

# DNAS-STriDE Framework for Human Behavior Modeling in Dynamic Environments

Muhammad Arslan<sup>1</sup>[0000-0003-3682-7002], Christophe Cruz<sup>1</sup>[0000-0002-5611-9479] and  
Dominique Ginhac<sup>2</sup> [0000-0002-5911-2010]

<sup>1</sup>Laboratoire d'Informatique de Bourgogne (LIB) - EA 7534

<sup>2</sup>Laboratoire Imagerie et Vision Artificielle - EA 7535

Univ. Bourgogne Franche-Comté (UBFC), Dijon, France.

muhammad.arslan@u-bourgogne.fr, christophe.cruz@ubfc.fr, dominique.ginhac@ubfc.fr

**Abstract.** Numerous studies have been conducted over the past few decades on human behavior modeling and simulation by incorporating the dynamic behaviors of people for different Facility Management (FM) applications. For example; the Drivers, Needs, Actions and Systems (DNAS) framework which provides a standardized way to conceptually represent energy-related occupant behaviors in buildings and allows an exchange of occupant behavior information and integration with building simulation tools. Despite numerous studies dealing with dynamic interactions of the building occupants, there is still a gap exists in the knowledge modeling of occupant behaviors for dynamic building environments. Such environments are best observed on construction sites where the semantic information linked to the building spaces evolve often over time in terms of their location, size, properties and relationships with the site environment. The evolving semantic information of a building is required to be mapped with the occupant interactions for an improved understanding of their changing behaviors using contextual information. To fill this research gap, a framework is designed for providing a 'blueprint map' to integrate DNAS framework with our Semantic Trajectories in Dynamic Environments (STriDE) data model to incorporate the dynamicity of building environments. The proposed framework extends the usability of a DNAS framework by providing a centralized knowledge base that holds the mobility data of occupants with relevant historicized semantic information of the building environment to study occupant behaviors for different FM applications.

**Keywords:** Behavior, Knowledge Modeling, Spatio-Temporal, Safety Management

## 1 Introduction

Humans are the important factor for building FM operations as they impact the building environments actively (i.e. production of heat because of their presence) and passively (i.e. operating building appliances) [1]. For ensuring an appropriate level of

quality of services to the building occupants, the most crucial challenge faced by the facility managers is to understand the occupant behaviors and their interactions with buildings [1, 2]. Although, this is a complex activity because the occupant behaviors and the buildings are dynamic in nature and context-dependent. Here, a context refers to any information based on the contextual factors such as space, time and environment utilized for categorizing the situation of occupants [3]. Failure in understanding occupant behaviors because of inadequate integration of all relevant contextual factors associated with the occupants and the building environments can result into serious financial and management crises such as under-utilization of the building spaces, decreased productivity due to poor environmental conditions, increased energy usage, and safety hazards [1, 3]. On the contrary, if the occupant behaviors are modeled and predicted effectively by incorporating all the possible contextual factors (social-personal, economic, etc.) which may influence occupant behaviors will lead to an increased physical comfort, enhanced safety at work and improved work performance of the occupants while keeping the level of building resources to the optimum [1, 3]. Existing literature [4 – 9] encompasses many studies for constructing occupant behavior extraction systems which help facility managers in decision making for facility management operations by modeling dynamic behaviors of building occupants which change over time according to the building environment. Despite numerous existing studies which model dynamic interactions of the building occupants, there is still a gap exists in the knowledge modeling of occupant behaviors for dynamic building environments. To fill this research gap, one of the prominent occupant behavior models i.e. DNAS is selected from the existing literature [4] based on its relevance to our case-study and popularity that is perceived from its citations. For incorporating the dynamicity of the building environments in terms geometry and semantic information, a frame-work named ‘DNAS-STriDE’ is proposed which aims to serve an extension of the original DNAS by integrating the conceptual modeling of DNAS with our data model named ‘STriDE’ (Semantic Trajectories in Dynamic Environments) [10]. The resulted framework by integration has provided a centralized knowledge base that holds the mobility data of occupants with relevant historicized semantic information of the building environment to study occupant behaviors for different FM application scenarios in buildings.

