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TOWARDS REPRESENTING TRANSITIONAL SPACES: DEVELOPMENTAL DIRECTION FOR INDOORGML ANCHOR NODE

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ABSTRACT:

Naturally, human beings freely navigate indoor space to outdoor space and optionally to another indoor space. However, currently available data models to represent space do not fully reflect this freedom and continuity of movement. These shortfalls hinder the development of location-based applications from aiding this navigation activity and affect the accuracy and optimality of route analysis. Existing models used for this purpose either represent indoor and outdoor space separately or use direct links that do not fully represent the freedom of movement and the complexity of urban areas. While these approaches use single-feature representations of the connection of these spaces through nodes for the building entrances, Transitional Spaces exist at these locations and must be represented accordingly in navigation networks. In this paper, we illustrate how currently defined IndoorGML concepts can be utilized for integrating indoor and outdoor navigation networks through the Transitional Spaces. We perform an experimental case using sample data to demonstrate the limitations of this model. From this, we discuss the developmental direction of the Anchor Node concept towards developing a model to fully represent navigation on an integrated indoor-outdoor network.

1. INTRODUCTION

As the world is starting to brace upon the onset of the fourth industrial revolution, cities have delved into arising technologies to resolve issues that come with rapid population growth and urbanization. Digital twins form an essential part of Smart Cities, which are considered one of the critical technologies and main innovation drivers in this age (Deng et al., 2021). As a mirror of the real world, digital twins are helpful in identifying problems, increase efficiency, and formulating informed solutions for various challenges and vulnerabilities (Qi et al., 2021). Realizing digital twin models have been hindered by fragmented data sources and heterogeneous formats (Lu et al., 2020), and full mirroring of the physical world towards the virtual twin can only be achieved by unified models that integrate various components of the complex real world.

Furthermore, urban environments have become more complex due to the growth of the human population and activities. People navigating these environments experience difficulty in navigation due to lessened familiarity with the spatial layouts and landmarks as well as the presence of crowds (Vanclooster et al., 2016). Hence, spatial applications that are intended to aid navigation must be built upon data models that represent these spaces wholly and accurately.

While the real-world space is continuous and seamless, abstraction is inevitable as spatial data is generated for representation. For example, representation of navigation paths for outdoor space is done through road and street networks, while hallways and rooms compose data for indoor navigation. As shown in Figure 1, this abstraction leaves a gap in full representation. Furthermore, outdoor space models and their indoor counterparts have been developed separately, and research on integrating these aspects has been deficient. It is crucial to develop a unified data model because it aids the development of navigation applications. Furthermore, such a model establishes connections through spatial relationships between data of various forms that come from the fragmented development of space models. Enabling a robust method for connecting various forms of data also addresses data completeness issues and, conversely, duplications.

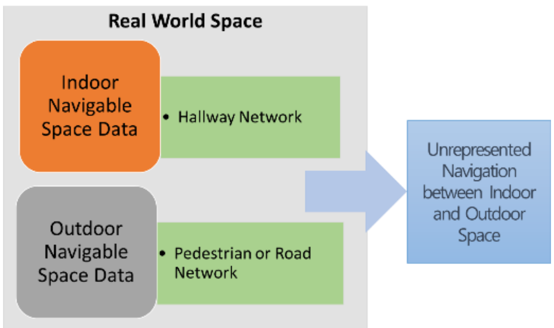

Figure 1. Representation gap in representing the real-world using spatial data.

Most studies that model the connection of indoor and outdoor navigable spaces use a link through the building entrance. While this approach is direct and straightforward, it disregards some spaces that may be present such as plazas or other large open spaces. With its role as both separators and connectors of indoor and outdoor space, transitional spaces, because of their location, extent, and size, can include multiple paths for pedestrians. Just as IndoorGML represents the navigation path for indoor space through a network representation, these spaces can also be represented as a network of their own.

