A normative approach to multi-agent systems for intelligent buildings

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A NORMATIVE APPROACH TO MULTI-AGENT SYSTEMS FOR INTELLIGENT BUILDINGS

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Abstract: Building Management Systems (BMS) are widely adopted in modern buildings around the world in order to provide high-quality building services, and reduce the running cost of the building. However, most BMS are functionality-oriented and do not consider user personalization. The aim of this research is to capture and represent building management rules using organizational semiotics methods. We implement Semantic Analysis, which determines semantic units in building management and their relationship patterns of behaviour, and Norm Analysis, which extracts and specifies the norms that establish how and when these management actions occur. Finally, we propose a multi-agent framework for norm based building management. This framework contributes to the design domain of intelligent building management system by defining a set of behaviour patterns, and the norms that govern the real-time behaviour in a building.

1. INTRODUCTION

A modern building will have many proprietary systems, including HVAC (Heating, Ventilation, and Air conditioning), TV surveillance, access control, etc. that require constant management in order to achieve occupant wellbeing, cost efficiency, user safety, security and environmental (green) issues, etc. To be truly effective, data from systems should interact to satisfy the changing goals of building stakeholders. Conventional BMS (Building Management System) products focus on automating management functions rather than providing goal-centric building management. The capabilities of conventional BMSs are therefore limited by function, making them less able to satisfy changing user needs or building goals. If, for example, the building owner changes the building use, a conventional BMS would not be able to easily change its behaviour, is fundamentally unable to service the building high level goals. Moreover, it is difficult to handle the building management rules, which are embedded in the culture of the occupants.

This paper proposes a norm based EDA multi-agent system (MAS) based building management framework to minimize problems identified within conventional BMS.

2. RELATED WORK

The objectives of the Co-ordinated Management of Intelligent Pervasive Space (CMIPS) project were: to automatically assess a building environment in real-time; to automatically personalize the workspace environment; and to readily deploy sensors using wireless networking technology (Yong, et al., 2007). A key component of this research was to deliver a multi-agent system for building control. The resultant MASBO (multi-agent for building control) system (Qiao et al., 2006) was designed using organizational semiotic methods to address two major issues in intelligent building. The first issue related to balancing energy use and occupant productivity. The second issue relates to learning and predicting occupant behaviour. In MASBO the central agent is responsible for the whole building. In each zone of the building there is a local agent to control the devices that are located in that zone. The EDA (epistemic-deontic-axiological) agent architecture (Filipe and Liu, 2000) shown in the Figure 1, is adopted in MASBO, which was fully embedded in CMIPS. It helps CMIPS to address the limitations in building management and enable stakeholders to achieve their requirements.

The personal agent enables personalization of the environment.

The MASBO still has less ability to have a global view of the building due to it has less understanding of the high level building goals.

3. ANALYSIS OF NORMS IN THE BUILDING

Our understanding of Intelligent Buildings (IB) is based on the attitudes and associations of norms, since this captures key IB knowledge during execution. We classify IB knowledge using ontological, axiological, epistemic and deontic perspectives and characterize them with by defining norms as being either Perceptual, Evaluative, Cognitive and Behavioural norm.

The EDA Agent model enables the representation of agent informational states and simultaneously defines the conceptual communication framework. Agents use their knowledge (epistemic) and take into account their obligations and authorizations (deontic), which they may choose to accept or to violate when deciding what to do next, i.e. to define their goals. In the process they use individual preferences defined in their system of values (axiological).