The rest of the paper is organized as follows: Section 2 describes the background of the study. Section 3 is based on the proposed prototype system. Section 4 presents the discussion, a conclusion and an outlook of the future work.

## 2 Background

Behaviors are the interactions (leaving or entering a room, visual and thermal indoor conditions adjusting using windows or blinds, doors, etc.) of building occupants which can be categorized into different movements, simple presence or actions with their environment (building, its systems and appliances) which impact on the building performance (heating/cooling, indoor air quality, energy, comfort, etc.) during a

building lifecycle [1, 2, 4, 5]. In majority of the situations, the occupants' presence is the precondition for any kind of behavior understanding as building occupants can only interact with the building environment only if they are present inside the building [1]. Thereby, an occupant interaction which results in changing a building state (presence or absence in case of occupancy monitoring) or no interaction leaving the present state of a building unchanged are both facets of occupant behaviors [1]. For understanding the occupant interactions, the modeling process of their behaviors conventionally initiates from the data acquisition of occupants along with the building environmental parameters [5]. The quality of data captured from various types of sensor data acquisition systems differs greatly in terms of the resolution of the sensors deployed [1, 5]. Spatial, temporal and occupant resolutions are combined for determining the overall resolution of the system for capturing the occupant behaviors. As the resolution of the captured sensor data increases, the building space gets more precise, the occupants become more distinct based on their identities and the information from the sensor data is accessible faster [5]. For example, a low-resolution system will only capture the binary information (presence/absence) of the occupants in a specific time where the identities of the occupants are not recognized. Whereas, a high-resolution system will be able to detect the number of occupants, their identifications, as well as their activities [5].

Once data is acquired of occupant behaviors, the quantitative analysis is performed on the collected data and correlations are extracted between the occupant behaviors and the environmental parameters using a set of contextual factors. For modeling the occupant behaviors, conventionally there exists four types of approaches [1, 5] which are: 1) static-deterministic, 2) static-stochastic, 3) dynamic-deterministic and 4) dynamic-stochastic. After applying the most appropriate modeling approach, a process of understanding occupant behaviors is evaluated to find out the reliability and effectiveness of the employed model used for extracting insights. The whole process of modeling occupant behaviors and evaluating a model is iterative which helps in tuning the model for best results [1, 5]. As a result, occupant behavior model functions as a stand-alone system or the output of the model is linked with the Building Performance Simulation (BPS) programs or Building Information Modeling (BIM)-based tools for further experimentations or generating information-enriched visualizations [5].

### 3 DNAS-STriDE Framework

After an extensive review of behavior modeling, it is observed that majority of the existing systems [4 - 9] model human behaviors by capturing the stochastic and reactive nature of their behaviors in building environments. However, these models do not cater the complex dynamic environments where the building objects evolve over time. For example, DNAS framework is proposed by Hong et al. [4] which is based on ontological modeling and used for describing the impact of occupant behaviors on energy use of buildings. This impact can be represented using four components which are drivers, needs, actions and systems. These four components of the framework

encompass the building environment and cognitive processes of the occupants. DNAS framework has provided a basic ontological method for representing the energy-related occupant behaviors. However, DNAS is only a conceptual ontological model and requires more developments so that it can be used as a stand-alone or an integrated solution for extracting insights about occupant behaviors in dynamic environments. To further develop the existing DNAS framework, this work reports upon a DNAS-STriDE framework which offers; 1) a centralized knowledge base for mining behavioral interactions of the occupants which can be in the form of occupant-to-occupant, occupant-to-building or building-to-occupant interactions, 2) a process of data enrichment of DNAS ontology using the results of a state-of-the-art machine learning model (Hidden Markov Model (HMM) in our case) in the form of ‘hidden states’ which are used to find the correlations and patterns in the acquired sensor data for studying the occupant behaviors, moreover 3) incorporation of the dynamicity of the building locations in data modeling stage in terms of the evolving spatial and semantic information over time.

