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Networked Embedded Computing: Current Developments for Tomorrow's Architecture

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Abstract

This paper reviews current ideas and technology related to the development of embedded computing systems in buildings. It concludes with a prioritization of systems to be selected for integration in a new research building to be constructed in 2008-09 in Cork Ireland.

Introduction

Digital visualization has transformed the process and products of architectural representation. The ability to digitally model complex geometric surfaces, and to directly link digital models with component manufacturing tools, have also demonstrated their potentially dramatic impact on the appearance of certain built works of contemporary architecture. Less obvious at present is the impact of embedding computing into the actual fabric of architecture. This is not surprising, as these components operate at the meso-scale, measured in millimeters and centimeters. Embedded systems may however become the primary area in which convergence of the digital and physical worlds significantly impact daily human experience.

Historical context

The current work is being carried out as part of a multi-disciplinary team of fifteen partners from five different institutions under the acronym *NEMBES*. The team has received funding of over 13 million Euros to undertake research, to support teaching and technology transfer, and to build a new facility to serve as a centre for such work, as part of the Irish government's PRTLI4 scheme. The author is providing an architectural input to the investigation of the potential, and the effectiveness of networked embedded systems, and is contributing to the development of their application in the built environment. This is a progression from earlier work in the design of 'smart' homes (Chapman & McCartney, 2002) and the study of occupant reactions in "intelligent" office buildings (McCartney and El-Bastawisy, 1997). This paper is a first stage in addressing the requirements of the 2,000 square metre new building for the NEMBES team. Following an initial review specific embedded systems which meet the requirements of utility, economy, and robustness, in the context of the new building, will be identified.

Two or three decades ago, discussion of *intelligent buildings* would have been dominated by the development of automation made possible by centralised Building Management Systems providing control of HVAC and security functions. The personal computer at that time would still have been a hobby interest for many, rather than a vital work tool. A decade ago, attendants at an international conference on *Intelligent Buildings*, accepted the proposition that the primary application areas for smart systems were to provide enhanced control in three areas: HVAC and energy, security, and entertainment. By this time, computers were ubiquitous. Ubiquity is now being replaced by pervasive computing. We are increasingly surrounded by microprocessors applying arithmetic logic to tasks which we are not even aware require the application of calculation. Not only do we carry lap-top computers in our shoulder bags, but we carry or wear microprocessors in our watch, PDA, mobile phone, and our children's toys. As Addington and Schodek (2005, p202) point out: *"Already the human body is 'tethered' to the digital world through the many wearable and portables devices each of us routinely carry"*. In such an environment, we would hesitate to call computer controlled heating, ventilating and air conditioning evidence of an intelligent environment. Addington and Schodek, (2005, p203) distinguish "intelligent" from "smart". At one point they associate smart sytems with the "fetishisation of gadgets" and argue that: *"The aspirations of intelligent environments, however, are higher, as they must operate in multiple contexts and simultaneously interact with the transients behaviours and desires of humans"* They envisage a future in which *"systems become smaller and more discrete, freeing our bodies and perhaps our environments from an overarching web of control."* (Addington and Schodek, 2005, p20). This surely is a goal more worthy of architecture, than the mere display of the latest products of technology. However achieving this goal will require some appreciation and understanding of the smart systems and materials which will be constituents of the intelligent environment.

Technology

Smart systems depend on sensors which respond to specific environmental conditions. For useful effects, these are linked to actuators which create signals to produce electro/mechanical changes. Photo-sensors for example, detect reductions in daylight, and send signals to devices which increase the level of electrical illumination. Smart materials incorporate the sensor and actuator functions in one element, which also serves some other function. Thermo-chromic glazing for example, automatically reduces its transmission properties when its temperature exceeds a specified level.