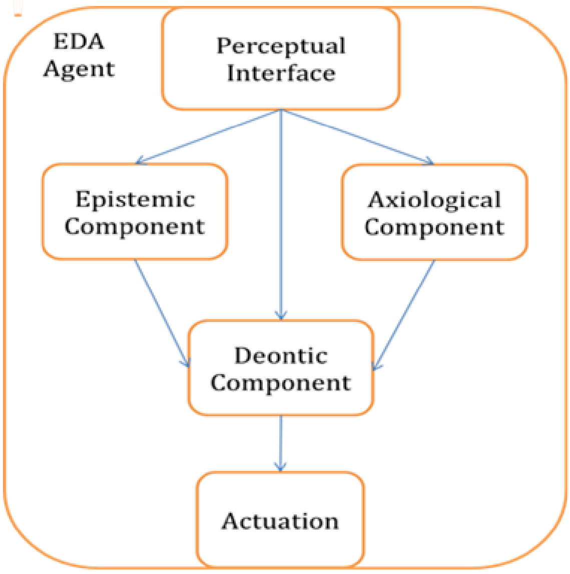

Figure 1: the EDA agent Model

Organisational concepts and activities, such as power relationships, roles, or contracts, are defined by norms in terms of the basic EDA components. Using an EDA model, it is possible to define an explicit representation of the institutional roles the agent can play, where a role is defined as a set of services plus a set of policies (Filipe and Liu, 2000).

Perceptual norms define how signs (i.e. sensor data, control commands, agent communication messages, etc.) are perceived by agents (Liu, 2000). Once the role of agents and communication protocols are defined, the signs for a particular agent is fixed in the MAS defining the perceptual norms within the system. Evaluative norms indicate policies determining which concerns are deemed as important under specific situations (Liu, 2000). IBs need to achieve several potentially conflicting goals (i.e. building safety and security, reduction of energy, and occupant wellbeing). Evaluative norms take requirements of all the agents and determine the optimum solution. Evaluative norms are not explicitly defined in IBs, but are implicitly defined as either axiological attitudes (based on epistemic and deontic attitudes that determine goals) or decision making processes (based on evaluating the weight of each of the factors involved).

Cognitive norms define the semantic structures and cause and effect relationships, and include conditional beliefs about the present state of the building and expectations concerning future building states. Cognitive norms describe services within IBs and historical operations, for example the availability of a device and the attributes relating to its use, i.e. machine capacity, hardware address, operation hours, and past related decisions. Cognitive norms, take the form of beliefs, such as “if the request exceeds the maximum capacity of the device, alert the facility manager” or “if time is 18:00 switch off air-conditioning”. Cognitive norms not only give the detailed description of operations including availability and service information, but also provide a guideline to support service use.

Behavioural norms describe agent activities as a result of certain events. Deontic logic is a modal logic that studies the formal properties of normative behaviours and states (Liu, et al., 2000). Within IBs deontic knowledge includes the logic of agents’ reactions. For example, “if fire event detected, then sound the alarm and switch on the sprinkler”.. This type of norms can be captured from building operation documents, building managers, organisation managers and building experts. The form for a behavioural norm can be seen below:

whenever the request of using air-conditioning received

if the device is in operation hours

then agent

is obliged

to send the command to the address of air-conditioner in the form defined in the protocol

4. THE EDA MODEL FOR BUILDING MANAGEMENT

4.1 Deontic Component

Behavioural norms are embedded in goals and actions and guide the agents execution of probable actions to achieve suitable goals and personalized processes (Filipe, 2000). The deontic component holds a set of behavioural norms that guide the agent's actions.

Intelligent building control requires comprehensive knowledge that specifies what actions are needed in certain situation. This knowledge can be extracted from building rules and regulations.. The deontic frame has been characterised by making necessary adaptations to the goals in the EDA model for the sake of achieving them in customized processes:

Deontic Frame{

Goal: name of the goal;

Goal states: not start/ in process/ completed;

Action: action to take;

Norm: Whatever (condition) If (state) Then (agent) Is (deontic operator) To (action)

}

It is worth noticing that there may be more than one norm governing a goal or action. The norms in actions will help to compose the actions in an intelligent way. For example, if room temperature is 27 °C and the temperature outside is 25°C, we have an air-conditioner and an electronically controlled window, and the room needs to be cooled to 24 °C; the deontic frame for this process would be:

Deontic frame {

Goal: Cool the room ;

{Action: Open the window;

