ACTIVITY BASED & BEHAVIOURAL OCCUPANCY MODELLING FOR EE BUILDING DESIGN

Christos Malavazos, Dimitrios Tzovaras, Dimosthenis Ioannidis

Analysis of building energy efficiency at the early stages of the design process has been viewed in the past few years with increasing interest by key stakeholders such as architects, designers and mechanical engineers as well as by the research community. Early design products comprise features that determine to a large extend energy performance and thus can provide critical evidence to simulation and analysis tools for thorough evaluation of design alternatives. Capitalizing on the actual effect of building occupancy (human presence and movement) in the overall energy consumption during the early design phases of a building, this paper addresses the need for a common set of reference models definition for correlating the two disjoint worlds in the building domain, the building information models and the business processes models of an organization that will be housed in the building. The paper introduces a set of domain semantically enriched models that can express occupancy using spatio-temporal information and incorporate space utilization definitions taking into account enterprise-related information at various levels. To cope with interoperability with existing simulation tools, a provisional extension to the green building schema (gbXML) is examined towards incorporating the necessary information needed for realistic and accurate evaluation and optimization of alternative energy efficient building designs.

1. INTRODUCTION

1.1. Motivation

Energy Efficiency is considered to be a key component of the European energy policy underlying the fundamental objectives of the European Union's (EU) 2020 strategy. Buildings are a major constituent of the urban ecosystem accounting for almost 40% of the overall energy demand in Europe[1]. Urban Sustainability heavily relies on building operational and space utilization characteristics as well as the behaviour of their occupants.

Past and recent studies on energy efficiency in buildings indicated that appropriate design improvements, tailored with the support of building performance simulation software, could reduce energy use in both existing and in new building envelopes[2]. With enriched simulation results in hand, planners, designers and architects will be able to analyse the future performance of a building envelope with sufficient accuracy and granularity, taking into account both descriptive data on the building (material, components, equipments, space layout, etc) and information related to the dynamic behaviour of the building due to its usage and operation by humans. Focusing on the early design phases of a construction product, there is lately an increasing emphasis on delivering simulation tools and methods that improve the prediction of the building energy use by analyzing also the performance in connection with the space utilization of the building by its occupants[3].

Focusing on the early design phase and attempting to deliver a holistic building performance simulation framework that fully captures the dynamic behaviour of buildings operations addressing the various features underlying the organizational processes and respective spatio-temporal occupancy and control behaviour patterns, this paper presents a thorough analysis of the shareable information that needs to be modelled and proposes a set of provisional reference data models.

The models and the vocabularies proposed can be considered as a further extension of BIM in the domain of commercial premises, towards incorporating business process modelling (BPM) elements regarding organizational structure and respective business processes performed by its occupants. The appropriate utilization of the respective models would allow further enhancement of Building Performance Simulation (BPS) tools with advanced capabilities such as i) the more robust and accurate analysis of the performance of a facility under design regarding its space usage at an early stage and ii) the optimization and balancing of often conflicting building performance aspects, namely energy efficiency, business performance and comfort, taking into account the information from the later "real" behaviour of the building due to its occupancy.

The rest of the paper is organized as follows. Initially, section 1.2 provides a literature review on the current approaches used for modelling the building occupancy as well as the human activity behaviour in buildings. Section 2 presents data models related to the user behaviour as a building occupant. Next Section 3 investigates the delivery of a flexible set of data schemas for incorporating organizational aspects such as actors, roles, enterprise units and other information related to business process models, whereas Section 4 exploits the interaction of the user behaviour models with the enterprise ones. In Section 5, the proposed XML schema for space utilization simulation is presented, whereas Section 6 concludes with an overview for the use of such models in building performance simulation frameworks.

1.2. Related work

Construction products are designed and delivered to accommodate user's organizations and respective assets, and eventually to enable its occupants to utilize its spaces[4] by performing every day activities. As of today, several methods and modelling techniques have been investigated towards analyzing and predicting the building occupancy that can serve as input to building performance simulation tools for predicting and evaluating its performance in terms of space usage and energy consumption.

Abushakra et al.[5] proposed a well-established method that represents occupancy in a building via a time-variation model, which is described through schedules and diversity factors[6]. Daily or yearly schedules can be estimated using onsite survey or through individual experience. Then these schedules can be applied to building spaces with similar characteristics for calculating the energy consumption due to the impact of human presence in internal heat gains and cooling loads. In addition, diversity factors were proposed to correct average heat gain estimations from the aforementioned schedules, but in general they cannot elucidate the stochastic variations of building occupancy in the spatio-temporal domain. Overall, diversity profiles offer a cost effective "black-box" modelling approach of the average occupancy, however they fail to capture many of the underlying relations between features and critical evidence affecting occupancy variations.

To cope with occupancy dynamics and human presence in time and space, Wang et al.[7] proposed a probabilistic method to estimate the occupancy schedule in a single person office. The method proposed, assumes that building occupancy and vacancy intervals during working hours are independent and sequential random variables and models the durations of presence and absence during business hours with exponentially distributed random variables. The coefficients are estimated through measurement data, whereas indicative time-dependent parameters such as arrivals and departures in the single office are modelled with normal distributions towards simulating the occupant pattern. The specific approach addressed single person offices which is not always the case in real life situations. Furthermore, intermediate periods of presence and absence during the working day were treated as exponential distributions with a constant coefficient over the day. This hypothesis was confirmed in the case of absence but not in the case of presence.

A more comprehensive occupancy model was proposed by Zimmerman[8] for the aim of improving the building control system (lighting, heating and cooling system), which investigated the modelling of user activities over time taking into account user groups, their roles in functional units and the tasks that they may perform.

In addition, Tabak[9] presented a sophisticated framework for simulating the human behaviour in buildings for any given organization. He investigated thoroughly the activities performed in office-based organizations and tried to make a taxonomy of tasks executed by building occupants as well as to analyze the factors (individuals, organizational) that influence the interactions occurred between individuals (e.g. attend a business meeting, give a presentation, etc).

In his study, Tabak categorized activities in three different ways depending on i) the nature of the activity (social, physiological or business related; ii) the number of occupants involved resulting in solo or group activities, and iii) the type of the activity such as planned or unplanned. His approach to the human activity behaviour simulation was based on the definition of activity schedules, which were linked with the employees of the analysed organization. An activity schedule contains a time ordered set of activities consisting of primary (skeleton) and secondary activities, whereas each activity is performed in a building space (location) and can involve, depending on the nature of the business process, one or more enterprise resources (e.g. occupants or facilities).

Skeleton activities as defined by Tabak reflect actual business processes, which eventually increase the level of complexity and degree of granularity of the models. As a result, the approach requires a high number of input parameters related to organizational structure and operations. A sensitivity analysis indicating the statistically significant input features that influence the occupancy variations is lacking. Furthermore, a more high level, abstract modelling of activities could provide equivalent simulation performance while at the same time minimizing the necessary user input parameters.

