Enhancing Intelligent Buildings' Performance Through a GIS Central Control

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SUMMARY

Every building is integrated in an external environment and this environment is continuously changing, with heavy repercussions on performances of the building and on the amount of energy and costs needed to keep comfort constant according to assigned parameters. Since the Nineties, a lot of research and development has been done on the Intelligent Building in order to obtain a building capable to adapt itself to external changes, keep the maximum internal comfort and optimize the energy usage. A new challenge for Intelligent Buildings is now to highly improve the buildings' performance while heavily decreasing energy requirements and improving environmental performance. The target of our present research is to provide communication within a group of Intelligent Buildings through a GIS central control in order to exploit the experience of each building to maximize performance of the connected buildings. The Intelligent Building Community represents a big "social organism" capable to interact with the external environment and the users. All the connected buildings are supposed to behave like cells in an organism, taking advantage of the organism thanks to the GIS capabilities of handling geographic data and topology and providing decision support. The selection of the application scenario, the role of GIS and the needed technology are also illustrated in our present paper.

KEYWORDS: *GIS, Intelligent Building, communication, simulation, technology integration*

INTRODUCTION

Every building is integrated in an external environment, and this environment is continuously changing. In particular, weather changes at our latitudes can be quite sudden, with heavy repercussions on the internal comfort performance of the building and on the amount of energy and costs needed to keep comfort constant according to assigned parameters.

It has been globally agreed that energy consumption has a significant impact on the environment. Year by year, the built environment has been growing and the demand of high-technology buildings is bigger and bigger, with serious impact on the environment. Energy consumption is not the only building item that impacts on the environment. Other items like the selection of materials and the design for flexibility, site and waste planning, as well as energy planning represent a critical factor in the environmental crisis (Ngowi, 2001). Building and construction highly contribute to the environment crisis by the exhaustion of resource, energy consumption, air pollution and creation of waste (Spence & Mulligan, 1995). According to Dimson (Dimson, 1996) globally, buildings consume 16% of the water, 40% of the energy used annually, and close to 70% of the sulphur oxides (produced by fossil fuel combustion) are generated through the creation of the electricity used to power houses and offices. Furthermore, energy and material input into the construction process increase the amount of total energy needed for building production (Kua, 2002).

CURRENT STATE-OF-THE-ART ON INTELLIGENT BUILDINGS AND TOTAL PERFORMANCE

The high technology concept of Intelligent Building (IB) was introduced in the United States in the early 1980s. IBs use electronics extensively and are high technology related. Energy efficiency, life safety systems, telecommunication systems and workplace automation are well integrated in the building (Hartkopf, 1997). Building elements and components, Intelligent Façade and internal coatings concur to provide internal comfort. Since the Nineties, a lot of research and development has been done on the IB, in order to obtain a building capable to adapt itself to external changes, keep the maximum internal comfort and optimize the energy usage.

Energy usage in the building is related to the following local factors:

- climate (sun elevation angle, sun radiation, temperature, wind force and direction, rainfalls);
- exposure and surface of the ground (slope angle, form, geometry, proportions);
- location, geometry, dimension and volume of the surrounding buildings, topography, areas with water and vegetation (reflection, emission, changing in the thermal body). (Gallo, 1998) (Fig. 1)