In this study, we aim to illustrate how to integrate indoor and outdoor navigation network data through transitional spaces. We

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illustrate how various cases of these spaces can be represented using the Anchor Node concept. Using sample data, we demonstrate how the connection of these spaces to identify limitations in representation, as well as opportunities for extending this concept for a complete representation of the transitional space to enable the connection of indoor and outdoor navigation networks. The paper is structured as follows. The next section briefly discusses relevant studies, while the following section defines transitional spaces and the proposed model. The fourth section contains the experimental implementation in real-world transitional space and developmental directions for extending the Anchor Node concept. Finally, the last section summarizes and discusses future directions for this study.

2. RELATED STUDIES

Indoor spaces share multiple similarities between outdoor spaces, such as concepts of connectors, barriers, containers, and surfaces (Yang and Worboys, 2011). In navigation models, indoor space is viewed in the context of human activity, containing spaces that are limited by boundaries and are physically enclosed. On the other hand, outdoor navigation space is associated with roads and streets. Although these two have always been modeled and treated in applications separately (Vanclooster et al., 2016), indoor and outdoor space does not have a crisp boundary. Research has shown that there are spaces that can be perceived as neither indoors nor outdoors through different elements that identify each space, and they are situated in between them. These spaces challenge not just our perspective of how spaces are classified but also directs us to reimagine how we strategize navigation and how we model it in applications. Transitional spaces can also act as a buffer or circulatory course between indoor and outdoor space, allowing people to adjust from one space to another (Kray et al., 2013; Sabeen and Kim, 2020).

Indoor and outdoor spaces are commonly modeled separately, with each having its own standards for spatial data representation. The CityGML standard (OGC (Open Geospatial Consortium), 2012) represents built environments, particularly buildings, as well as their immediate environments but lack indoor space information relevant to pedestrian navigation and access (Slingsby and Raper, 2008). In navigation applications, indoor and outdoor spaces must be integrated through entrance/exit points leading to the indoor network. However, while entrance points are almost always available on platforms, the indoor network is missing to provide a complete representation. In some cases, both are unavailable. This leads to problems in navigation guidance especially when intended for multimodal routing applications (Vanclooster and De Maeyer, 2012).

Node-relation structure (NRS) data that represents the connectivity of indoor spaces were connected to the street network through a particular node at entrance halls in order to minimize entry point uncertainty to improve the emergency response (Kwan and Lee, 2005). Similarly, a connection through the building entrances between 3D city models and the road network in order is vital to provide a fully operational 3D routing application (Kim and Wilson, 2014). Teo and Cho (2016) used BIM data to the street network through an entrance-to-street strategy by converting BIM data to NRS (Teo and Cho, 2016), while Wang and Niu (2018) used OpenStreetMap primitives (Wang and Niu, 2018). Tashakkori et al. (2015) proposed an IFC-based indoor emergency spatial model for a complete 3D indoor-outdoor routing network, also through entrances (Tashakkori et al., 2015).

However, these approaches presume that the current models are sufficient of fully and wholly representing the spaces. The mere fact that a connecting approach has to be formulated emphasizes that the models are separately modeled. Although the results of these studies have shown that a certain degree of integration has been achieved through this method, it still lacks in achieving seamless navigation because the approach for connecting indoor and outdoor space is heavily reliant on the data used for each case and the connection is assumed to be as simple as the building entrances.

3. TRANSITIONAL SPACES

The representation of the connection between indoor and outdoor spaces through entrance data as a single point is a simplistic method. In these approaches, there is a presumption that the external transportation network is present immediately in the vicinity of the building entrance. Transitional spaces are intermediate spaces right outside indoor spaces but are not yet fully considered as existing outdoors. They exist primarily in between indoor and outdoor spaces, most prevalently in the built environment. These spaces may act as buffers between the two, such as the plaza in Figure 2. While directly linking indoor and outdoor space models is straightforward to implement, it restricts navigation movement and clearly lacks in fully representing the real world.