A similar approach for generating fictional occupancy in buildings was proposed recently by Goldstein et al.[10]. A hybrid approach was proposed to produce more realistic patterns of human behaviour in buildings, in which information found in statistical occupancy schedules was combined with optional parameters supplied by the user in the form of personas attributes (e.g. arrival/departure times per occupant, probabilities for office meetings, offsite break, etc).

In a recent study from Shen et al.[11], a framework is introduced, namely Building Information Modelling-based user activity simulation and evaluation method (UASEM), whose ultimate goal is to conduct preoccupancy evaluation of buildings under design and to provide via user activity simulation better understanding of the design solutions in terms of space layout utilization.

The above overview indicated several ongoing developments and research studies that aim at demonstrating various modelling techniques with the capacity to realistically reproduce significant properties and attributes of human presence and movement in buildings under design. Results have mainly been used as input to building performance simulations tools[12], towards improving the energy use predictions of the building under design.

2. ACTIVITY BASED AND BE AVIOURAL OCCUPANCY MODELS

Accurate analysis, prediction and simulation of occupant behaviour in the early building design phases can significantly improve the predicted performance of the buildings, while simulation tools can further assist designers, planners, architects and engineers to reduce uncertainty at early design phases due to occupancy.

The ultimate goal for the delivery of a detailed occupancy model in buildings is to provide the necessary information related to occupants' presence and movements in the building spaces, to define user-related activity schedules with high level of granularity (sub-hourly, hourly, daily, weekly, monthly, yearly, etc.) and to analyze with mathematical methods the spatio-temporal correlation between the occupant and the locations (*spaces or zones*) in which the human activities take place.

Combined approaches that incorporate both occupant's presence and movement with occupant's control actions (behaviour) into a single model, present significant limitations and weaknesses. We propose a modular approach consisting of two separate models: a) an activity based occupancy presence model, subsequently followed by b) an occupant control behaviour model. This approach presents several obvious advantages. Firstly, we significantly reduce the model dimensionality problem during training

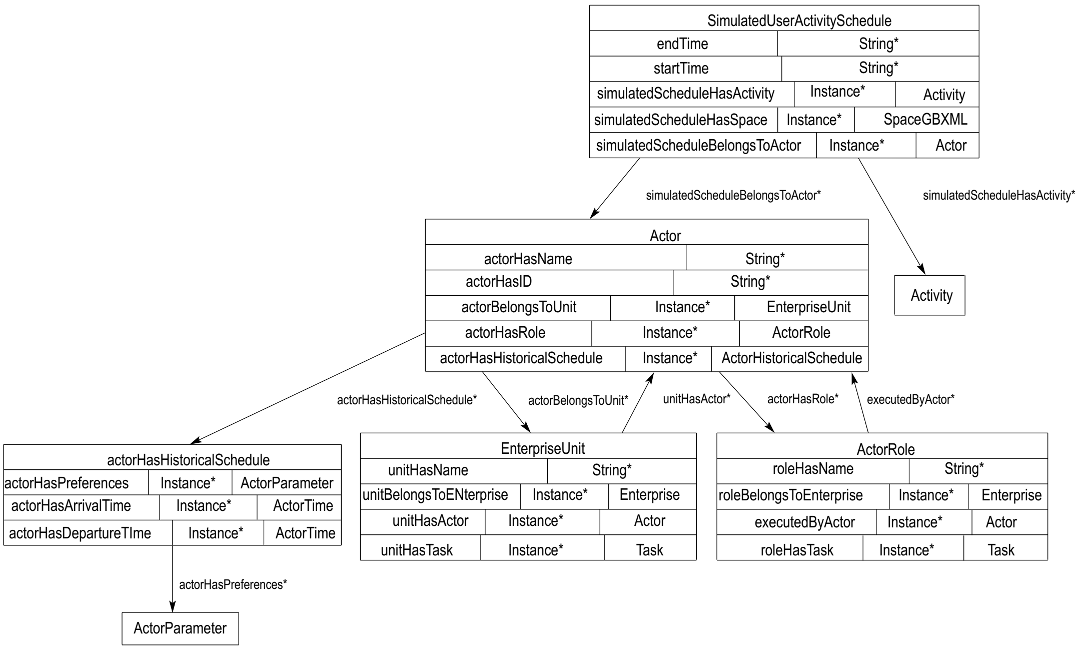

Fig. 1. Semantically enriched data schema for the definition of actors (occupants of a building) and correlation with activities/business processes, equipment utilization through human presence and movement in building spaces.

and calibration. The two models can be trained and calibrated independently focusing only on a subset of the relevant contextual evidence. Secondly, both models can be used independently providing flexible input to other building performance simulation tools, covering alternative aspects of building design (lighting, windows, etc) that require input of varying granularity. Finally, the overall approach is considerably more flexible and more parameterised towards addressing alternative building and domain alternatives.

The term activity schedule is used in the literature to encapsulate an individuals' schedule in a temporal manner, composed of various series of activities performed during his/her presence in the building. The complexity of each task is highly correlated to the occupant's role (*actor*) in the *organization* and is partially depended on his/her role in respect to the enterprise (visitor/guest, employee, etc). Furthermore, business-related tasks depend on the building static layout (space adjacencies and locations) as well as from additional key factors (enterprise assets, *equipment* type and locations in the building spaces) that are mostly provided via BIM models.

A provisional schema for the building occupant (actor) is illustrated in Figure 1. The schema correlates the building occupants with an enterprise department (e.g. actor belongs to a unit and has a specific set of roles), with user preferences (schedules, optional parameters for absence durations, breaks, etc) and associates an actor with business tasks due to its position to the enterprise.

The data schema is semantically enriched with concepts (classes), has a formal representation (ontology data and object properties), and can be seen as a basic generalized model for defining a building occupant correlated with the enterprise domain model.

A more detailed schema view for modelling the user activity behaviour is provided in Figure 2. The proposed activity modelling

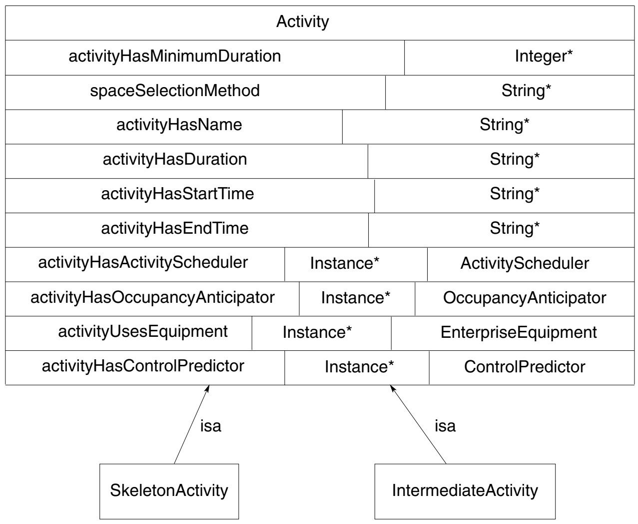

Fig. 3. High-level schematic representation of an activity and instantiation via skeleton or intermediate activities.

schema further elaborates on the groundwork presented by Tabak[13], where both activity and workflow modelling approaches are integrated to enable mimicking the behaviour of real human beings when scheduling activities in an enterprise building.

