Smart and Intelligence in Building Materials Discourse

Subjects: Construction & Building Technology
Contributor: Ikechukwu Ogwu

The fundamental notion of 'smart' in building materials discourse is responsiveness—the ability of materials to react to environmental stimuli by manifesting a noticeable physical change when there is a difference in the conditions of their immediate surroundings. This notion, however, is also interchanged with 'intelligence', which involves an array of control protocols. Notwithstanding, both notions are used synonymously and as occupant comfort and energy efficiency strategies in buildings.

energy smart intelligent building materials

1. Introduction

The primary notion of smart and smartness in building materials discourse is responsiveness—the ability of a material or system to react to (environmental) stimuli by manifesting a noticeable physical change when there is a difference in the conditions of its immediate surroundings [1][2][3][4][5][6]. Inspired by the need to find alternative solutions to the issue of energy consumption by exploring the properties of (building) materials, the notion provides an efficient means to manage energy in and around buildings [7][8][9][10][11], which has not changed since the energy crises of the 1970s and is still dependent on the combustion of fossil fuels. In fact, coal, oil and natural gas currently make up about 80% of today's energy use globally [12]. Energy, which is linked with all aspects of development and has a tremendous impact on the wellbeing of urban citizens' health, education, productivity, as well as economic opportunities, mainly comes from fossil-based sources [13], and the building industry, with its complex matrix of houses, factories, offices, schools, roads, bridges and parks, is one of the biggest consumers in the world, accounting for about 40% of energy consumption globally [14].

The resulting consequences of this combined with the increased awareness of climate change and other environmental concerns are empowering innovative solutions that seek to improve quality of life while being environmentally friendly. In fact, it is now possible to satisfy and eventually reduce the energy demands of buildings with less carbon-intensive approaches through advances in the realm of building physics, new technologies and materials science [1][15], among which advances in materials would make the most impact since it has the most direct influence on buildings. Eight trends have been identified that are inspiring the new material science research directions [6][8]. They include:

- Green materials (materials that can be reused with no adverse effect on the environment)
- Fashion materials (materials developed for their aesthetic appeal)
- Security materials (materials that provide increased resistance against storms/natural disasters as well as detection and alert systems)

- Modern materials (referring to style genres—modern design, based on the use of new materials and processes)
- Digital technology materials (materials aligned with technological fabrication processes otherwise difficult to realize)
- Biomimicry (materials that imitate nature/natural processes)
- Nanotechnology (materials used at atomic scale for industrial purposes)
- Intelligent materials (materials that are responsive to external stimuli)

Intelligent materials have been described as being imbued with built-in sensors, actuators and control mechanisms able to detect stimuli, respond to it and then revert to its original state as soon as the stimuli is removed [16]. Intelligence has also been used in connection with buildings since the early 1980s, with the first definition given by the Intelligent Buildings Institute as “one which provides a productive and cost-effective environment through optimization of four basic elements: structure, systems, services and management, as well as the interrelationship between them” [17]. It uses computer technology to provide a more efficient environment by enhancing the connection between a building’s form, flow, mechanical and electrical services, as well as its operation [18]. Thus, intelligent buildings adjust basic elements to meet user requirements using computer technology to make the communication between the elements possible. They are able to recognize stimuli (by acquiring information from the environment), discriminate (making good judgment by analyzing recognized stimuli), and then adjust accordingly (making regulated or controlled responses to stimuli received) [19][20] by using computers and electronic technology systems. However, a common factor with all electronics, computer technology control systems, machines and any material with an electrical control need, is the provision of power. No matter how small, direct or distributed a component may be, electricity must still be supplied. If the device is made smaller, its power needs, in terms of both voltage and current, are reduced accordingly, but traditional power sources, which mostly come from fossil fuel combustion, cannot be correspondingly reduced [4].

With smart materials, however, the response ability to the received environmental stimuli is embedded in the material itself, requiring no external control system. Smart materials will exhibit the characteristics of immediacy (respond in real-time), transiency (respond to more than one environmental state), self-actuation (triggered discernment internal to, rather than external to, the material), selectivity (respond in distinct and predictable way), and directness (respond head-on to the stimuli) [21].