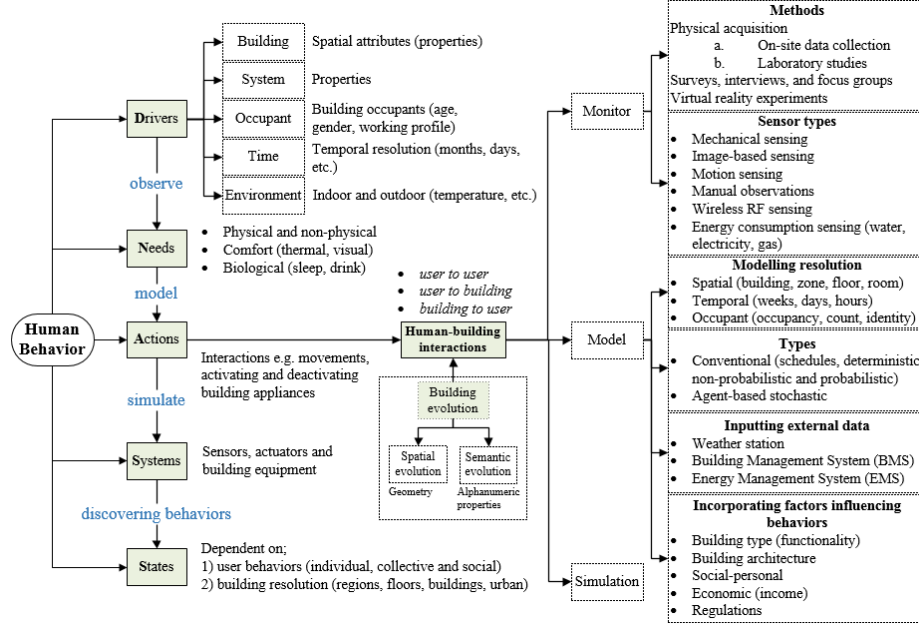
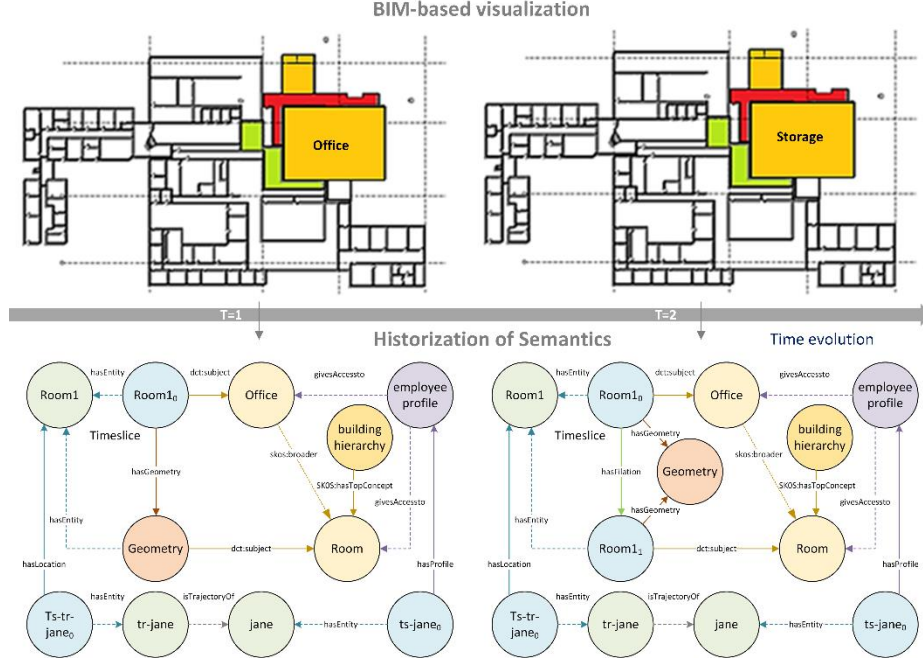


