakroom, and the production environment.

Figure 7: Practical example of the space in a space concept by referencing to a production environment.



The production environment is secured by an air lock to establish special cleanroom conditions as described in Section 2.1. From the production environment, with cleanroom conditions, it is not possible to get directly into the outdoor space. In that respect, the production environment and the outdoor space are two disjoint spaces. However, the cloakroom in *indoor space 1* is accessible via the outdoor geography and the production environment (*indoor space 2*) is accessible via an airlock located between the cloakroom (*indoor space 1*) and the production space (*indoor space 2*).

This example points out that spaces can be very closely located but still disjoint. Both indoor spaces are separated from the outdoor space only by a wall. In contrary to *indoor space 2*, *indoor space 1* is accessible from outdoors. The conditions behind the wall are the only reason for enabling the access only via an air lock and thus limiting the access to *indoor space 2* – which is visualised in Fig. 7. Additionally, indoor spaces can also change over time due to the need of a higher level of air quality for new products or new production devices that require a reshaping of the indoor space.

4 Discussion and Conclusion

The paper elaborates on the connectivity of indoor and outdoor spaces, which includes mainly the connection of outdoor and indoor space and indoor to indoor space. On one hand, spaces, both outdoor and indoor, are in a co-existence state, meaning that the spaces are connected. On the other hand, we introduced a "*space in a space*" model, where spaces may be related while other spaces are disjoint. An example is given that highlights an indoor production environment with specific conditions and limited accessibility. Currently, to our best knowledge there is no approach that models the "*space in a space*" problem described in this paper. Especially for production relevant systems, there exist applications that show space that is traversable by humans and where production assets can be stored. The concept described here could be of vital interest for production environments – also for context aware systems that would restrict humans/production assets if they would like to enter an area they are not allowed to – e.g., specific production assets are not allowed to enter a certain production area, because of the contamination risk.

Future research directions include the investigation of possible connections between outdoor and indoor spaces, as well as any other possible connections of indoor spaces. Both aspects may be investigated with respect to space and time (e.g., how to model changes in indoor spaces), scale and/or fuzzy boundaries. This paper can also contribute to topics that seem thematically further away such as spatial-temporal analysis of indoor movements, simulation of movement behaviour, as well as an investigation of necessities and peculiarities of spatial-temporal analysis methods for indoor space.

Acknowledgements

The work has been performed in the project EPPL, co-funded by grants from Austria, Germany, The Netherlands, Italy, France, Portugal- ENIAC member states and the ENIAC Joint Undertaking.

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