

Live Space Modeling and Location Tracking For Emergency Evacuations: Application of TIPPERS Builder

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Abstract—The creation of a “digital twin” or digital representation of a smart space, which is a building or an environment powered by IoT devices, can provide numerous capabilities and insights into the everyday interactions that take place in a given building. The TIPPERS Builder tool provides extensive capabilities in designing digital representations of smart spaces through space models of physical environments and structures, and it has been used extensively to emulate smart spaces such as the Donald Bren Hall at the University of California, Irvine, and also a senior care facility centered around assisted living based in Southern California. The Builder is currently being deployed in educational settings to observe and gain a better understanding of different activities that take place in an educational environment.

I. INTRODUCTION

Recent years have seen a rise in the number of IoT-enabled environments and buildings. Smart spaces powered by IoT devices can be found in residential settings, corporate offices, and university campuses as well. The creation of a “digital twin” or digital representation of a smart space can provide numerous capabilities and insights into the everyday interactions that take place in a given building.

We have created and emulated smart spaces such as the Donald Bren Hall at the University of California, Irvine, as well as a senior care facility based in Southern California using the TIPPERS Builder tool. The digital representations of these smart spaces contained details at the level of floors, and even individual rooms and regions, and could accurately locate people in different sections of the building. These digital representations provided insights into everyday movements, activities, and interactions taking place in this smart space environment, and also assisted emergency personnel in locating injured or trapped individuals during the evacuation drills that took place in these smart spaces. The TIPPERS Builder tool which is a part of the TIPPERS project and the CareDEX project under which the evacuation drills in these smart spaces took place are described as follows.

The TIPPERS project was started with the objective of providing a mechanism to model and create representations of IoT environments and provide various insights and understanding about the movement and activities taking place in these environments so that these insights can be used to obtain a better understanding of the general operational state and the everyday-interactions taking place in the given environment or building [1].

The CareDEX project’s purpose is to assist the population group of senior adults in disaster events by providing a combination of services that aid emergency personnel in the evacuation and rescue of senior citizens during such disasters. One of the central goals of the CareDEX project is determining and evaluating how smart space technologies like the TIPPERS Builder can be used to assist disaster response efforts [2].

The digital representations of the smart spaces were created using the TIPPERS Builder, a tool that can be used to create a geographical space model of a given physical environment or building. The created smart space can have many layers in a structural hierarchy. The Builder was initially used to emulate smart spaces centered around senior care and assisted living facilities in Donald Bren Hall at the University of California, Irvine, and this digital representation created by the builder was used to aid the evacuation of the facility during a drill that took place as part of the CareDEX project. This emulation was successful and showed promise which led to the creation of a digital representation of an actual senior care facility based in Southern California as part of the Great Shakeout project. This digital representation of the senior care facility provided key insights into the movement and activity patterns of various seniors in the facility and aided emergency personnel in the evacuation that took place as part of the Great Shakeout.

We now present a description of the TIPPERS Builder tool and its components, along with a comparison to other related tools, and then showcase how we used it for emulating and modeling assisted living.

II. DESCRIPTION OF TIPPERS BUILDER

The Environment Builder is a front-end application that enables the user to effectively design a digital representation of a smart space through the creation of an encompassing database schema. The smart space as modeled by the Builder is comprised of five main components: Space, Sensor, People, Events, and Relationships between these entities. These components were primarily selected as the core building blocks of the digital twin to ensure that our application would be flexible enough for use in various application settings (e.g. university campus monitoring, assisted living, etc.). Implementation-wise, we chose to adopt a standard REST architectural style due to its flexible and efficient execution. We created a simple but effective NodeJS user interface in order to facilitate the process of creating the digital twin, while also taking into account usability and user satisfaction. Below is an overview of the application's architecture and the TIPPERS Builder portal interface:

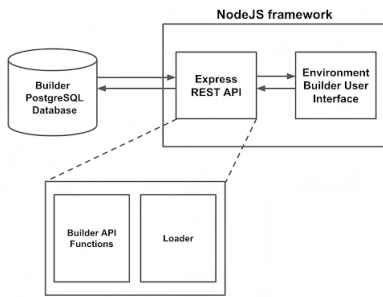


Fig. 1. Builder Architecture

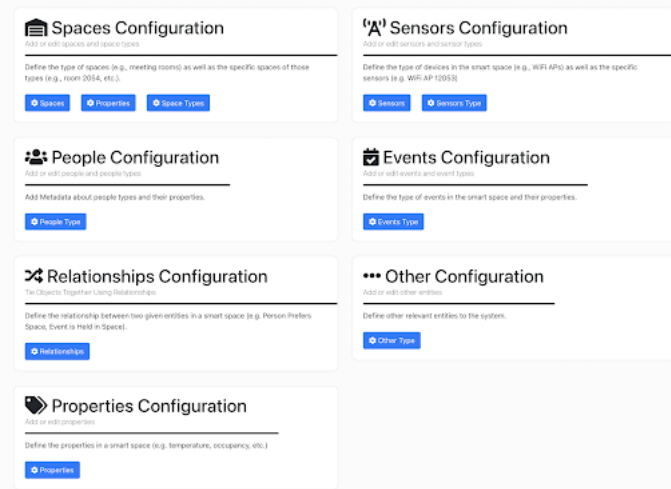


Fig. 2. The Builder Portal GUI

The Builder user interface separates the main components of the system into stand-alone “Configurations”, as shown in Figure 2. Such a decoupling of components significantly improves usability of the application and enables the user to partition the process of creating the digital twin, while also

leaving room for potential collaborative work. The application thus completely handles the semantic connections between such configurations in the back-end (e.g. enabling the selection of properties previously defined in the Properties Configuration for a sensor type in the Sensors Configuration). The following is a detailed breakdown of the major components of a smart space as modeled by the Builder:

A. Properties

Properties is an essential sub-component that applies to all the main components of this application. Certain component instances, for example, an event type entitled “Meeting”, might want to have a special property entitled “meeting place”, or “meeting time”. To account for this additional information which might want to be tracked in a smart space, the Properties Configuration is created, and should be the first information entered within the Environment Builder. These properties will later be associated with the appropriate component instances in their separate configurations. Having a separate and optional Properties component is a crucial decision which maintains the flexibility of our application, while also efficiently allocating storage for such metadata across the different core components of the application.

B. Spaces

Spaces are modeled in a hierarchical structure, as shown in Figure 7. Such a design enables applications built on top of the digital twin to perform inferences based on it. For instance, knowing that the occupancy of a room is 42, then the occupancy of its parent floor/building has to be at least 42. Any space created in the builder starts with the Earth layer which is the top-most entity in the hierarchy. Under this, a particular building, physical structure, or physical environment can be added by tracing out its physical GPS coordinates on the provided Open Street Maps interface by simply drawing its shape. Following this, floor plans (such as Figure 3) can be added to the space hierarchy and each individual region and room on this floor can be added separately, each appearing under the respective floor that it is a part of.

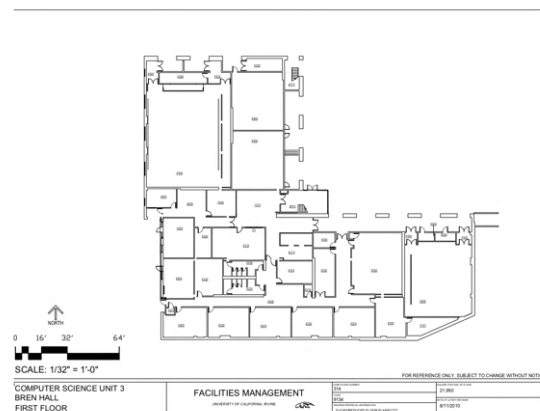


Fig. 3. Floor 1 plan of Donald Bren Hall used for creating space model

We chose to use floor plans on a 2-dimensional coordinate plane as this drastically facilitates the creation of spaces that might not have precise GPS coordinates such as rooms or corridors. Indeed, our application includes a complete translation module which automatically translates 2-D coordinates to the GPS plane upon insertion. Through this framework, we are also able to define the coverage of sensors, by considering such coverage as an independent spatial extent, then later connecting it with a specific sensor instance defined in the Sensor Configuration.

Space properties, similar to the properties definable in the Property Configuration, are properties which may be associated with a certain spatial extent defined in the Space map sub-component (e.g. “capacity” may be a property associated with a certain extent). The properties sub-component simply defines the name of the property and its type, so that this property can successfully be rendered on the Map component as inputs for the user to enter information (the value of the property).