It supports the division of users' activities in "*skeleton*" and "*intermediate*" activities (Figure 3), where the former are related to direct enterprise workflow dependent activities (e.g. "give a presentation", "perform health check-up on a patients' room", "do research", "attend a meeting") and the latter are strongly depended

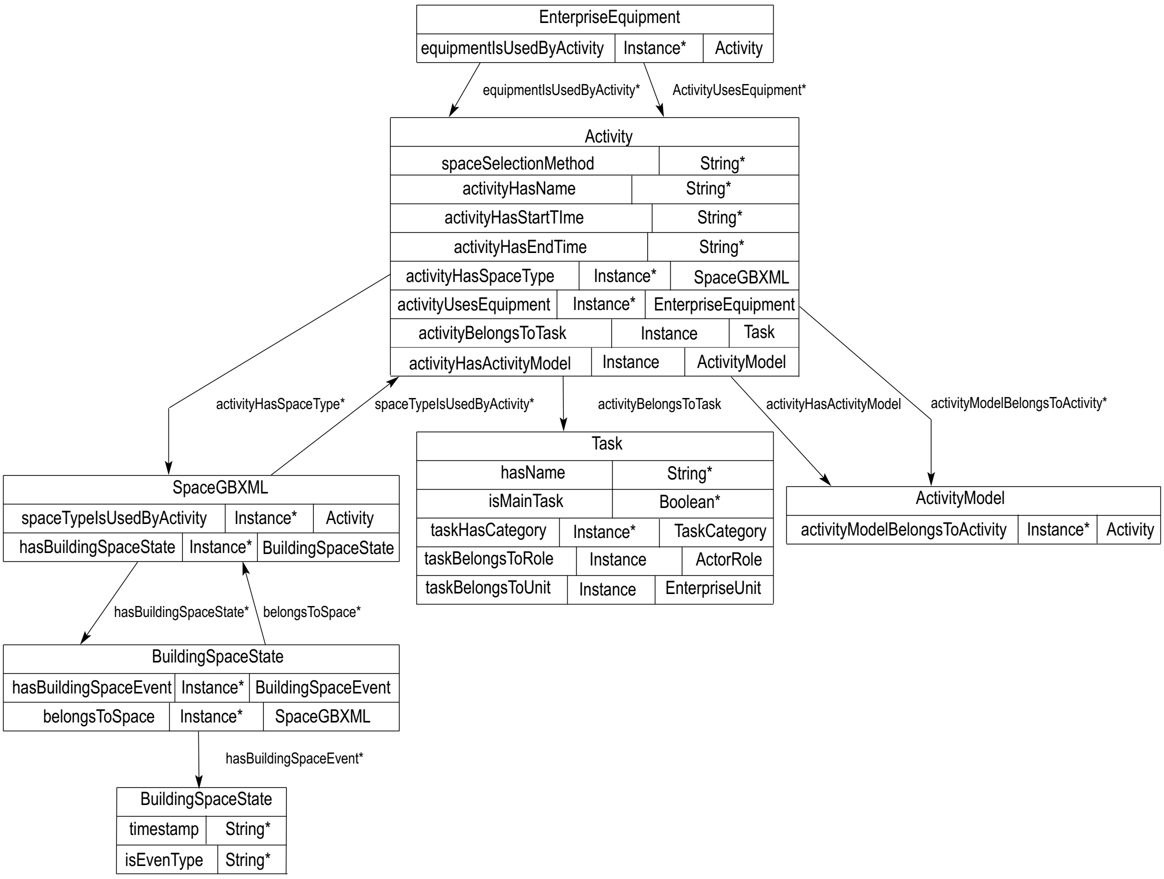

Fig. 2. Detailed schema view of the activity modelling and provisional correlation to the building spaces and resources (equipment, material, etc.)

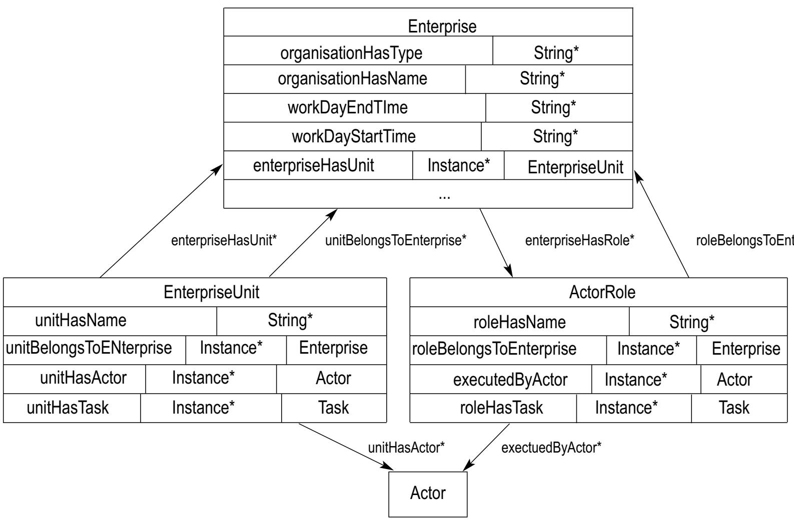

Fig. 5. Schema for enterprise modelling and utilization in frameworks for analysing building occupancy.

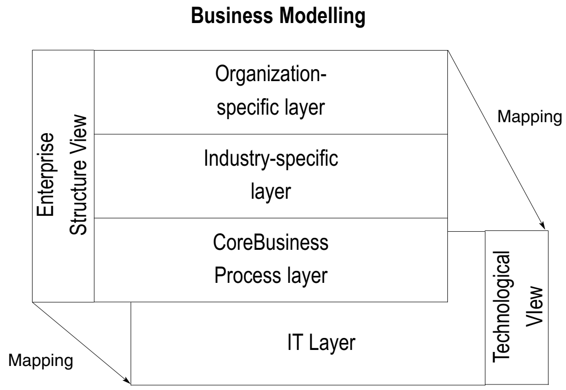

Fig. 4. Semantically enabled three-dimensional layers for business process modelling and management.

on the social or physiological needs (e.g. "get a drink", "smoke", "have a break", "walk to enterprise asset", "receive visitor/guest").

The efficient management of continuous time series of recorded sensor and meter data poses significant challenges. To this end, our framework proposes the pre-processing and normalization of low level data and decoupling of input/sensor data of different time and spatial granularity. This way we reduce the spatio-temporal dimensions of the various learning models while also delivering more semantically abstract, robust and flexible models, applicable to different variations of similar building spaces (e.g. when we move from one office to another, even though retaining similar sensor settings and topologies, low level data acquired by sensors present variations that are handled at the lowest level, before entering input data to the occupancy models).

After the pre-processing and normalization of input data, feature vectors are extracted, consisting of features that present the highest Information Gain. Low level building space events (*BuildingSpaceEvent*) are extracted based on these, reflecting the basic changes in the contextual environment of each building space (*BuildingSpaceState*). Higher level events related to activity based occupancy and control behaviour, will subsequently be extracted and composed based on these low level events.