Indeed, while the responses of smart materials and systems come direct from the material itself and are reversible and predictable, it is practically impossible to have intelligence without (additional) computers and electronic technology (control) systems [3][22][23], which require a constant supply of energy, currently mainly sourced from the combustion of fossil fuels, which exacerbates climate change.

Both notions (of smart and intelligence) have also been combined in some instances as hybrid systems, with computer intelligence connected with smart materials to provide occupant comfort and efficient ways to manage energy. In fact, one of the first uses of the term “smart” in association with buildings was in connection with improved sensor-based monitoring and control systems for “intelligent” regulation of the indoor thermal environment of a house, which was imbued with computer intelligence along with miles of wiring and walls that concealed a household-wide skeleton of pipes to facilitate the distribution of data throughout the house [24].This hybrid system also promises to solve many of the issues associated with progressive urbanization, such as traffic congestion and strains on energy and water systems, amongst other things, through digitalization, with the use of computers and the internet. As a result, several highly innovative information technology companies, including IBM, Cisco, Telekom, Siemens, Toshiba, and Google, along with public utilities around the world, are actively investing in what has been termed “smart city development.” Indeed, the socio-political requirements for energy management as a result of the energy crisis, and the possibility of interconnectivity within the internet of things (IOT) framework, are inspiring the transformation of urban centers into smart cities [25], and “…technology enabling data capture and analysis, connectivity, monitoring and control is becoming the new baseline for smart buildings” [26]. However, as far as the preservation of energy and the conservation of the environment are concerned, computers and the associated infrastructure facilitating communications between them, are a huge part of the problem. Receiving, analyzing and processing data requires a great deal and constant supply of (additional) power. Buildings are already huge energy consumers. Why make a case for additional energy, only to justify its management and efficient use? Even if alternative energy is used to satisfy this ‘additional’ power, how much of it will be left to substitute current fossil fuel sources? Indeed, although information technology (IT) is transforming the way we create and interact with buildings, their energy, as well as associated operational requirements, cannot simply be overlooked.

2. Smart and Intelligence in Building Materials Discourse

The energy efficiency and comfort strategies concerned with intelligence involve machine components of learning and control algorithms, actuators working under a governing central intelligent system, an integrated system of sensors complementing each other, as well as integrated circuits to help increase the accuracy of measured data and convert the same into digital signals that can be transmitted wired or wirelessly to a control system. These control systems require the application of information and communication technology (ICT) to facilitate the implementation of advanced sensors and control algorithms. Thus, the measure of energy efficiency and comfort is largely dependent on the degree or level of automation and sophistication of the control system, which has also been described as complex and expensive, requiring high operational energy and a payback period, in some cases, of up to 20 years.

So-called ‘hybrid systems’ featuring human-in-the-loop approaches enabled by human-centric computing, smart devices and machine components of intelligence complementing each other have been suggested. However, the machine components still require continuous monitoring technology, computers for supervisory control, and other associated hardware, including data transmission systems, which would consume power, increase equipment costs and decrease the overall system efficiency. Consequently, systems with zero additional energy demand remain the best approach to the issue of energy use, and passive systems were identified as meeting these criteria, with smart materials able to respond independently to environmental stimuli without any external or induced input. Additionally, their installation is easy and reliable. However, direct user control according to occupant/user preference is not possible. Indeed, while smart/passive systems comprise advanced materials with multiple functionalities able to respond to the emerging environmental-energy problems in the society, it is practically impossible to have intelligent/hybrid/active systems without additional computer control and its resulting implications. Moreover, user control (an identified problem with smart systems), still presents a problem in intelligent systems, with some occupants still reporting feeling uncomfortable with the deployed optimized solutions, especially with mechanical heating, ventilation and air conditioning (HVAC). Studies reveal that as many as 43% of occupants are actually dissatisfied with mechanical HVAC, and 56% to 89% of government workers regard it as a problem in Europe and the US [27], and thus a mismatch between building systems and occupant comfort. Since energy savings in intelligent systems are largely determined by the degree of automation of the control system, and system performance depends on user behavior or acceptance, the personal preferences and requirements of each user would need to be taken more into account when optimizing control algorithms to achieve better system performance and thus higher energy savings. This, however, still presents a problem, because occupant behavior is not a precise and quantifiable science. Even with passive sensors (widely used because they are cheaper and consume less energy than active ones), an external power source is needed, 'false-off' readings may also occur frequently in systems as sensors may fail in detecting a stationary body, and so on [28]. Generally, now, building occupants actually accept a larger range of temperature variation in naturally ventilated buildings than in computer controlled air-conditioned ones [3].