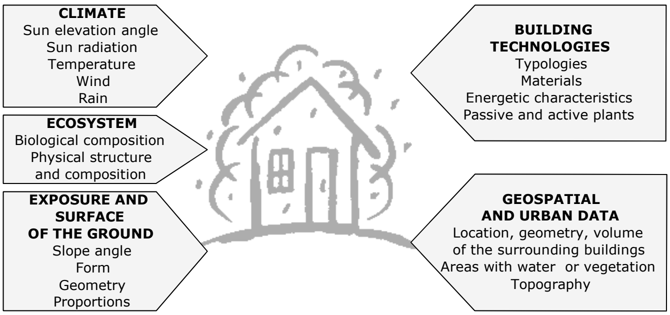

Figure 1: Factors related to the building planning process

Studies and research have proved that a well performing IB can require up to 30% less energy than a traditional building to keep the internal comfort in the quality level required by the energy consumption laws and regulations. Intelligent Buildings have been successfully designed and realized and their performances have been increasing in the last ten years. In the past few years design and engineering of IBs have provided not only major advances in office technology, but also better physical and environmental settings for the occupants (spatial, thermal, air, acoustics and visual quality, plus building integrity versus rapid degradation). Research on IBs is now addressed to promotion of ecological sustainability (energy), economic sustainability (costs) and social/cultural sustainability (cultural heritage) (Kua, 2002). The new challenge is to dramatically improve building performance while dramatically decreasing energy requirements and improving environmental performance (Hartkopf, 1999).

IMPROVEMENT OF INTELLIGENT BUILDINGS TOTAL PERFORMANCE UTILIZING GIS

Approach

Basic Assumptions

The Intelligent Building is able to learn how to adapt itself according to specific inputs, e.g. detecting external environmental changes and reacting properly to keep the internal comfort constant. Through the learning process, the IB gains experience that can be stored and eventually used in subsequent events.

The target of our research is to provide communication within a group of IBs in order to exploit the experience of each of them to maximize the performance of the connected buildings. In other words, create an Intelligent Building Community (InteBCo) that provides internal co-operation with the aim of improving the performance of each building and of each room in every building in terms of comfort, low energy consumption and costs containment, also according to users' interactions.

Basic hypotheses for the research

The research is focused on the two main topics of total performance and communication within buildings, according to the following hypotheses:

- Performances of a group of buildings are of higher quality (optimized) than for each building in a stand-alone scenario.
- A group of buildings can behave like an organism.

According to the hypotheses, the Community represents a big "social organism" capable to interact with the external environment and the users. As a starting point, all the connected buildings are assumed to behave like cells in an organism. (Fig. 2)

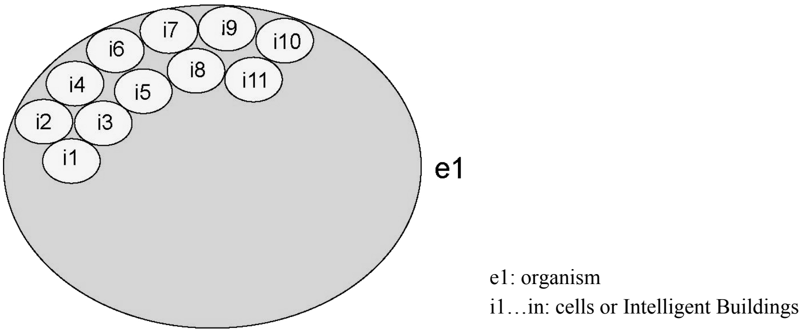

Figure 2: Each Intelligent Building is a cell in the building organism

Similar buildings (cells with similar behaviour) go through a process of learning and exchange local experience within each other. Detection of external (environmental) changes has to be realized through sensors installed around each building at a specific distance according to the kind of data they collect and the specific application they will be used for. The net of sensors represents the skin for the Building/Urban Organism, informing on-line about variations happening in real time. Inside sensors will collect the impacts of the users' interactions.

Communication in the Community is planned be provided by a Geographic Information System (GIS) application capable to handle reciprocal topological relationships, connections and interactions between buildings, sensors and environment. According to on-line or off-line simulations, each IB would get instructions from a central control unit about how to behave in order to maintain high quality internal comfort and would forward recommendations to the Community. In other words, each building makes experiences and communicates them to the other buildings proposing possible adaptations via GIS. The other buildings get the results of another building's experience and can follow the recommendations, according to local constraints. Human decision plays here an important role: recommendations are sent and made available and understandable by GIS, but human beings take the final decisions. GIS plays the role of an information system and tool for decision support, acting as a central control: it collects the experiences, finds out which other buildings are involved and forwards recommendations. Locally each building will decide whether to acknowledge the information or not.

According to the local constraints, humans will take decisions about the adaptations of the other buildings. Buildings can acknowledge the recommendations only if they have the characteristic of adaptability: this means that the present research can be applied to IBs, but not to simple buildings. Furthermore, connected buildings will be of the same usage, in order to reproduce the organism situation, with similar cells.