The schema provides a basic reference to activity types such as skeleton (primary) and intermediate activities (secondary) and links them with mathematical methods (*ActivityModel*) that can analytically describe their scheduling prediction method.

The basic schema is notable for its flexibility as different levels of detail can be instantiated depending on the design phase of the building (level of development - LOD). For instance, in the schematic design phase, the building models would contain geometry and functionality of building objects, including spaces, base, walls, decks and roof, which are essential for the early analysis of selected systems in terms of sustainability, structure and space utilization.

Focusing on the energy efficiency and space utilization simulation, the provisional enterprise behavioural model (imported from a knowledge share repository) in this phase, could contain information for the actors, their roles and the business tasks they can perform in the enterprise. Then, behavioural patterns could be reproduced in a simulation (space utilization) based on various attributes described in the mathematical models used for the activities, such as the frequency, duration, number of occupants involved (solo or group tasks) depending on the probabilistic method used for modelling each activity.

In case the level of design and development progresses (BIM is also enriched with precise quantities of materials, equipments, etc.), the human behavioural modelling can be further elaborated with more information about user preferences (in terms of "personas" with different attributes such of presence time, duration of breaks, involvement in business tasks based on their role to the organization, number of occupants in business processes, etc), towards providing a more realistic simulation for the building under design. The additional characteristics and attributes of "personas" are encapsulated within the concept "*ActorParameter*", as illustrated in Figure 2.

The additional parameterization would support key stakeholders involved in the design process with customized occupant behaviour simulations towards assessing the building energy use and overall performance, taking into account the specific requirements set by the building tenants and property owners.

3. BUSINESS MODELS

One of the key ambitions for the near future in designing and constructing energy efficient buildings is to capitalize on the synergy between the collaborative use of two correlated models, the building information models (BIM) and the business process models (BPM) defining the organizational structure of an enterprise. As of today, architects, designers and engineers lack the tools that will assist them in the complete evaluation of the energy performance of alternative design decisions towards producing better and more sustainable construction products, taking into account all aspects, including one of the most important factors, that of occupants' behaviour.

The last generation of business process management tools provide an integrated view on business aspects (actors, activities, events, processes) and according to Saravanan et al.[14] the enterprise view can be conceptualized, as illustrated Figure 4 in into three semantically enriched layers: i) the core business layer, ii) the industry-specific layer and the iii) organization-specific layer.

Depending on the purpose of use, different business models can be instantiated having as main scope to accommodate the context of use. In this paper, focus is given on the specific view of an organization model that is "housed" in a building envelope and targeting one of its main catalysts factors, the building occupants. The ontological schema defined for modelling an organization for this purpose is illustrated in Figure 5.

An *enterprise* typically consists of many individuals (*actors*), who have diverse roles (*ActorRole*) and belong to different organisation units (*EnterpriseUnit*). As already described in Section 2, the behaviour of building occupants (as individuals) is highly dependent on their assigned roles, their individual preferences and other factors correlated with their social and physical needs.

The core business layer (Figure 4) can be used to define the generic role concepts (actors, units) of an enterprise, while the organization-specific layer would extend these concepts by defining roles that are specific to that particular organization. At the very end, the IT Layer represents the translation and mapping of the business knowledge (business flows, events, etc) into a "technical" representation.

The conceptual model (ontology) of an enterprise presented in Figure 5, is a provisional set of classes and corresponding properties that need to be interchanged between the BIM and the BPM models. The exchange of the information shall support both import and export functionalities, focusing mainly on the data imported in BIM model during the design phases of a building. Data integrity is still an open issue in the AEC industry, thus the contribution on this part will be on enhancing the so called Virtual Building Modelling (VBM), in which more informative models are delivered for utilization in diverse but complementary domains[15], such as building structural detail, energy-use analysis, cost estimation, business performance analysis, etc.

The incorporation of business modelling in the BIM process will foster the optimal collaboration between project stakeholders through the whole life cycle of a building. Moreover, their utilization in the early design phases will enrich current practices in space usage analysis and energy consumption, by delivering new services and tools to planners, designers and engineers to understand the building performance from different perspectives, including the dynamic performance of the building due to the human presence and movement.

To cope with dynamic building occupancy, the incorporation of static and descriptive data of an enterprise is not enough. The actual business flows (tasks, processes) encountered in an organization shall be modelled and certain parameters that may affect the building performance models shall be investigated.

Furthermore, even though business activities and respective tasks are different in scope, however the contextual information describing these business events is often quite similar. Spatio-temporal data acquired by building sensors will not always provide sufficient evidence to differentiate between the activities. Therefore, appropriate analysis of the underlying business models in conjunction with statistical data acquired from pilot premises must be combined in order to identify the most representative and informative contextual evidence (actors, artifacts/equipment per zone and activity). Moreover, incremental processing and parsing of these data will be required in order to establish robust and accurate correlations between activities and contextual evidence.

Next paragraphs introduce the necessary schema definitions towards correlating the building descriptive data (spaces, resources, material, and equipment) with the business processes (tasks, activities) that will encounter in the building under design during its operational phase, having as main catalyst the building occupants. By analyzing the relationships in spatio-temporal domain (spaces, activities, occupant schedules, etc) of a building under design, key stakeholders will have the opportunity via parameterization of the models, to easily and rapidly simulate the building space utilization, towards supporting their decisions in both optimal space planning and energy efficiency of the buildings at the early stages of the design.

4. COMBINING ACTIVITY AND BEHAVIOURAL OCCUPANCY MODELS WITH BUSINESS MODELS

Existing building energy modelling and performance tools primarily focus on the building envelope itself and rarely use detailed information for the building users and the activities that they may perform (e.g. organization and business processes).

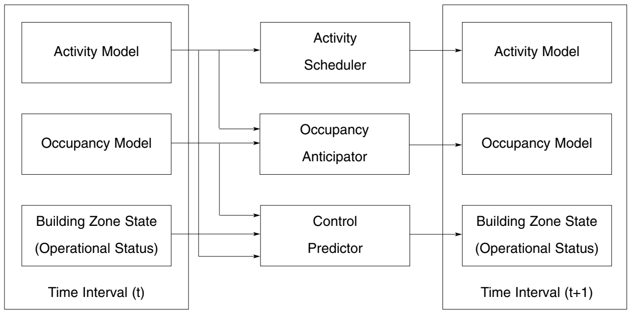

Fig. 6. Activity-based occupancy and Control Behaviour Prediction.

Specifically, current tools use detailed information for building spaces when evaluating the energy performance such as the envelope material, HVAC systems, lighting systems, etc. However, designers and engineers utilize only limited data about the business organization and the processes that the building under design will “house” during its operation phase.

For example, current tools use information about the single usage of a building space and static historical occupancy schedules that may not provide an accurate prediction of the real energy performance of the building under design. To cope with this, the correlation between the two disjoint worlds is needed, the one that contains information for the building spaces and resources in terms of material and equipment (BIM) and the one that provides detailed information on the most frequent business flows (BPM). The exchange of information among these two models is essential towards better supporting the AEC industry in delivering energy efficient buildings fully respecting the building construction standards and its occupants.