C. Sensors

Sensors can be added in the Environment Builder and mapped to spaces such as particular regions, rooms, or floors to provide contextual data about the space that they are mapped to. Important metadata can be defined for a sensor, such as its name, owner, protocols, etc. With flexibility in mind, we designed this Configuration to fit various types of sensors, meaning that the user can associate custom properties with each sensor instance, as well as associate a custom schema for the payload table of a specific sensor type. In this manner, the user has the ability to create various table schemas without direct interaction with the underlying database, and can thus adapt to the eclectic sensor types that a smart space might encompass. As the Environment Builder is a compact database used solely to interact with the user interface, the sensor types tables are not created, as the sensor types table is enough to store all required information to create the final database, i.e. the type properties, as well as the payload schema.

D. Relationships

As the name indicates, Relationships refer to the mappings between the main components of the Builder application. In its essence, a relationship defined by the user in this application corresponds to a relationship in the ER diagram of the environment defined, where the Entities are the main components (Sensors, Spaces, People, Events, Other). This component provides significant flexibility in our application, as typically relationships are fixed within a database schema, and not dynamically created by users as the Builder does. This Configuration is extremely useful when defining a relationship that may not apply across all smart space applications (for instance, the relationship between the Space and Event entities called “Meeting Located At” may not be applicable in a smart house setting).

E. People, Events, and Other

The final entities, People, Events, and Other, are modeled in a similar, generic fashion. The Environment Builder only enables the creation of types related to these entities, and all three have an associated type id (automatically generated by the Builder database), a parent type id (to support a hierarchical representation of entities), and associated properties.

Similar to how the TIPPERS builder is used to create a representation of spatial data, it also creates information about occupants in spaces by adding metadata about people types and their properties. This is represented in the TIPPERS system as follows:

people		
PK	person_id	integer
	name	text
	organization	text
	username	text
	credential	text

Fig. 4. Representation of occupants, along with their properties, present in spaces in the TIPPERS system

people_types		
PK	type_id	serial
	type_name	text
FK	parent_type_id	integer
	type_properties	JSON

Fig. 5. Representation of type id, parent type id and associated properties of occupants present in spaces in the TIPPERS system

Additionally, TIPPERS provides an interface to model application-level data and write queries that use the Observable Entity-relationship Model (OER) to define attributes and relationships that can be observable about people in the spaces. For example, the figure below represents how TIPPERS models a resident (occupant) with attributes (age, vitals, ambulatory, etc), their location, and other observable characteristics:

Since the values of the observable attributes and relationships of the people are dynamic, they are stored in a single relation referred to as the temporal relation.

In this manner, the TIPPERS Builder can create flexible smart space metadata and generate a complete database design used to store and manipulate data relating to people and their environment. It can simulate residents with various conditions and preferences, including mobility status, medical needs, diagnoses, and more. Therefore, the TIPPERS Builder acts as a tool that can be used to provide on-demand access to critical information in various scenarios.

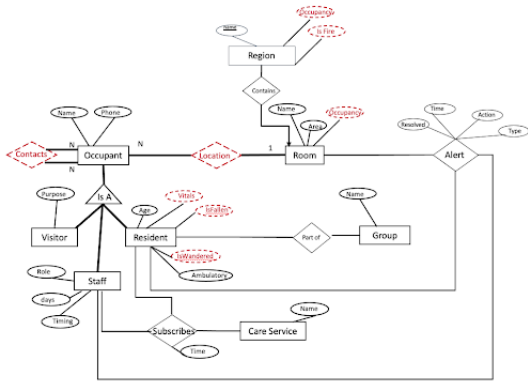


Fig. 6. Model of occupant with various attributes and observable characteristics

III. COMPARISON OF TIPPERS BUILDER TO RELATED TOOLS

There are tools related to the TIPPERS Builder which also enable users to create digital twins of smart spaces. However, compared to these tools, the TIPPERS Builder tool offers certain advantages to users as it provides features that encourage and enable simplicity, ease of use, and flexibility.

VANTIQ offers a Smart Space Digital Twin working application [3], however, unlike the TIPPERS Builder tool, this working application does not provide a portal interface for designing digital representations of smart space environments and instead, only provides a code base for developers to create their own applications and then create digital twins. Moreover, this working application by VANTIQ is not readily available and users need to contact the company with a brief description of their project in order to get started with creating digital representations of smart spaces.

The TIPPERS Builder tool also has the advantage of being open-source compared to Ubisense’s SmartSpace® software [4] and the Builder tool is also simpler and easier to use as it can translate spaces from 2D to GPS coordinates, a feature lacking in platforms and services such as Microsoft’s Azure Digital Twins, in which users need to create 3D models [5].