Technology (1)

According to the research hypotheses and target, a connection between buildings, sensors, simulation, tools for decision support, actuators and building components has to be realized by a central control unit that collects input data, which is derived from external sensors and outputs consequent recommendations according to on-line or off-line simulations. Tools for the realization of connections can be the following: GIS, CAD, Simulation Programs, Building Automation, Facility Management, SAP, Neural Networks, 3D Visualization. (Fig. 3)

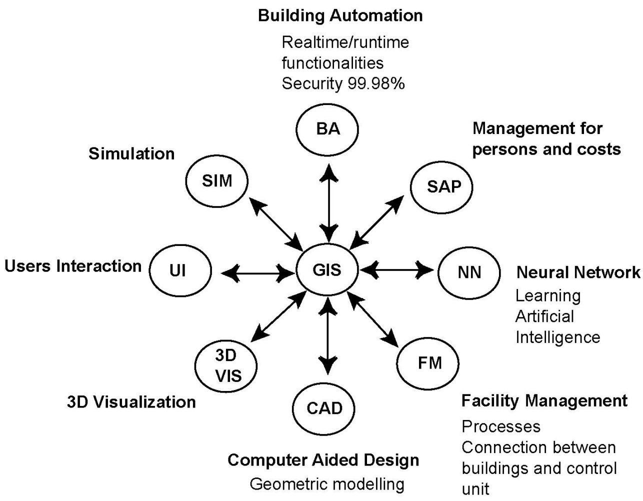

Figure 3: Tools for connection of cells in the building organism

GIS is the only tool that can play the basic, fundamental role of an information system and can support integration. The GIS role will be:

- data management;
- control of communication of sensors and between sensors and control information;
- detect the behaviour of one building and find out the impact on the other buildings, and therefore:
- perform analysis on data and produce building control data (recommendations) on basis of what other tools provide;
- provide recommendation scenarios for decision support;
- transfer the recommendation data to the control unit in order to forward them to the other buildings.

The GIS-managed database will contain, according to the proper capabilities of a GIS:

- topology (absolute and reciprocal position of the buildings);
- attributes of the buildings (kind of buildings, usage, etc.)
- present or expected attributes of the rooms in each building (rooms utilization; target values for internal comfort: target range of sensor-value, also according to the utilization of the rooms in the building);

- additional attributes (dependencies/relationships of values and parameters:
  - static (pre-defined scenarios)
  - dynamic (coming from the results of internal or external simulation (on-line or off-line), also according to users' interactions and human perception.

Collecting experiences and data, producing new information out of the existing and provide decision support is the role of a GIS system. Other tools are not designed for system integration. Some of them, like CAD and Simulation Programs, can provide data sources and therefore can play the role of data acquisition tools for GIS. All other tools to be connected to GIS must have an open, known structure for input (data/interface) and output data (DB structure or export file).

Preliminary results

Selection of a suitable application scenario

The first hypothesis on which the present work is based is the assumption that providing communication within a group of buildings is a new, smart way to enhance the global and local building performance exploiting the experience of each building to bring advantage to all the others. Therefore, a focal point is represented by the selection of the application scenario by answering the following questions:

- in which scenario does the community behaviour bring more advantages?
- where are connected IBs more powerful?

Different scenarios and building performances have been analyzed and compared, with the aim to understand which of them is more suitable to prove and/or support the research hypotheses. If every Intelligent Building is already capable to optimize the internal performance, why should it be connected to other buildings? Which effects are expected by this operation? Which are the situations in which buildings can take advantage of the community structure?

The following topics have been analyzed:

Building Performance Criteria (Hartkopf et al., 1997)
- spatial quality (including physical safety and security)
- thermal quality
- air quality
- acoustics
- lighting and view
- building integrity vs. rapid degradation

Performance assessment model for buildings (Green Building Challenge) (Cole & Larsso, 1999)
- resource consumption
- environmental loadings
- indoor environment
- longevity
- processes and contextual factors (location, transportation)

Global scenarios
- lighting
- heating/energy
- energy consumption
- weather protection
- security

From the point of view of the group behaviour, in some of the above-mentioned scenarios no clear advantages can be expected by connecting the buildings. Characteristics of the indoor environment like air quality, spatial quality and lighting represent too local qualities of a building and it would be difficult to adapt the experience of one to the others. On the other hand, other aspects like weather protection, energy balance and security would offer a good perspective of which targets could be achieved by cooperation between buildings.