Towards delivering new tools and methods for building simulation frameworks that supports both space utilization and energy use analysis of design alternatives, there is a need to define reference schemas (data models) that will allow the decision-makers to easily share, generate and compare several design scenarios.

Figure 6 presents the proposed occupancy prediction framework for a single building zone, between consecutive time intervals. The Occupancy Anticipator is responsible for the occupancy prediction for the next time step, based on the current activity and occupancy data. The Building Zone Control (on single space level) operations on the next time step are governed by the Control Predictor based on the existing Occupancy data and Zone status (environmental conditions and equipment operational status). Activity flows are estimated by the Activity Scheduler based solely on Activity statistical data.

Moreover, Figure 7 illustrates the definition of a cornerstone hierarchical conceptual model that will enable building simulation engines to support space utilization simulation, which is one of necessary steps for delivering fictional and parameterizable occupancy schedules for building performance evaluation and assessment.

The schema is capable enough to represent the basic interactions among the building, the enterprise and the occupant’s domain. Particularly, a set of business processes (*Task*) can be defined and correlated with enterprise units (*EnterpriseUnit*) and subsequently with the actual individual employees (*Actor*).

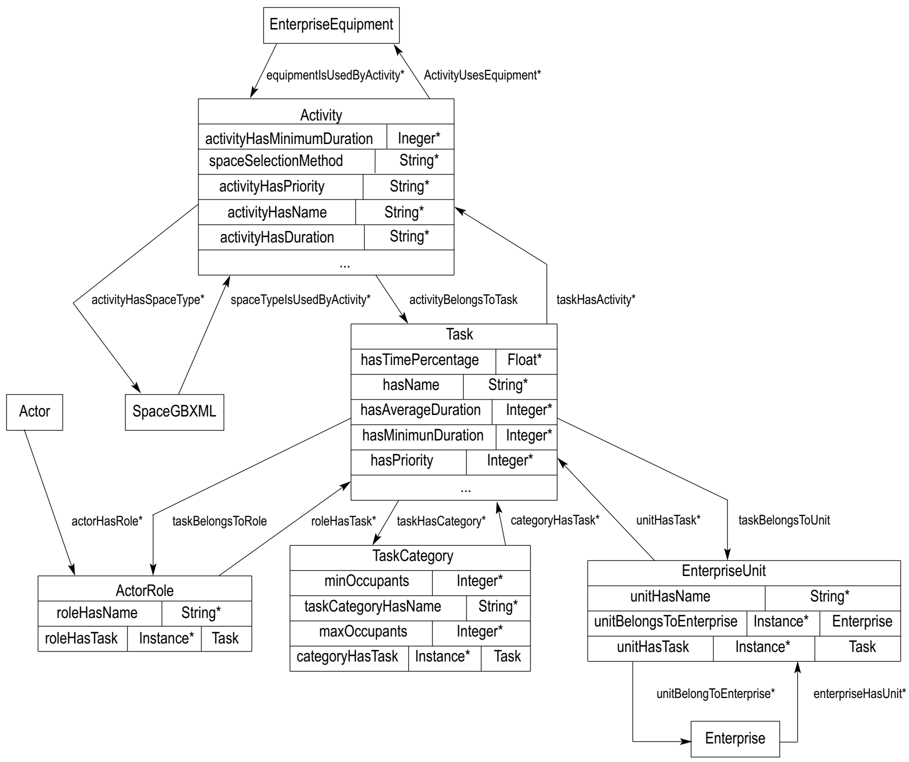

Fig. 7. Schema for business processes (tasks, activities) encountered in a building and correlation to occupants and building material and equipment.

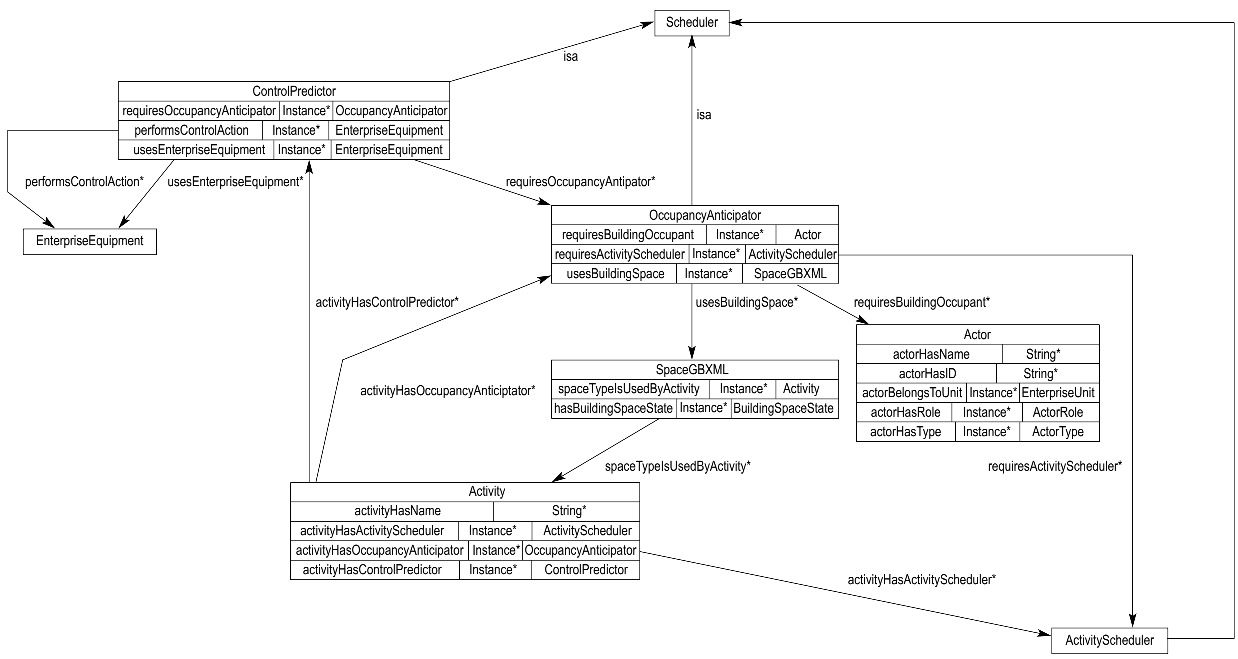

Fig. 8. Incorporation of schedulers to support scheduling processes for activities, interaction among activities and/or actors, role-based activity location and participants' selection, etc.

Capitalizing on the definition of a business process, which involves a sequence of several processing steps (*Activity*) to accomplish organization related objectives, each actor can be assigned according to its role in the organization in several tasks during a working day.

Going one step further, as already described in section 2, tasks are associated with primary and secondary activities (*SkeletonActivity*, *IntermediateActivity*) and can occur at certain locations of a building envelope (*SpaceGBXML*). Depending on the level of development of the building, the BIM may contain detailed information on technical systems (*EnterpriseEquipment*) such as lighting and HVAC systems. In such as case, the model is flexible enough to accommodate such concepts, fully interoperable and shareable with the definition of corresponding models in the BIM domain (e.g. gbXML internal and external equipment).