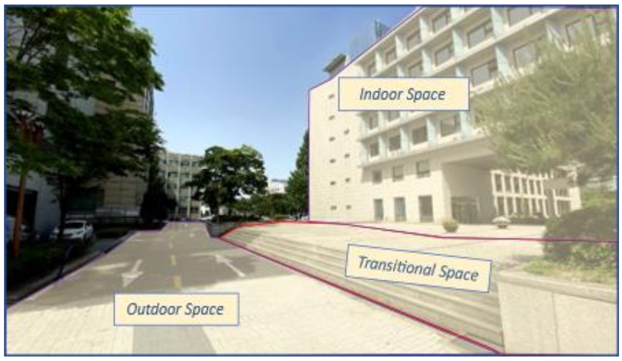

Figure 2. Transitional space between Indoors and Outdoors

These spaces also serve some architectural purposes, such as an aesthetic, safety, or separation tool. These are areas that are not indoors yet not entirely part of outdoor transportation networks. Some studies refer to these as semi-indoor (sI) or semi-outdoor spaces, depending on the enclosure on the sides and top (Yan et al., 2019). Nevertheless, as spaces are conventionally classified dichotomously as either indoor and outdoor, their formal representations and definitions cannot be found on spatial data standards. Essentially, these spaces form the connection of the indoor space to its adjacent spaces, whether it is to the outdoors or to another indoor space. As an indispensable component of space, its effects on how agents navigate across and within these areas cannot be ignored. Hence, a formal manner on how to represent these spaces must also be specified for a more accurate depiction of navigation.

Representing the indoor network representation is straightforward, such as in IndoorGML, because the system of corridors and rooms is apparent. On the other hand, and the outdoors mainly consist of available street and road transportation networks, leaving transitional spaces unrepresented in currently available space models, as in Figure 3. In contrast, most studies assume that the end of the indoor network and its progression to the outdoors through the entrances (or exits), the IndoorGML standard (OGC (Open Geospatial

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Consortium), 2018) stipulated the Anchor Node based on this principle as the connection between indoor and outdoor space. The Anchor Node is defined as the entrance of the building, represented differently from other nodes that represent the indoor spaces. As specified, it must contain information that references the outdoor transportation network and optional parameters to convert in-between coordinates. However, the standard did not explicitly specify how to implement this concept.

An extension model was defined in a separate discussion paper. This defined the SeamlessNavigation Module to fulfill the limitations of the IndoorGML document in the implementation of the Anchor Node concept, as shown in Figure 3. The IndoorGML node representing the building entrance is replaced by an AnchorState node.

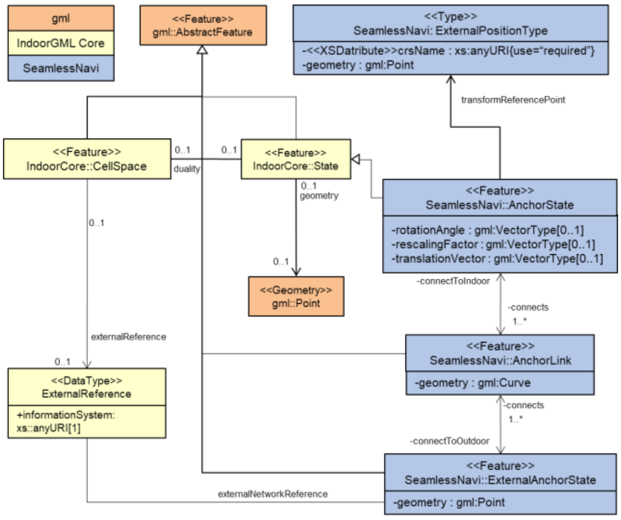

Figure 3. UML Diagram of the SeamlessNavigation Module (OGC (Open Geospatial Consortium), 2019)

Consequently, the closest node in the outdoor network is represented as an ExternalAnchorState, which points to an ExternalReference to be able to refer to data expressed through other standards such as CityGML. Accordingly, these two are connected by an AnchorLink edge. With this specification, implementing the AnchorNode model in establishing a connection between the indoor and outdoor network is straightforward, referring to a single connection between one node from each side.