Fig. 1. DNAS-STriDE framework

The proposed framework (see Fig. 2) requires sensory data to perform behavioral analysis. The acquisition of relevant sensor data is based on the application requirement. For example, the safety manager of a building requires to monitor the movements of the occupants in a building. In this case, using our DNAS-STriDE framework, ‘driver’: monitoring movements of occupants, ‘need’: safety management in a building by identifying unsafe movements, ‘action’: tracking movements of occupants using their spatio-temporal trajectories, ‘system’: Bluetooth Low Energy (BLE) beacons for sensor data acquisition and ‘states’: 1) static (no movement), 2) normal movement ( $0 < \text{steps} \leq 84$  and  $\pi/2 \leq \text{angle} < \pi$ ) and 3) risky/unsafe ( $\text{steps} > 84$  angle  $\geq$

$\pi$ ). More information on movement states can be found in [11]. For understanding mobility-based behaviors for a safety management application, BLE beacons are installed on different building locations. After sensor data acquisition, the acquired location data is transformed into trajectories after preprocessing (i.e. filtering). More information on trajectories and their preprocessing can be found in [3]. After preprocessing the trajectories, the STriDE model is used for the semantic enrichment [10] for incorporating the contextual and application-based information in processed trajectories. The STriDE model is designed using a Continuum model having the ability for storing data as well as performing semantic enrichments of moving and changing objects' trajectories [6]. For the semantic enrichment, the STriDE model uses a set of classes and properties from the existing vocabularies. The vocabularies are used for defining the concepts and relationships by classifying the terms used to describe an area of concern for a specific application. Our STriDE model uses three different vocabularies which are; 1) Simple Knowledge Organization System (SKOS), 2) Dublin Core Terms (DCT) and 3) GeoSPARQL (GEO).

For tracking the evolution of building objects (users, trajectories and rooms), the STriDE model uses the concept of timeslices [10]. A timeslice includes four components which are; an identity, some alpha-numeric properties, a geographical component and a time component for indicating the validity of timeslices [10]. At the occurrence of any modification in any component of a timeslice excluding the identity, a new timeslice is generated inheriting the components of the last known timeslice. In addition, to achieve user profiling, corresponding concepts are tagged with the user timeslices for achieving the desired access control of building locations. To show a proof-of-concept application of our DNAS-STriDE framework for holding the building evolution along with the semantically-enriched trajectories, let's suppose we have a building from where the spatio-temporal data has been acquired (as discussed above) as shown Fig. 2 and the purpose of one of the building locations is changed. The location 'office' is now a 'storage room'. As shown in Fig. 2 that the STriDE model uses 'concepts' which are stored in 'concept scheme' for describing the building locations. As soon as the semantics which is the functionality of a room is changed, a new timeslice is created. In Fig. 2, there is a hierarchy of SKOS concepts. It has a `skos:hasTopConcept` link towards the `skos:Concept` room. Two other `skos:Concept` (office and room) are defined. All these concepts form a hierarchy. In addition, there is a profile named `employeeProfile` which gives access to all the concepts and to its members. For instance, a user Jane is an entity of a `TimeSlice` `ts-jane0` and her position is tracked by a `Trajectory` `tr-jane`. There is also another entity called `room1` which was initially an office (as suggested by the `dct:subject` link of `tr-room10` towards the concepts office). Later, this room is changed as a storage unit as shown by a relation between `ts-room11` and storage. Note that a geometry of the room (in Red) is not changed, but only its usage. We can also observe using a link between `tr-jane0` and `room1` that Jane is in `room1`.



**Fig. 2.** DNAS-STriDE historization of building evolution (Timeslices (ts) are in Blue, entities are in Green, SKOS concepts are in Yellow, profile is in Purple and geometry is in Red color).