The schema can be further extended (Figure 8) with the introduction of "Schedulers"[16], as well as "Occupancy Anticipators" and "Control Predictors".

The "*Schedulers*" determine the order in which activities and tasks are activated within the building. The complexity of the data model can increase further when personal scheduler per occupant must be combined with the business processes encountered in an organization. Activity schedulers (*ActivityScheduler*) are responsible to determine the plan of an activity (skeleton or intermediate, solo or group, etc) including but not limited to the estimation of the start time, end time and duration. Given the activity status, "*Occupancy Anticipators*" can further support the simulation process with additional functionalities such as finalizing the involvement of one or more occupants (*Actors*) to specific activity schedules thus also enabling the interaction between building occupants (e.g. number of people needed to perform a primary activity) as well as the specific building zones where occupants will move to perform these activities. Finally, given the occupancy status within each building zone (as provided by the anticipators) the "*Control Predictors*" determine the control actions made by specific actors over the utilities of a specific building zone and towards performing a specific task (e.g. activity "attend meeting" involves the use of a projector, computer, etc). Next section illustrates how the conceptual schemas presented for modelling the dynamic behaviour of a building due to its occupancy and the enterprise can be linked to the gbXML standard, towards further enriching the virtual representation of a building design (VBM) in a flexible and sophisticated way.

5. OCCUPANCY MODELS IN BIM

The past few years' significant progress has been made in terms of interoperability and data sharing in the building industry.

The delivery of respective informational infrastructures (e.g. gbXML, IFC) in the AEC industry has fostered the shareable knowledge between key stakeholders (facility managers, designers, planners, etc) and improved the data exchange among AEC tools and the processing procedure in various building simulation tools focusing on the energy efficiency of buildings.

In this section, a provisional extension schema is provided for the gbXML standard towards incorporating in BIM the necessary elements for enabling space utilization simulation in buildings under design. This is the first step towards better assessing new constructions at the early design phase based on the analysis of the human behaviour when housed in buildings, as building occupants

E	BPM_Enhanced_GBXML	(BPM_Enhanced_GBXML)
E	ref=Activity	ActivityType
E	ref=ActivityCls	ActivityClsType
E	ref=ActivityModel	ActivityModelType
E	ref=ActivityScheduler	ActivitySchedulerType
E	ref=Actor	ActorType
E	ref=ActorCls	ActorClsType
E	ref=ActorHistoricalSchedule	ActorHistoricalScheduleType
E	ref=ActorParameter	ActorParameterType
E	ref=ActorRoler	ActorRolerType
E	ref=ActorTime	ActorTimeType
E	ref=ActorType	ActorTypeType
E	ref=BuildingSpaceEvent	BuildingSpaceEventType
E	ref=BuildingSpaceState	BuildingSpaceStateType
E	ref=ControlPredictor	ControlPredictorType
E	ref=Enterprise	EnterpriseType
E	ref=EnterpriseCls	EnterpriseClsType
E	ref=EnterpriseEquipment	EnterpriseEquipmentType
E	ref=Enterpriseunit	EnterpriseunitType
E	ref=ExtEquipGBXML	ExtEquipGBXMLType
E	ref=IntEquipGBXML	IntEquipGBXMLType
E	ref=IntermediateActivity	IntermediateActivityType
E	ref=OccupancyAnticipator	OccupancyAnticipatorType
E	ref=ProbabilisticModel	ProbabilisticModelType
E	ref=SCurveModel	SCurveModelType
E	ref=Scheduler	SchedulerType
E	ref=SimulatedUserActivitySchedul	SimulatedUserActivitySchedulType
E	ref=Simulation	SimulationType
E	ref=SkeletonActivity	SkeletonActivityType
E	ref=SpaceGBXML	SpaceGBXMLType
E	ref=Task	TaskType
E	ref=TaskCategory	TaskCategoryType
E	ref=TaskCls	TaskClsType
E	ref=ZoneGBXML	ZoneGBXMLType

Fig. 9. Provisional XML Schema from the conceptual data models presented in section 3 for occupancy and business modelling.

have been proven to be one of the most significant factors affecting the energy consumption of a building during its operational phase.

The rationale behind the schema is to provide a groundwork reference schema that can be used for the seamless integration of the enterprise information to the BIM tools and the corresponding building performance simulation software. The schema links the BPM-related data (actors, roles, activities and units of an organization) with the BIM information, mainly with the spaces (or building zones if applicable), where organizational processes will take place and the actual enterprise resources (equipment such as HVAC), as they were provided by the designers and engineers through their design tools.

The overall schema with the additional elements to support the interaction between the business analysts and the designers is illustrated in Figure 9. The sub-models presented in the previous sections 2-4 are combined to constitute a flexible and extendable data model to accommodate the needs of the respective tools that will utilize them, fully supporting the design process through the virtual building modelling procedure (as the xml schema establishes links and connections with the gbXML representations).

The provided schema elements incorporate information needed for space utilization and behavioural user modelling and can be transformed easily to the OWL language format by using Extending Stylesheet Language Transformations (XSLT) documents[17].

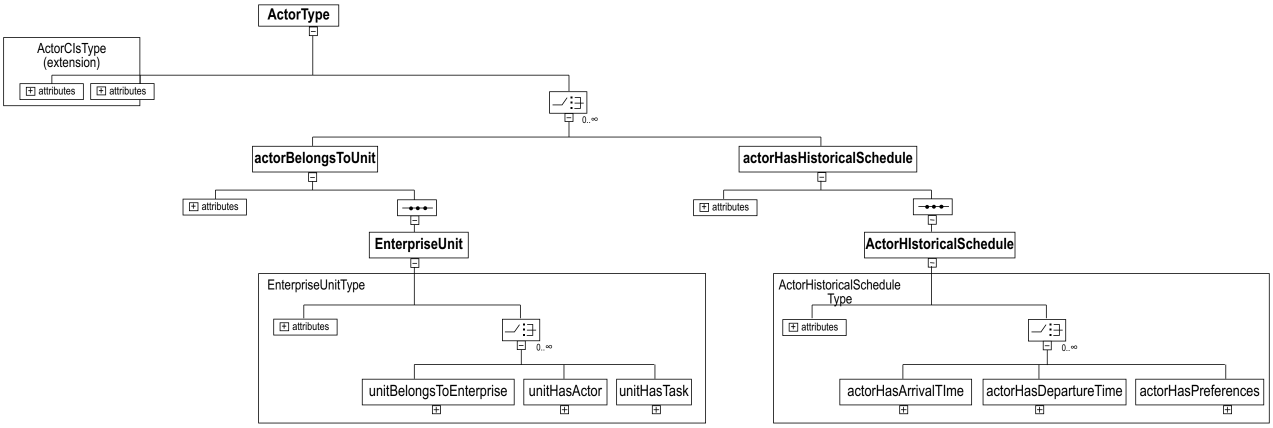

Figure 11: XSD Schema for defining building occupants in a building simulation framework. The actor belongs to an organizational unit, has several roles, performs business processes (tasks), and has a typical occupant schedule that can be parameterized (use of "personas"). A knowledge base will be available to the designers and planners towards modifying the key parameters only for the simulation purposes.