Ritter (2007) divides smart materials into three categories according to the nature of changes over which they provide control: property-changing, energy-exchanging and matter-exchanging. Under these categories he identifies the following functions:

Property-changing
- Shape
- Colour and optics
- Adhesion

Energy-exchanging
- Light emitting
- Electricity generating
- Heat storing

Matter-exchanging
- Water storing
- Gas storing

Ritter's (2007) book is particularly useful in providing images of the impact many of these materials could have on our built environment. Although many of the changes in the materials he discusses take place at the molecular scale, these changes can affect the patterns and colours of large areas of materials. He demonstrates the visual effect of dichroitic filters coating glass surfaces used in chandeliers in the Copenhagen Opera House. More dramatically, he illustrates the vivid colours in the facades of the German Research Foundation in Bonn, created from the work of artist Michael Bleyenburg with holographic optical elements.

The potential contribution of smart systems and materials, presented in such recent works as those of Ritter (2007), Addington and Schodek (2005) and Campagno (2005) have been mapped against the fundamental Vitruvian qualities.

VITRUVIAN QUALITIES	”SMART” SERVICE
Firmness	Stress detection
	wear/tear degradation
	emergency responses
Commodity	Security
	Communications
	Communications
	HVAC thermal control
	Adaptability
Delight	AV edu/entertainment
	kinetic beauty
	serendipity

TABLE 1
The potential services offered by "smart" systems mapped against the fundamental Vitruvian qualities of architecture.

Networked embedded technology enables ordinary materials, and component assemblies to behave in a similar way to inherently "smart" materials, by introducing sensors, logic processors, power systems and communications into those components. The NEMBES research team has identified a number of areas which will be the subject of particular attention in the R&D programme for the next three years: miniaturisation, wireless communication, massive connectivity and self-learning algorithms.

Miniaturisation will enable the increasing use of networked microprocessors in smaller building components, reduce the visual impact of such devices, and enable their use in identifying users and equipment (particularly utilising RFID technology) for purposes such as tracking, and inventory control. Sensors implanted in materials will be able to measures stress in structural elements, deterioration in properties such as thermal resistivity, and provide information for maintenance and replacement. Miniaturisation will also be a major contribution towards the increasing portability and wear-ability of sensors, signalers and communication devices.

Wireless communication is of particular interest to the team, together with the software, or middleware, required to manage connected arrays of embedded devices. Such networking is a distinctive feature of the intelligent environments promised by the current technological developments. Wireless communication in buildings will increase the flexibility of architectural spaces in terms of their future use. Rather than providing hard-wired solutions to all potential data distribution requirements, wireless technologies will enable adaptation to future needs. This can be seen in contemporary applications featuring wireless switching in large commercial spaces. This enables future sub-division of workplaces without the need for expensive re-wiring. Standards such as WiFi provide for wide bandwidth communication including demanding applications such as video transmission. *Bluetooth* provides for narrower bandwidth for simpler data transfer across shorter distances. The *Zigbee* standard, which lies between the two in its capabilities has attracted much attention in recent years and has found application in many building lighting control systems.

M*assive connectivity* will play an important role in work to be carried out with the Cork City Highways department where road safety and traffic management will be linked to a large number of sensors embedded in the road, signals and crossing indicators. Such developments may have future applications in coordinating the behaviour of multiple linked components in buildings.

Self-learning algorithms are used in complex systems where the optimum response to given environmental conditions is difficult to predict in advance. They monitor their own behaviour, the resultant environmental effects, and attempt to gradually improve their responses through iterative processes.

The potential “smart” services, shown in Table 1, were mapped against the areas identified as priorities for research and development. It can be seen in Table 2, that wireless communication has a potential effect on all the “smart” services identified earlier. Miniaturisation is also a significant feature in the development of over 60% of the “smart” services. Massive connectivity is not considered to have a role to play in current buildings, but self-learning algorithms have been identified as having particular value in improving the control of the thermal and luminous environment, and hence in reducing the carbon footprint of buildings. The immediate urgency associated with such functions is likely to lead to rapid development in this area.