4. MODELING NAVIGATION BETWEEN INDOORS AND OUTDOORS

Figure 4. The building study area for the implementation

Literature covering the AnchorNode extension has demonstrated the connectivity of the indoor with the outdoor network in use cases for generating the data. Since IndoorGML is primarily geared for navigation applications, representations based on this standard must be able to handle such analysis. To demonstrate the capabilities and limitations of the Anchor Node concept in the context of navigation, we conducted a case study with sample datasets. The experiment is based on the 21st Century Building (referred to henceforth as Building 1) of the University of Seoul, South Korea, and its surrounding environment, shown in Figure 4. Also included in the data is an underground building (Building 2) located on the same campus.

Geometric data derived from a 1:5000 topographic map is used to generate the IndoorGML-based network data in Figure 5. Building floor plans are used to generate the indoor geometric network of each of the buildings and the road in the intermediate vicinity of the two structures. Navigation on the dataset is demonstrated by implementing an optimal route search from a point on the indoor network of Building 1 towards another point on the indoor network of the underground Building 2.

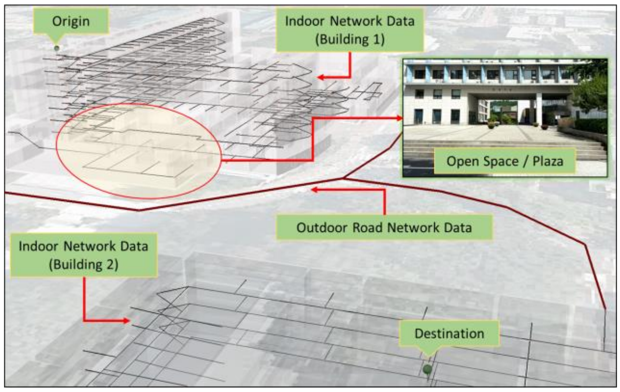

Figure 5. Sample data for the implementation

Based on the model of the SeamlessNavigation module in Figure 3, the connection between the indoor and outdoor network is implemented through the entrance of Building 1. As shown in Figure 6, the node representing this entrance is converted to an AnchorState, and the closest node in the outdoor network is converted to an ExternalAnchorState. Consequently, these two nodes are connected by a single edge to represent the AnchorLink.

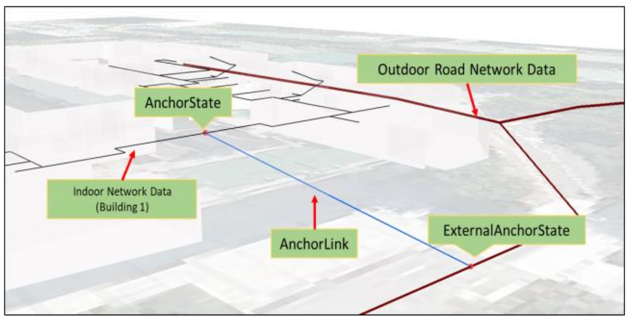

Figure 6. Defining the connecting nodes based on the SeamlessNavigation module

An optimal path search based on Dijkstra's shortest-path algorithm (Dijkstra, 1959) is implemented on the integrated sample data using the ArcGIS Network Analyst Tool. The origin and destination points are assigned as stops for the route, and the resulting path is shown in Figure 7 in yellow.

Results of the experiment above demonstrate that this connection enables navigation from the indoor network of Building 1 towards the external network. This may also extend further the external network towards a destination inside a separate Building

2. However, as in Figure 8, this means of expression disregards the presence of Transitional spaces in between the entrance doors and the outdoor network. The plaza in front of Building 1, which can be considered a Transitional Space, is not sufficiently represented as a location where navigation can occur within since only a single edge connecting the building entrance, and the road network is present.