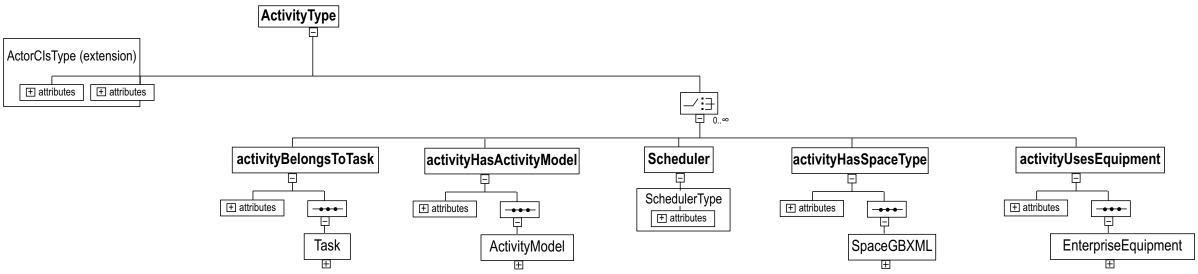

Fig. 12. Schema for an activity (e.g. skeleton or intermediate as part of business-related task) linked with elements of the gbXML schema. Activities executed in specific building spaces or zones as already depicted in element activityHasSpaceType. The element has an attribute that correlates the space with an existing space on the input BIM.

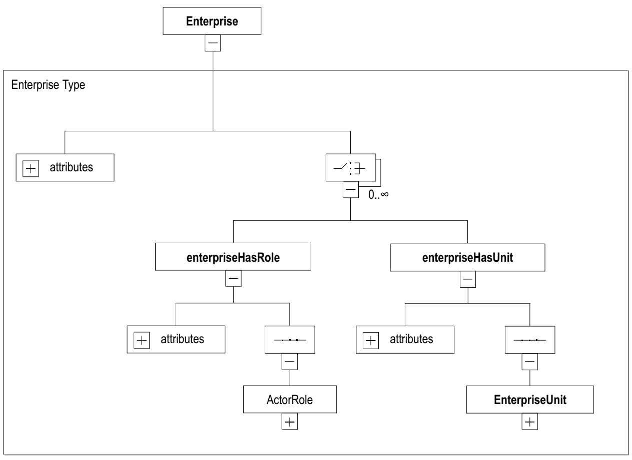

Fig. 10. Enterprise view of the proposed schema.

Storage and mapping can be made in a straight-forward manner and the formalization of the xml elements to semantic concepts (*classes*) with their attributes and properties can be then used in semantically enabled building frameworks, where reasoning capabilities on the actual instances will be available.

Several information of the schema will be directly inherited from the gbXML standard. For instance, the location where activities of building occupants with specific role in an organization can be performed is linked to the space element in the gbXML schema. Furthermore, each actor performing a specific task (composed of a series of activities, skeleton and intermediate) can implicitly be linked with the building information model equipment that has been included in the design process, depending on the level of building development.

Several different perspectives illustrating the schema defined for the enterprise, the building occupant and the business processes are presented in Figure 10 to Figure 12.

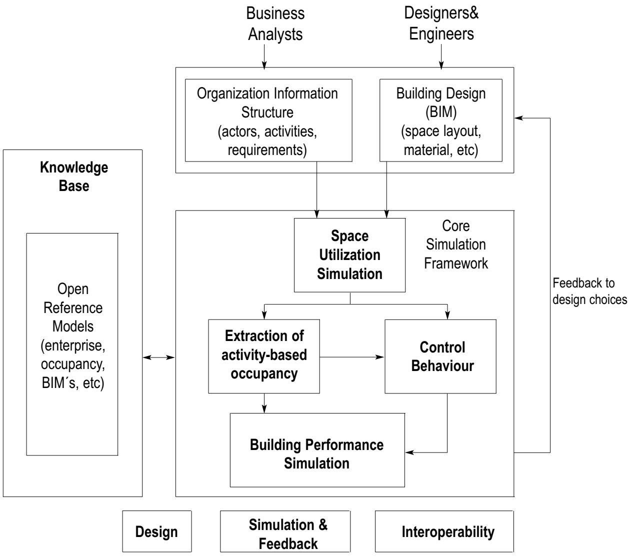

Fig. 13. Conceptual view of the next generation of integrated building performance frameworks that fuse two (currently) disjoint worlds, the BIM and the BPM, having as central reference point for analysis the dynamic behaviour of building occupants.

In this paper, the gbXML standard has been selected from the BIM modelling standards to deliver the set of models that will enable key stakeholders perform enhanced building performance evaluations (e.g. pre-occupancy evaluation, energy usage simulation taking into account the occupancy dynamics, business performance, etc).

The gbXML has been widely used in energy simulation tools developed by commercial software vendors and has the ability to carry additional metadata to the static building information models (BIM) for different purposes such as environmental sensing information (metering), loosing however in most times the semantic relation among elements. Efforts have been made recently to extend the applicability of the gbXML also to other simulations such as lighting control[18].

The xml schema defined can be either linked directly to the gbXML standard (via imports definitions) or standalone. It has references to the building information models through references to the actual instances of the xml schema of a building under design. In this context, the schema can also be linked to the corresponding representations of the Industry Foundation Classes (IFC).

The IFC and gbXML are the two dominant and well-established information structures in the AEC industry, focusing on improving the information sharing across stakeholders during the whole lifecycle of a building. IFC is the industry de facto standard that adopts a holistic approach to represent an entire building project from the requirements phase, building commissioning and construction to building operation. Its mission is to providing a universal basis for process improvement and information sharing in the construction and facilities management industries.

With a comprehensive "top-down" data schema, IFC shows potential benenifts in its highly organized and relational data representation. In contrast, the "buttom-up" gbXML schema, focuses mostly on energy related building aspects. It is simpler and easier to understand which facilitates quicker implementation of schema extension for different design purposes. It presents certain limitations compared to IFC (e.g. limited detail in geometric boundaries, etc.), however these are not of significant importance to the simulation of occupant activities and behaviour

To this end, our approach, was based on the gbXML schema, and several views of the extension have been provided towards providing the necessary information to the key stakeholders to further reduce the common set of assumptions and specifications that are adopted across the designer and engineers during the design phases of a building[19].

6. USE OF PROPOSED MODELS IN BUILDING PERFORMANCE SIMULATION TOOLS

Construction Products constitute energy intensive systems through their whole life cycle, comprising energy demanding assets & facility operations but most importantly, occupants that are the driving operational force, performing everyday business processes and directly affecting overall business performance as well as overall energy consumption.

As of today, energy efficiency concerns (and therefore respective solutions) have been presented in the past addressing all phases of construction product life cycle (PLC) from the design phase (early and detailed design and engineering), to the Realisation phase (procurement and development) as well as the Support Phase (mostly focusing on Operation and Renovation).