Examples

Scenario 1: Weather protection (wind)

By knowing local constraints (building locations) and transitory events (wind speed, direction, intensity) the first building that is invested by the wind is able to alert the other interested buildings and send recommendations for local protection. (Fig. 4)

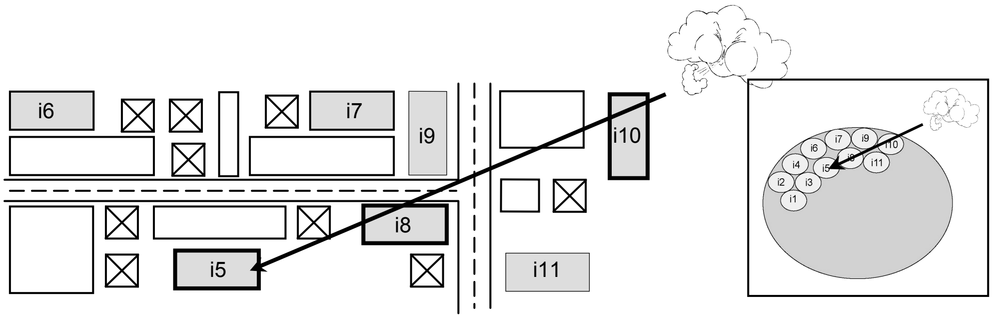

Figure 4: Analysing scenarios - Wind

Scenario 2: Energy balance

If more buildings are connected and a whole energy balance is calculated for them, energy losses in one building might be reduced by exploiting exceeding energy for the needs of another building. Local constraints (fixed differences, location) and transitory constraints (variable differences, weather) have to be considered. The system could for example decide to send more energy to the north oriented buildings or rooms and less energy to the south oriented ones or the ones with a winter garden planned for collecting solar gains. In case of clouds, when the global solar gain is low, the system could send recommendations in order to let the most energy-requiring buildings (north oriented) adapt themselves to a lower energy availability. Switching off some supplies that consume too much energy, in order to prevent usage of electricity from the net, could be one of the recommendations. On the other hand, buildings with less energy need can be singled out and the system can recommend to switch off or reduce the heating. (Fig. 5)

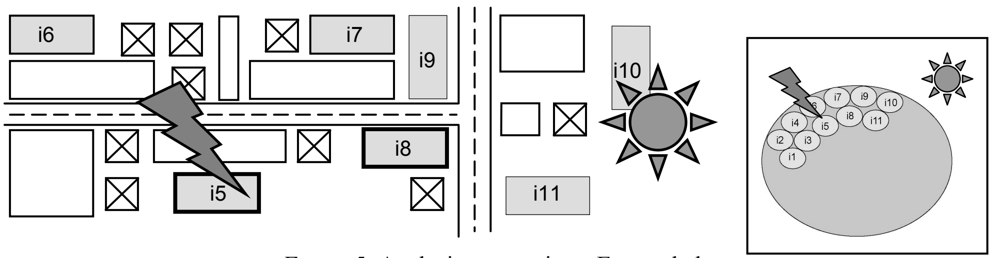

Figure 5: Analysing scenarios – Energy balance

Selected scenario

According to the above-mentioned considerations, thermal quality of each building and total energy balance for the whole building organism will be the application scenario for the present research. Office buildings with high occupancy (e.g. banks) will be cells of the buildings organism. In particular, the same building will be placed in several different environmental (natural and urban) contexts, in order to prove the adaptability of a building to the local situation in analogy to the adaptability of cells of the same type in different positions in the organism. In the selected context our research will try to give a contribution to the Intelligent Building challenge mentioned in the state-of-the-art.