Norm: Whenever (the room temperature is higher than the expected temperature) If (outside temperature is lower than the room temperature) Then (window controller) Is (obliged) To (open the window);

Norm: Whenever (the window is closed) If (safe to open*) Then (windows controller) Is (obliged) To (send an opening signal to the hardware);

}

{Action: use air-conditioning;

Norm: Whenever (the room temperature is higher than the expected temperature) If (outside temperature is not lower than the room temperature) Then ((window controller) Is (obliged) To (close the window) and (air-conditioner) Is (obliged) To (use air-conditioning))

}

{Action: close the window;

Norm: Whenever (the window is closed) If (safe to close*) Then (windows controller) Is (obliged) To (:close the window)

}

}

*: sometimes the window is not safe to open or close i.e. in the event of fire or out of building opening hours, this tag is evaluated by the axiological component.

To support more complex situations, norms allow a combination of independently developed goals to be used for intelligent control. With the deontic component, the agent controls the building by representing plans as behavioural norms. The process can be composed dynamically by sensing environment data and performing actions that satisfy behavioural norms.

4.2 Epistemic component

The Epistemic element of the EDA model relates to existing knowledge and beliefs that are attained from the building regulations, policies, building device capability, occupants' profiles and preferences, and historical process logs. Additionally, agent's description of specific services is also indicated within the epistemic component. A service repository is used to capture cognitive norms, which facilitates the checking of new norms against our current building activity, allowing activity planning. services are based on actual building management specifications and are invoked by abstract actions within the deontic component. The list of services is described declaratively, using the following frame to indicate the context of the service:

Service frames: service name

Action: action to take;

Rule: If (pre-condition) Then (deontic operator) Is (deontic operator) To perform

Action name indicates the action being invoking within this service; and norm describes circumstances when this service is not suitable for execution. This description enables the agent to give detailed information of suitable ways to execute specific actions, according to user's situation and organisation resource allocations (Li, 2009). For example, before performing the action "opening the window", we need to make sure that it is not raining.

4.3 Axiological component

The Axiological component is concerned with the evaluation of critical goals. This component helps to solve dubious or conflicting situations within potential conflicting norms in epistemic component and deontic component by establishing preferred sets of agent beliefs, and prioritising goals in the form of an evaluative norm. For example, the building has two goals: one is to reduce the running cost and the other one is to enhance the occupants' wellbeing. If there is an important meeting that takes place, the building may decide to 'ignore' one of the goals (i.e. running cost) temporarily to ensure the wellbeing of the important meeting attendees.

Since there will always be conflicting situations in real building management, the preference evaluation in the axiological component is important for the building management.

5. TYPES OF AGENTS FOR IB

Within existing MAS research there exists four types of agents: the central agent, the local agent, the personal agent, and the monitor and control agent (Qiao and Liu 2002). In the proposed framework, these four types of agents are still present, but the system structure has been changed. The building is divided into zones. There is one central agent for the building and the many local agents, with each local agent being assigned to a particular zone. The local agent governs the personal agents and monitor and control agents within its allocated zone. Personal agents and monitor and control agent can move from the one zone to another as required.

Therefore we propose four kinds of EDA agent to support the operation of intelligent building management: central agent, local agent, MC agent (Monitor and Control agent), and personal agent.

The central agents in the system perform the roles of rule and policy facilitator, and manage the rule and policies for the entire building system (see Figure 2). They capture building rules and policies and communicate them to distributed agents. The rules and policies are in the form of cognitive norms. There are multiple central agents for each of the main systems in the building, however this can hierarchy can be defined based around norm activity, i.e. systems that have less interaction with other systems or are less important to building activity will have less or no central agent.

The central agent is an EDA agent. The perceptual component takes user input, e.g. special requirements of the facility manager. The axiological component then generates the weight values to the local agents, requests or sorting the orders of the goal of the building system based on the policies and rules in the epistemic component. The deontic component then sends generated information to appropriate local agents. If we consider again the HVAC system example; the central agent contains a norm set relating to the running of the HVAC systems in the building, e.g. "if the time is 18:00, then switch off air-conditioning".