3. Summary

It was found that both notions were often used interchangeably even though they have distinct implications. On the one hand, while smart materials could be connected to computers to provide building occupants with control, the resulting intelligence, on the other, adds complexity to the system and ultimately increases the demand for energy. It has been argued that this 'additional energy' could be supplied from renewable sources. However, renewable energy systems still fall short because of their high upfront cost, intermittency and general low capacity. Additionally, sensor feedback is necessary to deploy comfortable solutions and energy savings in intelligent systems, but only after they have 'sensed' or detected all environmental variables. Monitoring, calculating, analyzing and transmitting all this data across a range of users with different needs would consume a lot of power, increase equipment as well as associated (installation) cost, and decrease the overall system efficiency. Consequently, until the global community finds more considerable alternatives, focus and attention should indeed be on zero energy demand technologies and systems.

Buildings remain the biggest energy consumers in the world, and thus present a huge opportunity for significant savings in global energy use, especially when the focus is shifted to address the issue from the point of demand. With smart materials, the requirement of zero additional energy demand and occupant comfort can be achieved without the need for computer-controlled intelligence. In fact, the current study revealed that while smart materials and systems independently manifest direct responses to external stimuli by altering their physical state and reverting back when the stimuli is removed, intelligent materials and systems provide occupant/user control of the environment and technological appeal, rather than comfort and energy efficiency. The prevalence of information and communication technology, interconnected devices and IOTs, enabled by even faster internet speeds, inadvertently positioned intelligent buildings as the next logical step in the evolution of buildings, and is now gradually expanding the current approach to building design to include automation and computer-based (control) systems, which will require machine learning and human-in-the-loop approaches with computers able to predict behavior and deploy solutions after close monitoring.

The world is experiencing an increase in energy demand. From energy use charts, energy use is on the increase, and this is largely due to the demand from electrically powered technologies that are presented as clean or efficient. The current study makes the case that focus should be on reducing or eliminating demand altogether with less pressure on existing sources of energy production. Thus, when assessing the key challenges of buildings in making them truly smart, the focus should be towards zero additional energy. Interventions in old and new buildings alike can come in the form of advanced, high-performance, passive smart materials that use their (material) properties to respond to the changes in their environment, resulting in significant energy savings by eliminating demand and ensuring overall occupant comfort. The approach to design and overall solutions to environmental problems should be region specific. Technology is not a one-stop approach to issues, and the 'one size fits all' approach is no longer feasible. Instead of changing energy use, the focus should be on eliminating demand altogether. The properties of existing advanced smart materials with multiple functionalities can be further modified so they are able to respond to the emerging environmental-energy problems in our society.