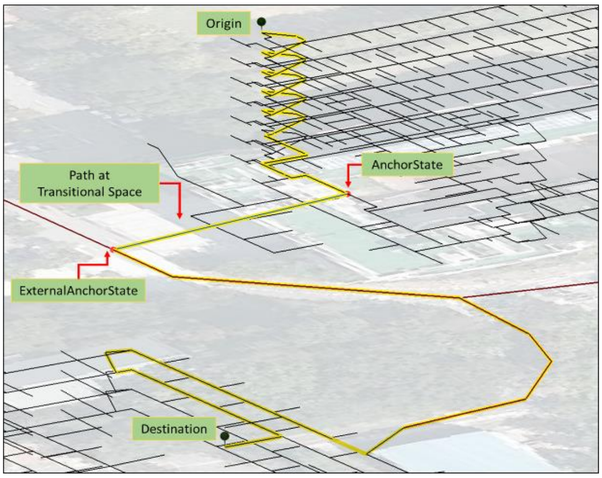

Figure 7. Results of the routing implementation

Such as in Figure 8, the buildings are treated as an independent entity rather than space seamlessly connected with their surrounding environment. Despite being bound by physical (gates, doors) or virtual (in the semantic sense) elements, these buildings present connections to neighboring spaces where navigating agents can traverse. When routing is implemented, such as from Building A, the agent can only go from the building exit (represented by AnchorState) directly to the road network (a node represented as ExternalAnchorState). From the road network, if the agent desires to proceed to another indoor space, such as in Building B, intermediately located open spaces are also disregarded. Since the Transitional Space is neither contained in the representations of the indoor and outdoor networks, the model must be expanded to include representation of navigable spaces within them.

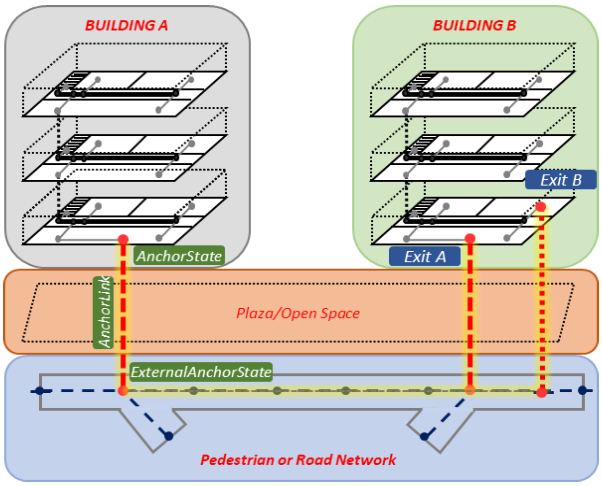

Figure 8. The connection between indoor and outdoor navigation networks using the SeamlessNavigation module

Correspondingly, Building B presents a case of indoor space with multiple exit points. This is a limitation of the SeamlessNavigation module since multiple connections between the indoor, and outdoor networks are not represented in the model.

Furthermore, instead of a single representation of connection towards indoor space, multiple entrances must be allowed in the model. Especially in urban areas, buildings are accessible at different levels, in multiple locations, through various modes of transportation. This compels multiple access to the buildings, which are essential in indoor space navigation, particularly in emergency applications. This will also allow opportunities for utilizing the model in multi-modal navigation applications. This case of transitional spaces may be represented as a graph, portraying the connection of an indoor to an outdoor network through an intermediate space having its own navigation paths (Claridades and Lee, 2021).

Similarly, Transitional Spaces can also exist directly in between two buildings. Suppose an agent in a room located at Building A wants to travel to another location in Building B, such as in Figure 9. If a connection between two buildings is present through accessory exit points, there is no need for the agent to go through the main entrance, pass through the outdoor pedestrian network, and enter the main portal of Building B. If the direct connection is part of the optimal path, this must be represented in the integrated navigation data. However, this representation is also impossible to execute using the current Anchor Node extension model since the AnchorLink can only connect between an AnchorState and ExternalAnchorState.