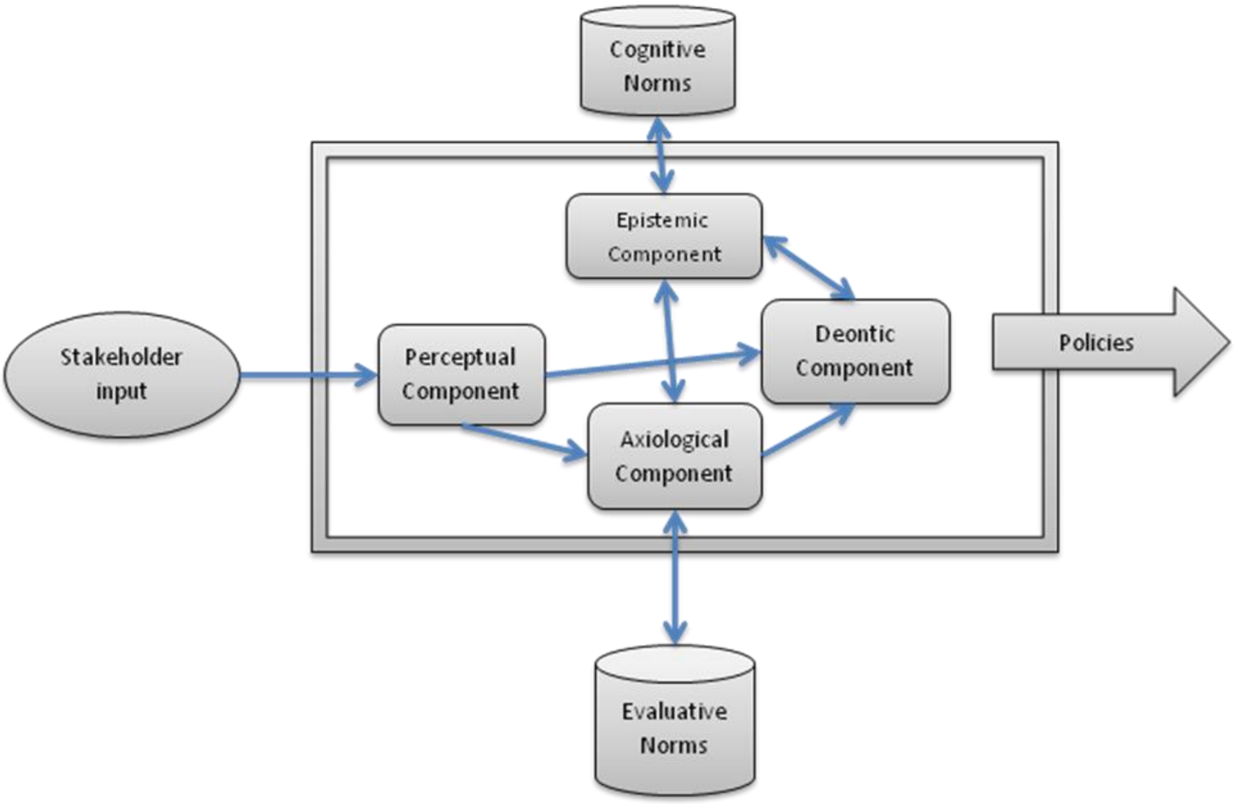

Figure 2: Central agent norm structure

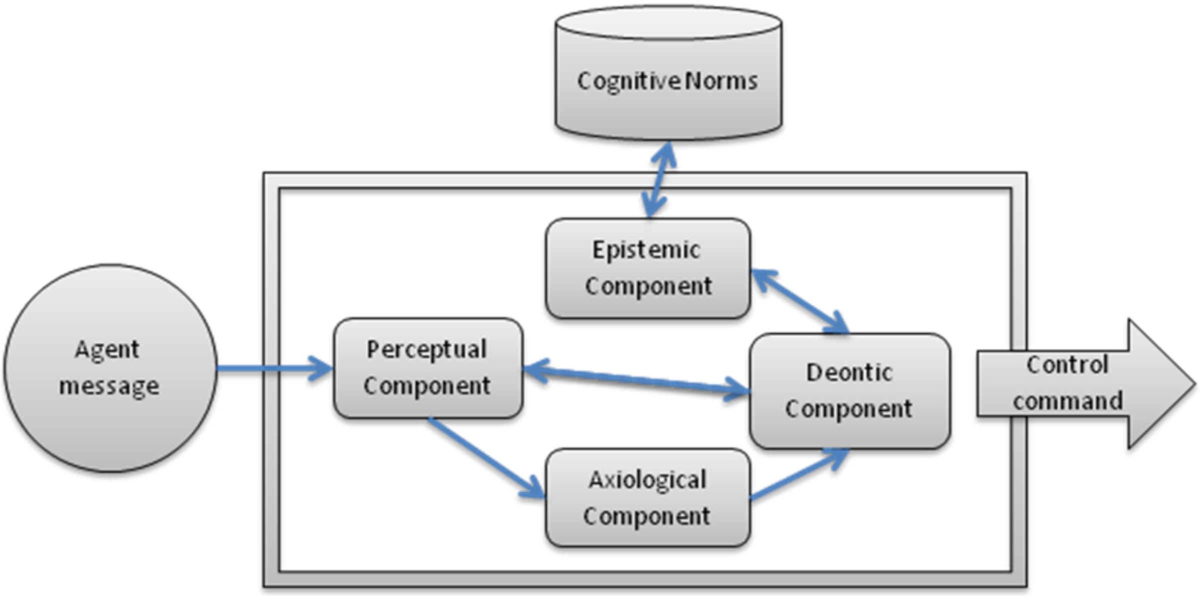

Figure 3: Local agent norm structure

At 18:00 every day, the central agent triggers a time event impacting the behavioural norms of deontic component that sends a message to every local agents to request them switch off the air-conditioners within their zones. Local agents receive weighted messages from multiple central agents and make an activity decision based on the message weight value in context of local activity.

The local agents are in charge of zone management decision-making and rule and policy execution. When a particular request is received, the local agent will apply the appropriate algorithm to make a decision that respond to this request, and then take action to execute the decision.

If for example, the local agent receives requests from personal agents located in the zone about adjusting the temperature to satisfy their personal preferences. The local agent (see Figure 3) invokes the appropriate algorithm in its axiological component. The algorithm takes the personal agents requirements, a weighted value for the HVAC system from energy management agent and other related values, and calculates a temperature. The temperature value is passed to the deontic component and the component request the information of the related MC agents from the epistemic component. The deontic component then sends a message, which includes the temperature value, to the air-conditioning MC agent. The local agent encapsulates the cognitive, behavioural, and evaluative norms of IBs and provides the core support of IBs management