## 4 Discussion and conclusion

The STriDE is primarily designed to carry out mobility-based analysis after incorporating the semantics in raw spatio-temporal occupant trajectories. Once the spatio-temporal data of occupants is collected, a process of knowledge modeling will take place. Knowledge modeling is a process of capturing and modeling knowledge into a reusable structure for the sake of historization of information, sharing as well as reapplying it for different applications [12]. DNAS ontological framework is integrated with our STriDE model to provide a data storage and enrichment platform to generate semantically-enriched data of building occupants. After achieving the historization of semantically-enriched trajectory data of building occupants, probabilistic models can be applied for categorizing different types of movements in the mobility data. For categorizing the mobility data of occupants in our study, HMMs are used. However, literature contains numerous other probabilistic models for data categorization and each one of them has different benefits and limitations. To categorize trajectory data into three states which are static, normal and risky, the values of step length and turning angles are used for defining the hidden states. In Fig. 2, at a time instance the most probable stay locations of occupants are shown in Green in color using the universal Architecture, Engineering & Construction (AEC) industry standard i.e. Building Information Model (BIM). Whereas, the most probable building locations at a time instance where there are the normal and risky movements of occupants are

shown in Yellow and Red in color. Such BIM-based dynamic visualizations provide insights about building occupants' movements in real-time. As a result, locations with risky movements can be easily identified, and necessary actions can be taken accordingly by the safety managers. Managing the safety in a building by acquiring spatio-temporal trajectories is one of the use-case of the proposed DNAS-STriDE framework. However, the proposed framework can be used in different other applications for managing the information of occupants and evolving building infrastructure during a building lifecycle starting from a construction phase to a facility management phase.

### ACKNOWLEDGMENTS

The authors thank the Conseil Régional de Bourgogne-Franche-Comté and the French government for their funding. The authors also want to specially thank Orval Toutou for his technical assistance to this research work.

### References

1. Wagner, A., O'Brien, W., Dong, B.: Exploring occupant behavior in buildings, Methods and Challenges. Springer (2018), ISBN: 978-3-319-61464-9.
2. Chen, S., Yang, W., Yoshino, H., Levine, M.D., Newhouse, K., Hinge, A.: Definition of occupant behavior in residential buildings and its application to behavior analysis in case studies. *Energy and Buildings* 104 (1), 1-13 (2015).
3. Arslan, M., Cruz, C., Ginhac, D.: Semantic enrichment of spatio-temporal trajectories for worker safety on construction sites. *Personal and Ubiquitous Computing*, 1-16 (2018).
4. Hong, T., D'Oca, S., Turner, W.J., Taylor-Lange, S.C.: An ontology to represent energy-related occupant behavior in buildings. Part I: Introduction to the DNAs framework. *Building and Environment* 92, 764-777 (2015).
5. Yan, D., O'Brien, W., Hong, T., Feng, X., Gunay, H.B., Tahmasebi, F., Mahdavi, A.: Occupant behavior modeling for building performance simulation: Current state and future challenges. *Energy and Buildings* 107, 264-278 (2015).
6. Chen, H., Luo, X., Zheng, Z., Ke, J.: A proactive workers' safety risk evaluation framework based on position and posture data fusion. *Automation in Construction* 98, 275-288 (2019).
7. Goh, Y.M., Ubeynarayana, C.U., Wong, K.L., Guo, B.H.: Factors influencing unsafe behaviors: A supervised learning approach. *Accident Analysis & Prevention* 118, 77-85 (2018).
8. Fang, W., Ding, L., Luo, H., Love, P.E.: Falls from heights: A computer vision-based approach for safety harness detection. *Automation in Construction* 91, 53-61 (2018).
9. Ding, L., Fang, W., Luo, H., Love, P.E., Zhong, B., Ouyang, X.: A deep hybrid learning model to detect unsafe behavior: integrating convolution neural networks and long short-term memory. *Automation in Construction* 86, 118-24 (2018).
10. Cruz, C. Semantic trajectory modeling for dynamic built environments. In: *IEEE International Conference on Data Science and Advanced Analytics (DSAA)* 2017, pp. 468-476. IEEE.
11. Arslan, M., Cruz, C., Ginhac, D.: Understanding worker mobility within the stay locations using HMMs on semantic Trajectories. In: *14th International Conference on Emerging Technologies (ICET)* 2018, pp. 1-6. IEEE.
12. Pittet P., Cruz, C., Nicolle, C.: An ontology change management approach for facility management. *Computers in Industry* 65(9), 1301-1315 (2014).