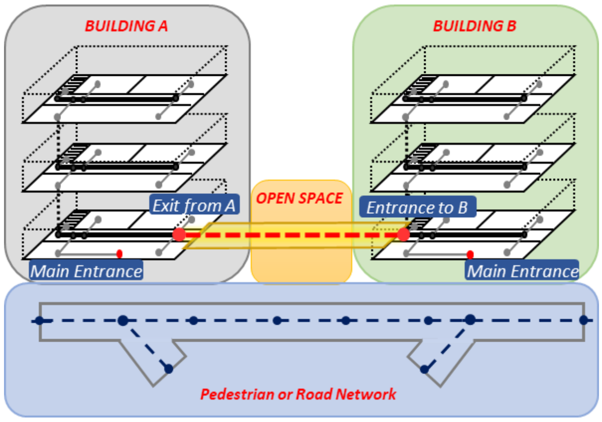

Figure 9. Connecting transitions between two indoor spaces

Furthermore, past studies have shown that variety of data models and the need for conversion hinder the integration of spatial data (Vanclooster et al., 2016). In the current specification, there is a need to modify the input datasets before integration. In the indoor data, the entrance node is converted to an AnchorState. In the outdoor road data, which is on a specification different from IndoorGML, a node must be converted to an ExternalAnchorState. In practice, for every data model for a road network, a conversion strategy would have to be formulated.

Apart from this hurdle of conversion, this also poses problems in implementations, since the edges needed at these converted points would have to connect two nodes from different schemas. In order to further extend the Anchor Node concept towards a more realistic representation of navigation among indoor and outdoor spaces, the manner of connection must be expanded. Moreover, avoiding the modification of the input data prior to integration not only saves time and computational cost, but also maintains data integrity and allows a more flexible data management. The spaces immediately outside the building entrances may vary in form, size and in extent. While the SeamlessNavigation module provides a fundamental means for connecting indoor space to the outdoors for navigation, the pedestrian paths are not thoroughly characterized. Transitional spaces are insufficiently modeled and not included in the representations. This may lead to incorrect results for path analysis or may restrict paths of navigation agents.

5. CONCLUSIONS

As location-based applications aim to provide valuable geographic knowledge to users, spatial datasets that form their backbone must represent the real world as completely as possible. With navigation continuing to be one of the most essential tasks for human beings, its seamless nature must be reflected in applications to obtain valuable and credible results. As indoor and outdoor space have been studied separately and represented differently in data, current approaches in their integration to obtain a seamless indoor-outdoor networks have been lacking.

Large spaces occurring immediately outside indoor spaces, such as Transitional Spaces, indeed have influence in how agents navigate, but have not been included in spatial data models. While the IndoorGML standard has been expanded through the Anchor Node extension model, there are still shortcomings regarding a complete representation of the continuity of navigation across spaces. Furthermore, the existing model poses a notion that structures represented as indoor networks are units isolated from surrounding areas. This hinders indoor navigation data to be seamlessly integrated to outdoor data, and more importantly, the intermediate spaces that exist between them.

In this paper, we discuss the existence of Transitional Spaces that occur right outside indoor spaces in the context of navigation and their importance in integrating these spaces into outdoor networks or other indoor spaces. Using experimental data, we demonstrate the usage of the IndoorGML Anchor Node concept, as described in the original standards document and the SeamlessNavigation discussion paper, through a routing experiment. From the results, it is exhibited that the specifications of the model lack in representing these spaces in the context of navigation. Additionally, we discuss challenges in representing transitions between indoors and outdoors and how the extension of Anchor Node can consider these intermediate spaces.

As the current model implements a direct connection with the building exit to the outdoor network, navigable spaces within the Transitional Spaces must be represented to allow paths that occur in these intermediate locations. Multiple entrance points must also be considered, as buildings can have numerous access points at varying locations, especially in large structures. Likewise, the current model also cannot handle direct paths from an indoor space to separate indoor space without passing through an outdoor network. Hence, these outdoor or semi-outdoor connections that are not part of the outdoor pedestrian or transportation network must be considered correspondingly. Finally, connections must be facilitated without the need for conversion or using direct physical features that pose difficulties, especially when handling datasets having different schemas. Nevertheless, future research must be conducted to implement the proposed modifications to create an integrated IndoorGML indoor-outdoor navigation model, particularly having various structures of Transitional Spaces and further use cases with other spatial data standards.

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