All the identified R&D areas are seen as having potential significant impacts on the potential for increasing delight in future buildings. These impacts range from the role they play on increasing access to information and entertainment via the audio-visual channels which can be made available throughout future buildings. More intrinsic to the building, is the potential for the beauty of a building to be seen increasingly as related to its kinetic performance, as more use is made of mobile components such as retractable blackout screens, light shelves, shading shutters, insulating panels and ventilators are deployed. Furthermore there will be an increasingly complex and un-predictable interweaving of the effects these components have on each other. A reduction in daylight may increase the electric lighting, which may call on an increase in cooling ventilation and reduction in the solar transmittance of the windows. This may lead to damaging clashes where one system prevents the intended operation of another. However, whilst the building services industry might think of such interaction as a prime case for clash detection, the telecommunications industry would describe it as *feature interaction*. So long as the dangers identified by clash detection can be removed, the serendipity of feature interaction may become a source of pleasure to building users as the emergent behaviours of complex systems may take on some of the beauty of natural systems such as wind ripples on the surface of water, and cloud formations.

R&D TOPICS	FIRMNESS			COMMODITY					DELIGHT		
	Stress Detection	Wear & Tear	Emergency Responses	Security	Comms.	HVAC Light	Tracking	Spatial Adapt.	A.V	Kinetic Beauty	Serendipity
Miniaturisation	O	O		O	O		O		O	O	O
Wireless Comms.	O	O	O	O	O	O	O	O	O	O	O
Massive Connectivity	O	O	O							O	O
Self-learning algorithm						O		O	O	O	

TABLE 2

Circles plot those areas of potential "smart" services in a building which might be affected by the NEMBES research programme.

Conclusions

From the analysis in Table 2, it would be desirable if the new building for NEMBES was to demonstrate innovative use of wireless communication and miniaturisation, and/or design facilities to support design teams in using these technologies.

Five member organizations in the NEMBES team have existing achievements and interests that might inform the "smart" systems to be embedded in the new research facility. The Cork Institute of Technology Centre for Adaptive Wireless Systems have developed a system for tracking the location of individuals within their labs, and software for visualisation of the field covered by wireless transmitters/receivers in an office, to assist in the efficient positioning of such devices. University College Cork Department of Civil and Environmental Engineering are investigating how embedded technology can enable management, inspection and maintenance teams to interact seamlessly with buildings. The Knowledge and Data Engineering Group at Trinity College are involved in the communication across massively connected networked embedded systems. They have also developed a programme to provide a walk-through visualisation linked to a two-dimensional system view that takes into account lags in sensor reporting, blind spots caused by the building geometry and the location of sensors. The Tyndall Institute are producing prototype devices capable of sensing, processing and communicating, with built-in power generation, all in a device which fits within a 1 centimetre cube. The Cork Centre for Architectural Education have an interest in creating a shared, multi-disciplinary design visualisation space in which various types of design simulation can be carried out.

Linking these developments and interests, it is intended to create a building with moveable partitions which enable various configurations of laboratories and offices. Potential configurations will be simulated in a digital model of the building. Actual movements of occupants in the building will be recorded, and these will be used as the basis for creating various walk-through tests of the potential building layout variations. Their movements will be logged as real-word input to the digital simulation of the building as constructed, and it is hoped to produce a variety of narrative-based scenarios suitable for testing of future reconfigured labs and offices. It may be possible to use this method to develop a methodology for creating generic walk-through digital model tests for specific building types, initiallythose in which movements and timetables are particularly constrained; for example schools, museums, and art galleries.

A testing/demonstration laboratory will be created in the glazed south end of the proposed new NEMBES building. It is proposed to provide opportunities for creating an augmented reality simulation of designed environments enhanced by embedded technologies. The intention is to enable design teams to enter a shared space, with some of the functionality of a CAVE (Computer Assisted Virtual Environment), coupled with a partially physical test space in which real objects will be combined with 3-D projections of walls, windows, furniture etc. The glazed wall in this space will require layers of material providing different types of performance which will include: blackout, solar transmission control, and information display. It would also be desirable if the external appearance of this window wall were able to communicate something of the functionality and delight of a “smart” system, exploiting the kinetic features, and serendipity possible with such systems.

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