Moreover, extensive market studies through years verify the need to make better strategic solutions in the early design phases of a building.

The next generation of building simulation tools (Figure 13) and frameworks should allow key stakeholders in the early design phases of a construction product to progressively produce realistic simulations of human behaviour in buildings and depending on the level of development to have better predictions between the simulated and the later real behaviour. As illustrated in Figure 13, business analysts, designers and engineers shall be able to easily parameterize the inputs and the parameters to be used in the simulation tools such as the total number of occupants, the organization that will be housed in the building under design, the critical business processes associated with the organization to be hosted, etc.

A knowledge base with open reference models may be available, as illustrated in Figure 13, which will enable the end-users to load existing models for business, occupancy and BIM models. The collaboration among key stakeholders will embody a multiple-step processing procedure, in which the feedback from the evaluation of alternative designs will finally conclude on the delivery of a high performance building.

The conceptual models proposed in this paper will enable the key stakeholders to share the necessary information needed to the building simulation framework for analyzing user activity and behaviour in buildings, focusing on the space utilization in the spatio-temporal domain and eventually the impact on the energy consumption of a building due to dynamically estimated occupancy.

For instance, business analysts already have the tools to define business processes and the organization structure in respective data models. Formalizing the conceptual models needed by the building simulation framework, as presented in Sections 2 to 4 of this paper, business analysts will be able to exchange the necessary information (export and import) with the designer tools and viceversa. Ideally, a number of templates and reference models should be available and parameterizable by the experts to better align with the requirements of the building under design. Similar organizations (e.g. hospitals, commercial facilities, etc) may have the same units but some parameters are not always the same (e.g. two hospitals may have different spaces layout requirements and number of occupants to be hosted, etc).

Moreover, next generation of tools should allow designers and engineers to follow a "ceteris paribus" approach, meaning that the Occupancy factor can be isolated and examined separately. Focus will be given on how simulated space utilization affects the overall building energy performance evaluation and optimization, treating the rest of the building design parameters (mostly related to building structural aspects) that have already been thoroughly studied in the past, as constants. Furthermore, current practises indicate that designers and engineers may need one or more tools towards reaching the final goal of evaluating the building performance in terms of its energy efficiency. Thus, building performance frameworks that combine analysis of human behaviour in buildings (space utilization simulation) and simultaneously cope with energy efficiency evaluation are expected to gain the interest of the AEC industry.

In this context, the data models proposed in this paper contribute in fostering the developments in aforementioned end-user needs, by providing a set of reference models in gbXML format that cope with the modelling of occupancy in buildings in close correlation with its dynamic behaviour at the commissioning phases of its life cycle.

7. CONCLUSIONS AND OUTLOOK

Building simulation is considered to be common practice in the building industry. It has undergone a substantial growth both in the academic world and the building industry since its emergence three decades ago. Research in the field of building simulation is also abundant, for instance with regard to modelling the behaviour of humans in routine business activities or even activities in egress situations.

Moreover, much research effort within EU funded projects as well as international research action has been devoted to resolve the shortcomings of the current available building simulation and automation programs and respective Building Information Modelling (BIM) approaches. However, only recently the focus was shifted on analyzing the overall patterns, semantics and complexity of day-to-day human activity and movement within buildings, as well as the relation of these activities to domain specific enterprise processes governing commercial buildings operation and performance.

To facilitate the communication and shareable knowledge across key stakeholders during the progression of construction product (BIM), the Virtual Building Models need to be enriched with additional data models that can express the dynamic behaviour of a building due to the human presence and movements and can be utilized in the next generation of building simulation frameworks.

This paper contributes to this direction by proposing a semantically enriched conceptual schema for modelling the dynamic behaviour of building occupants and establishes a basic reference framework that can be used for both space utilization analysis and energy performance simulations. However, the schema is in its initial stage and needs further development and improvements towards incorporating them in the building performance software.

This is subject of future study that is currently performed in the context of the Adapt4EE EC-funded project that aims to deliver and validate a holistic energy performance simulation framework that analyzes occupancy behaviour (presence and movement) and incorporates them with architectural metadata (BIM) and critical business models (BMP).

The fusion of these two worlds, among other obvious advantages at the early stages of the design, will present the ability to effectively reconciling differences between the energy analysis of "real" and "simulated" buildings.

8. ACKNOWLEDGEMENTS

The work presented in this paper has been carried out in the Adapt4EE project, co-funded by the European Commission within the 7th Framework Programme (FP7/2007-2013) under grant agreement no 288150.

Dr. Christos Malavazos has received his Diploma in Electrical and Computer Engineering in 1995 and a Ph.D. degree (in 2001) from National Technical University of Athens, in the area of multilingual knowledge management. Dr. Christos Malavazos has been actively involved in EU funded research since 1995 as a researcher in Institute for Language and Speech Processing. Since 2002, Dr. Christos Malavazos is Director of IT & Organization Unit (ITU). His main job responsibilities include the Development and Implementation of the Company IT Strategy in general (through cooperations and projects) as well as the organization and supervision of the company's R&D Actions. Within the last 9 years he was actively involved as the head of the technical consulting team in several of the largest Greek IT Projects. He has been involved in more than 20 R&D projects 4 of which as a coordinator and he has publications and citations in international journals.

Dr. Dimitrios Tzovaras is a Senior Researcher (Grade A') in the Information Technologies Institute. He received the Diploma in Electrical Engineering and the Ph.D. in 2D and 3D Image Compression from Aristotle University of Thessaloniki, Greece in 1992 and 1997, respectively. He is also a Visiting Professor of the Imperial College London. Prior to his current position, he was a leading researcher on 3D Imaging at the Aristotle University of Thessaloniki. His main research interests include knowledge management, multimodal interfaces, virtual reality, visualization, computer vision, and biometrics in security. His involvement with those research areas has led to the co-authoring of over 70 articles in refereed journals and more than 200 papers in international conferences. He has served as a regular reviewer for a number of international journals and conferences (e.g. IEEE Trans.Image Processing, IEEE Trans. Circuits and Systems for Video Technology, etc.). Since 1992, Dr Tzovaras has been involved in more than 40 projects, funded by the EC and the Greek Ministry of Research and Technology.

Mr. Dimosthenis Ioannidis is a research assistant in CERTH/ITI. He received the Diploma degree in electrical and computer engineering and the MSc. in Advanced Communication Systems and Engineering from the Electrical and Computer Engineering department of the AristotleUniversity of Thessaloniki (AUTH), Thessaloniki, Greece, in 2000 and 2005 respectively. He has been a teaching assistant at TEI Thessalonikis (2006-2010). His main research interests include biometrics, computer vision, stereoscopic image processing, web services, semantics and development of applications and services for mobile environments. During the last three years, he has been the (co)author of more than 10 papers in refereed journals, edited books, and international conferences. He has served as a reviewer for several technical journals. He has also been involved in more than ten research projects funded by the EC (FP6 & FP7) and the Greek secretariat of Research and Technology. He is a member of the Technical Chamber of Greece.