Role of GIS

According to the basic assumptions, each IB (or cell in the building organism) makes local experiences and adapts itself to the local environmental changes. Experience and adaptation parameters will be sent to the organism central control, to be interpreted according to the local natural and built environment for each building. According to topological relationships of each IB and the environment, the GIS central control will be planned to translate the experience of the first building into suitable recommendations to each of the other buildings. (Fig. 6) Locally, in every building the user will decide whether to accept a default standard solution or to choose interactively in the palette of provided recommendations.

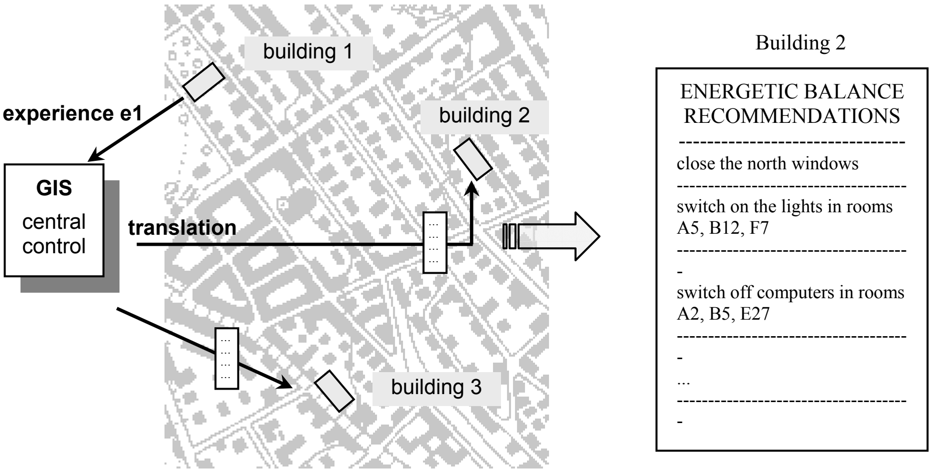

Figure 6: GIS central control as a “translator” of single experiences into targeted recommendations according to local constraints

The two main GIS capabilities are the key tools for success in communication of experiences and adaptability of buildings:

- topology/geographical handling of data (built and natural environment around each building is taken into account in the translation of recommendations);
- decision support: the system presents a list of recommendations to the user, who can autonomously decide how to behave.

Technology (2)

The selection of the application scenario is a very important step to lower the complexity of the integration of tools. Only the needed tools will be singled out and integrated according to the research application. For the selected application no CAD and FM will be needed: only Building Automation technologies and simulation programs will be connected to the GIS. (Fig. 7) 3D visualization is also not needed to represent recommendations on energy balance optimization and thermal comfort. The application scenario is already very complex and therefore users’ interactions will be kept as simple as possible.

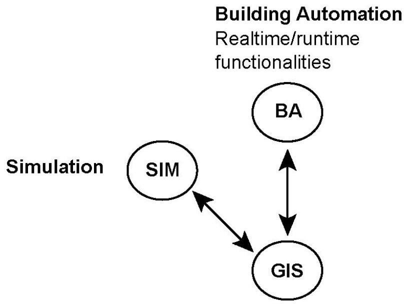

Figure 7: Selection of an applications scenario helps lowering the complexity of technological tools connection

For some aspects a CAD system is needed, but GIS needs only an abstraction of these data, and not necessarily a CAD must be connected. The needed CAD data can be singled out as attributes to each building represented in the GIS; the connection can be simply kept by sending to GIS a selected choice of information about design changes in the CAD. When a building in the community changes its aspects, for example when a new window is opened on the north façade, the information of a new north window in building i^n is needed, but not the position of the window on the façade. (Fig. 8)

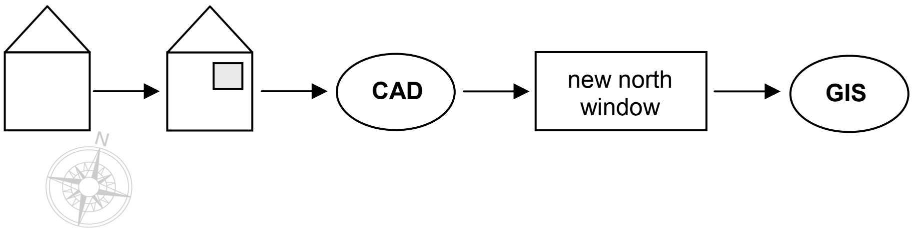

Figure 8: Only some characteristics of the building described in CAD are needed in GIS for simulation applications