There also exist software tools such as ArcGIS [6] and QGIS [7], which provide geographic information mapping capabilities. However, unlike the TIPPERS Builder tool, these tools have a steep learning curve and complex interfaces, and also do not provide users with the ability to add semantic metadata to spatial objects. The TIPPERS Builder tool on the other hand possesses the properties sub-component as described in the previous section which enables users to create flexible smart space metadata.

IV. USE OF TIPPERS BUILDER IN EMULATING AND MODELING ASSISTED LIVING

As described above, the Builder tool enables the creation of a smart space’s “digital twin”, which is a digital representation of both the semantic and physical aspects of a smart space environment. This provides assistance in emergency situations

for first responders and emergency personnel since they have access to this digital representation which facilitates identifying the location of people and determining the prioritization of individuals in emergency cases. Hence, it allows emergency personnel to identify and locate trapped individuals or individuals in need of medical assistance during disaster events.

The TIPPERS Builder was used to emulate smart spaces centered around senior care and assisted living facilities during the evacuation drills that took place as part of the CareDEX project. Each of these drills required the use of the TIPPERS Builder system to map the geography of the respective buildings along with the floor details such as rooms, corridors, and common areas. Spaces such as the ‘Memory Care Unit’, ‘COVID Isolation Unit’, dining halls, libraries, and other relevant rooms and regions of senior care facilities were configured in the builder system and each space was associated with particular WiFi access point coverages so that fire and safety personnel could locate stranded, lingering, or stuck individuals during the evacuation.

The smart space environment of Donald Bren Hall was modeled in the Builder system with the building itself forming the parent layer space in the spaces hierarchy, followed by the individual floors of the building as the next layer in this hierarchy, which was then in turn followed by specific regions and individual rooms of a given floor such as the 3rd floor as follows:

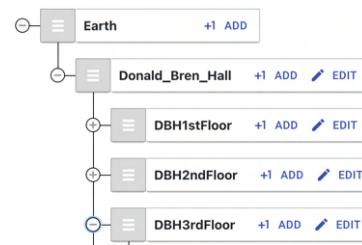


Fig. 7. Hierarchy between building and floor spaces in the Builder System

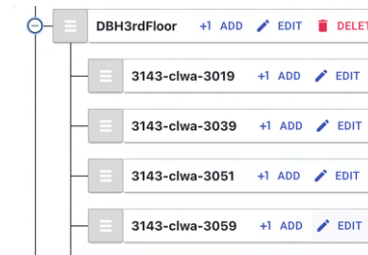


Fig. 8. Hierarchy between floor and WiFi access points in the Builder System

Emergency Evacuation Drills: TIPPERS Builder in Action

The evacuation drill in Donald Bren Hall utilized smart-watches worn by each individual to keep a track of the individual’s location. At the commencement of the drill, the location of each individual was visualized on a live dashboard floor map of the created digital representation of Donald Bren

Hall so that each person could be individually located and tracked. This dashboard also showcased details such as the priority and risk level of each individual, with green signifying low risk, yellow indicating medium risk, and red representing high-risk individuals.

This live dashboard map helped fire and safety personnel locate individuals who were unable to evacuate due to injury, physical debris, or obstructions along with a variety of other circumstances that hampered normal evacuation. Since the smart devices worn by each individual were connecting to the nearest Wi-Fi access point as they were moving through the building, this provided a live location of all individuals at any given point in time.

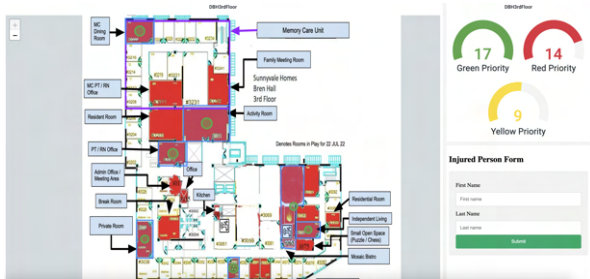


Fig. 9. Live dashboard for tracking resident location during Donald Bren Hall Evacuation Drill

The success of the emulation of a senior care facility in Donald Bren Hall led to the use of the Builder system to create a digital representation of an actual senior residential and care facility based in Southern California as part of the Great Shakeout. The Builder tool was used to map the residences and rooms of the senior adults at the facility as well as common areas such as dining halls, libraries, AV rooms, and other meeting points as well. This allowed for the observance of the activities and movement of the senior adults through the use of Arduino devices assigned and carried by each individual. The live dashboard map of the digital representation of the senior care facility created in the Builder system was instrumental during the evacuation as part of the Great Shakeout and helped coordinate and improve the evacuation effort so that all senior adults could be accounted for and any missing or trapped individuals could be located and rescued.