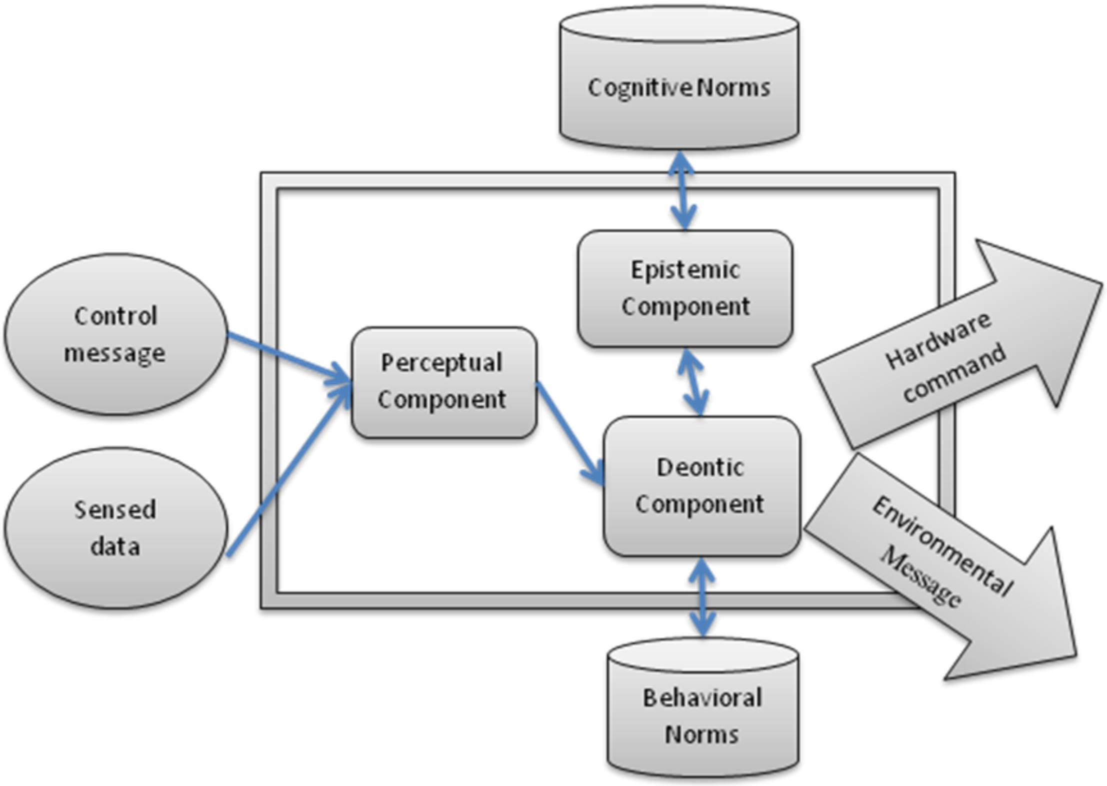

Figure 4: MC agent norm structure

The MC agent is a proxy agent for a specific functional unit, such as a device in the building. These agents work at the bottom level of the system and communicate to the hardware directly. It takes sensed environmental data from the device and translated the hardware message to system internal format. It also takes control messages as input and maps it to a certain hardware command. Because the behaviour of the MC agent is simple, we have designed it as a simplified EDA agent (see Figure 4). There is no axiological component in the agent, and in the deontic component there is a mapping table that maps the control message the agent receives to the hardware command output. It also works in the opposite way that maps the sensor data to a system internal message. In the cognitive component, there is information about the address of the hardware and the registers for the agent to read and write data.