The design characteristics of a building that are needed to perform energy behaviour simulation can be simply stored in the GIS as attributes of the object that synthetically represents the building. (Fig. 9)

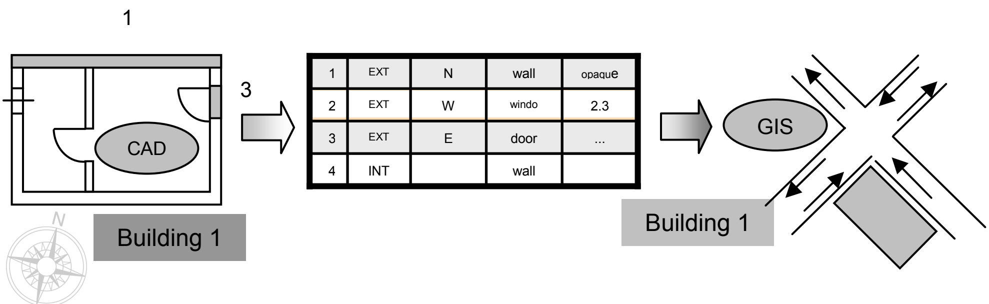

Figure 9: Design characteristics of a building can be stored into a GIS as attributes of an object

The Integration of the selected tools will be a components-based middleware solution. Building control, simulation and GIS will be connected and will provide functionalities to the middleware communication intelligence. We will use a commercial component-based GIS software package and we will utilize only the data management, analysis, and spatial reasoning components of the system on different levels (control and middleware level) in our architecture. The GIS visualization tools will not be needed for our application. Sensors, CAD and eventually other technologies will provide data capture and will input data in the source database for the server level. The middleware level will be responsible for individualizing the information flow from the central control to the respective IBs in order to gain individual recommendations for each building. (Fig. 10)

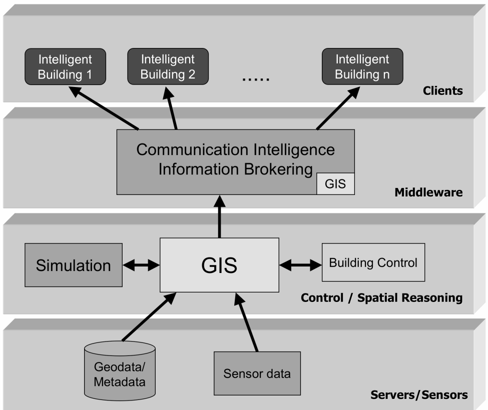

Figure 10: Proposed 4-tier software architecture

CONCLUSIONS AND OUTLOOK

The present research is focused on IBs total performance and is trying to give and interdisciplinary approach to the problem. Research, literature, design and construction have so far provided high quality IBs capable of answering to the main question of adaptability. This topic has been very well investigated and now research is setting new targets and challenges. A very well performing building but too much energy consuming is not an optimal solution anymore and designing a new building for each new location without taking into account the experience of other buildings in other contexts is not cost effective. The attempt of our research is to give a new solution to enhance the performance of the IB and contain energy usage by taking advantage of disciplines that until now have never been applied to building design.

A GIS is able to make a building "realize" where it finds itself, to describe the surrounding natural and built environment, to find out which resources are available and which are the reciprocal relationships within all these elements, in order to produce a cooperative organism able to optimise the total behaviour. Each cell in the organism does not loose its identity, because the whole system is able to respect local constraints, but can take advantage of the community behaviour to strengthen and power its quality and performance.

Our on going research is also trying to prove that not necessarily a wide amount of very complex technologies have to be used and connected to reach our target: by using the very powerful GIS capabilities as the key of the whole project and by focusing on a definite scenario we will be able to single out the strictly needed technology, in the general attempt to lower complexity and produce a prototype available and easy-to-use.

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