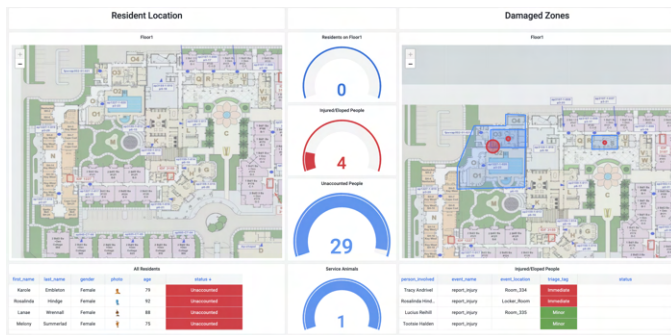


Fig. 10. Live dashboard for tracking location of senior adults during the evacuation as part of the Great Shakeout

Performance Evaluation of TIPPERS Builder during Emergency Evacuation Drills

At the conclusion of each evacuation drill, the first responders and emergency response team were asked for feedback to indicate if and how the live dashboard maps of the smart space environments' digital representations created in the TIPPERS Builder system aided them during the evacuation.

The first responders at the Donald Bren Hall evacuation drill indicated that the live dashboard map of the digital representation of Donald Bren Hall helped them locate individuals and also identify reports of those requiring paramedic response.

The emergency personnel and firefighters at the evacuation of the senior residential and care facility as part of the Great Shakeout confirmed that the live dashboard map of the digital representation of the senior care facility helped alert the response team that 8 residents were still missing after the primary evacuation and they were able to identify and locate these residents with the help of this live dashboard map.

This performance evaluation provided by the first responders and emergency response team is visualized in the following table:

Critical Task	Without Use of TIPPERS Builder in Evacuation Drill	Using TIPPERS Builder in Evacuation Drill
Locating Missing Individuals	Lower Certainty of Success	Higher Certainty of Success
Providing Paramedic Response to Injured Individuals	Lower Certainty of Success	Higher Certainty of Success
Rescuing Trapped Individuals	Lower Certainty of Success	Higher Certainty of Success

Fig. 11. Performance of TIPPERS Builder during Evacuation Drills

V. CONCLUSION

The TIPPERS Builder tool offers many capabilities for creating digital representations of smart space environments. Its extensive use in evacuation drills has proven its robustness as well as the benefits it provides to emergency response personnel. The Builder tool is currently being deployed in educational settings at Plaksha University situated in Punjab, India to create a digital representation of academic blocks. This representation would provide university administration and academic departments with insights regarding lecture attendance, space usage, interactions between different academic groups, and more.

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REFERENCES

- [1] A. Kobsa, S. Mehrotra, S. Rajagopalan, and N. Venkatasubramanian, "TIPPERS: A Privacy Cognizant IoT Environment", pp. 1-6 .[Online]. Available: <https://tippersweb.ics.uci.edu/research/>
- [2] "Enabling Disaster Resilience in Aging Communities via a Secure Data Exchange". <https://sites.uci.edu/caredex/> [Accessed: 26-Jan-2023].
- [3] "Smart Space Digital Twin". VANTIQ. <https://vantiq.com/connect/solution/smart-space-digital-twin/> [Accessed: 13-Feb-2023].
- [4] "SmartSpace®". Ubisense. <https://ubisense.com/smartspace/> [Accessed: 14-Feb-2023].
- [5] B. Anderson, D. Betts, G. Weinstock, T. Teebken, and L. L. Kasturi. "What is Azure Digital Twins?". Microsoft. <https://learn.microsoft.com/en-us/azure/digital-twins/overview> [Accessed: 14-Feb-2023].
- [6] "ArcGIS". Esri. <https://www.esri.com/en-us/arcgis/about-arcgis/overview> [Accessed: 19-Feb-2023].
- [7] "QGIS - The Leading Open Source Desktop GIS". QGIS. <https://www.qgis.org/en/site/about/index.html> [Accessed: 19-Feb-2023].