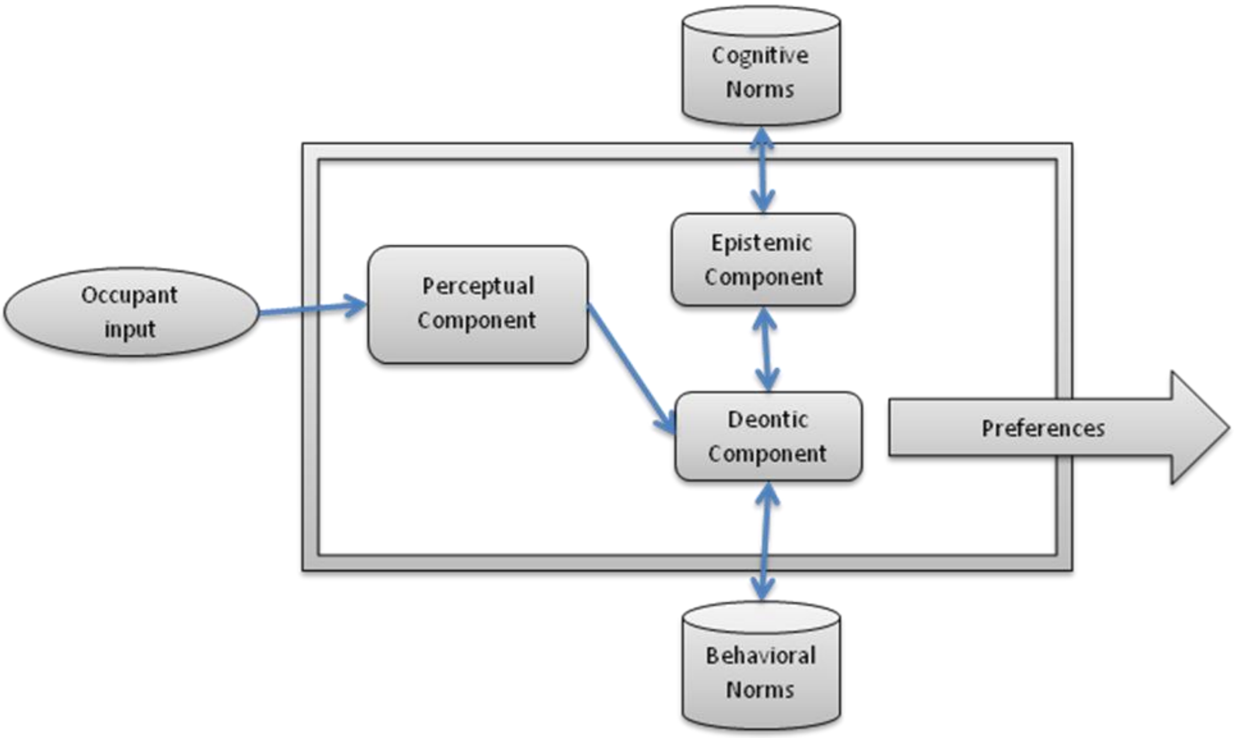

Figure 5: Personal agent norm structure

The personal agent is an intelligent agent that initiates action on behalf of specific building occupant. The personal agent takes the user input from web interface, or mobile personal devices. A personal agent (see Figure 5) is similar in structure to the MC agent, and as communication is mostly one-directional we have designed the personal agents using the same structure as the MC agent.

6. THE CONCEPT FRAMEWORK OF MULTI-AGENT SYSTEM WITH NORMS FOR IB

The proposed structure captures the four kinds of norms covering knowledge within the IB. These four kinds of norms are considered using three levels which facilitate the mechanism of IB management and support intelligent agent. The choice of agents as a solution technology is motivated by the following reasons:

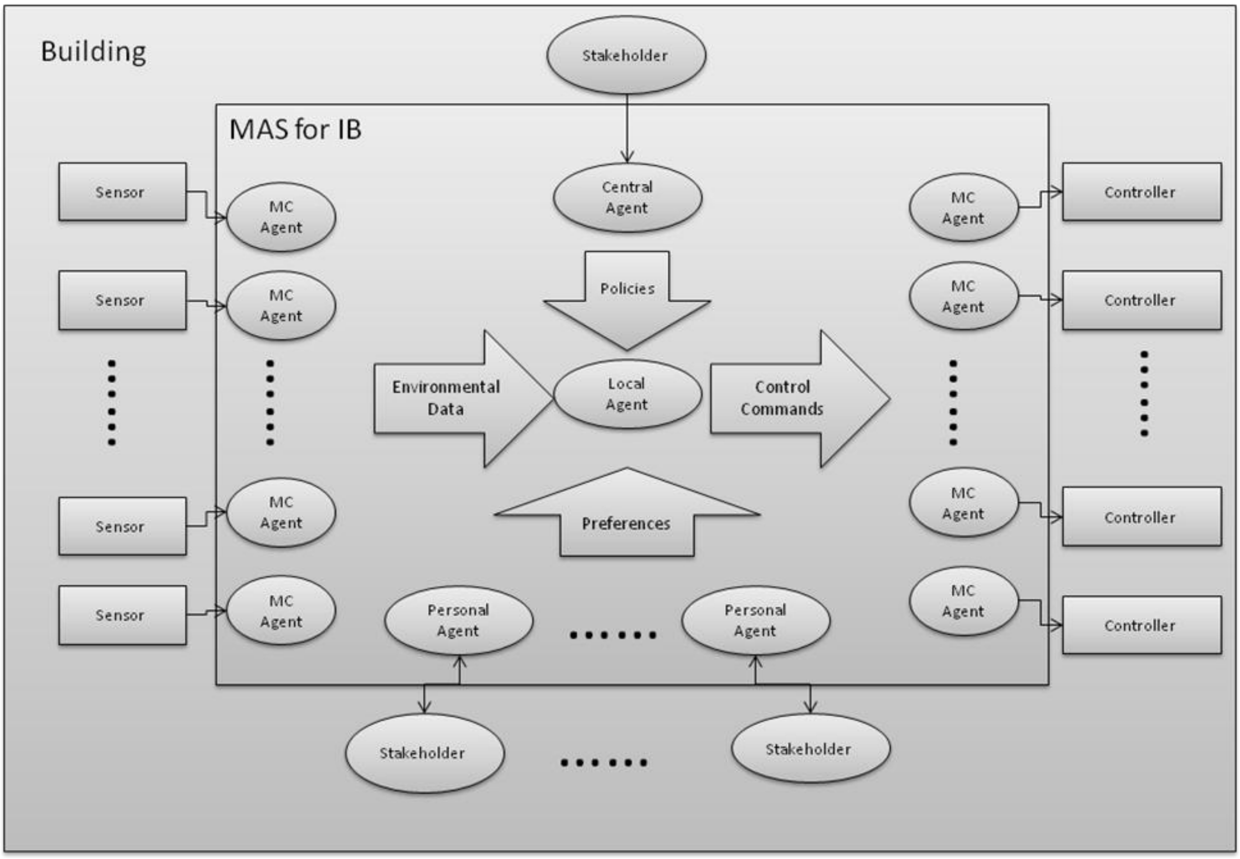

Figure 6: The concept structure of the norm-based MAS for IB

Formal classification of norms within the IB would serve as the basis for intelligent agents performing many regular activities (Liu et al., 2001), relating to IB management.

•Intelligent agents can record the patterns to support more efficient control.

•Agent communication, including negotiations and coordination, can be used to ensure interaction amongst devices and sub-systems information.

•The agent will take initiative to behave pro-actively in order to achieve pre-determined IB management goals, e.g. increasing the efficiency of energy use.

The taxonomy of norms, which support types of knowledge of IBs, will determine building activity to support IB management.

This constitutes the intention of agent components, which incorporates informational content to improve management of the IB. When taken together, this set of reasons leaves the agent embedded with norms as the strongest solution candidate to manage the complicated, adaptive and distributed IBs.

The agents in our approach are organised as shown in Figure 6.

Figure 6 shows the MC agents taking sensor data from the building and mapping the data to the multi-agent world. The local agents, based on the sensor data and the requirements from personal agents and central agents, can make decisions that control the building. The decisions are then executed by the MC agents by sending commands to the devices in the building.

7. CONCLUSION

Researchers in the area of Intelligent Buildings have focussed largely on energy-saving, environment personalization. This paper focuses on fulfilling the occupant's environmental requirements using multi-agent systems (MAS). Use of a multi-agent system has great potential in intelligent building management to support analysis of building goals and control actions to satisfy occupants' personalised requirements. The idea of using specifically EDA MAS agents and norms in the system addresses features including:

1. Balancing of occupant's wellbeing and the energy efficiency.
2. Achieving building goals.
3. Personalised indoor environment control.
4. Non-intrusive personal preference leaning and feedback.
5. Functionality transportation between buildings.

Conflicts between building goals and occupant wellbeing are highlighted in the paper, and the proposed solution makes use of agent technology and multi-agent system to solve conflicts in a normative way. By using agent communication and negotiation, the energy cost and occupants wellbeing can be balanced dynamically in real-time, giving fair consideration of building and business goals.

Current BMS systems communicate with various devices and sub-systems in the building, which have many different communication protocols. The ability of translating system internal commands and messages into packets of the device communication protocol is needed. Therefore, in the future propose the use of norms and EDA agents to make the protocol translation occur in an efficient way.

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