References

1. Ogwu, I.; Nzewi, N.U. Adopting the Principles of Building Physics, Smart Materials and New Technologies in the Design of Energy Efficient Buildings. Environ. Rev. J. Fac. Environ. Sci. 2017, 6, 1–9. Available online: http://erjournal.net/index.php/erjournal/article/view/30/pdf1 (accessed on 21 June 2021).
2. Ikechukwu, O.; Moses, O. Conceptual Issues in the Qualification of Intelligent Buildings. Open J. Energy Effic. 2019, 8, 52–63.
3. Ogwu, I.; Long, Z.; Okonkwo, M. Issues in the Conceptualization and Understanding of Intelligent Buildings. In New Ideas Concerning Science and Technology; Adnan, S.H.B., Ed.; SCIENCE Domain International: London, UK, 2020; Volume 1, pp. 12–21.
4. Addington, M.; Schodek, D. Smart Materials and New Technologies: For the Architecture and Design Professions; Architectural Press: Burlington, MA, USA, 2005; pp. 21–95.
5. Christopher, O.O. Chemical Indicating Devices. In Encyclopedia of Smart Materials (1 & 2); Schwartz, M., Ed.; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2002; pp. 173–182.
6. Bell, J.M.; Skryabin, I.L.; Matthews, J.P. Windows. In Encyclopedia of Smart Materials (1 & 2); Schwartz, M., Ed.; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2002; pp. 1134–1145.
7. Bax, L.; Cruxent, J.; Komornicki, J. Key to Innovation Integrated Solution: Innovative Chemistry for Energy Efficiency of Buildings in Smart Cities, SusChem—European Technology Platform for Sustainable Chemistry, European Commission Smart Cities Stakeholder Platform; The European Chemical Industry Council: Brussels, Belgium, 2019; pp. 8–12. Available online: https://cefic.org/app/uploads/2019/01/Innovative-Chemistry-for-Energy-Efficiency-of-Buildings-in-SmartCities-BROCHURE-iNNOVATION.pdf (accessed on 21 June 2021).
8. Gomaa, E.G.; Badran, E.E.; Mahmoud, M.A.; Saleh, A.M. The Use of Smart Materials in raising the Efficiency Performance of Buildings. Int. J. Appl. Innov. Eng. Manag. 2016, 5, 1–18.
9. Makakli, E.S. Potential of Smart Materials for Sustainable Architecture. Int. J. Soc. Sci. 2016, 55, 267–275.
10. Nitesh, D.; Ashish, C. Smart Construction Materials & Techniques AICMT. In Proceedings of the National Conference on Alternative & Innovation Construction Materials & Techniques TEQIP-II/Civil/AICMT-3; e-Proceeding: MITS under TEQIP-II, Gwalior, India, August 2014; Available online: https://www.researchgate.net/publication/297167802_SMART_CONSTRUCTION_MATERIALS_TECHNIQUES (accessed on 20 June 2021).
11. Federiac, R.; Fabiani, C.; Chiatti, C.; Pisello, A.L. Cool, Photoluminescent Paints towards Energy Consumption Reductions in the Built Environment. J. Phys. Conf. Ser. 2019, 1343, 012198.

12. ExxonMobil. Outlook for Energy: A Perspective to 2040; ExxonMobil Corporation: Irving, TX, USA, 2019; pp. 7–12.
13. Cristian, G.; Christian, I. Energy and Environmental Issues in Smart Buildings. CiteSeerx 2019, 26–51. Available online: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.582.2152&rep=rep1&type=pdf (accessed on 6 July 2021).
14. World Business Council for Sustainable Development-WBCSD. Communicating Collective and Individual Climate-Related Challenges and Action; Construction and Building Materials; TCFD Preparer Forum: Geneva, Switzerland, 2020; pp. 7–15. Available online: https://www.wbcsd.org/Programs/Redefining-Value/TCFD/Resources/Construction-and-Building-Materials-share-TCFD-implementation-experience (accessed on 20 March 2021).
15. Hens, S.L.; Hugo, C. Applied Building Physics: Ambient Conditions, Building Performance and Material Properties, 2nd ed.; Wilhelm Ernst & SohnVerlag für Architektur und technische Wissenschaften GmbH & Co. KG: Berlin, Germany, 2016; pp. 1–7.
16. Arvind, K.; Ajay, V.; Rawat, R.S.S. Intelligent Material for Modern Age: A Review. IOSR J. Mech. Civ. Eng. 2016, 13, 10–15.
17. Commscope. Available online: https://www.commscope.com/Blog/Defining-Todays-Intelligent-Building (accessed on 27 June 2021).
18. Caffrey, R. The Intelligent Building—An ASHRAE Opportunity. ASHRAE Tech. Data Bull. 1985, 94, 2–7.
19. Toshinori, T. A Concept of Intelligent Materials. J. Intell. Mater. Struct. 1990, 1, 149–156.
20. Mohamed, A.S.Y. Smart Materials Innovative Technologies in Architecture: Towards Innovative Design Paradigm. Energy Procedia 2017, 115, 139–154.
21. Moulaii, M.; Mahdavinejad, M.; Gheisar, M. The status of energy efficient usage of smart materials in sustainable built environment in hot and dry climates (case study: Middle Eastern countries). In Proceedings of the International Conference on Intelligent Building and Management, Proc. of CSIT (5), Singapore, 16–18 September 2011; IACSIT Press: Singapore, 2011; pp. 340–345.
22. Schlangen, E.; Joseph, C. Self-healing Processes in Concrete. In Self-healing Materials: Fundamentals, Design Strategies and Applications; Ghosh, S.K., Ed.; Wiley-VCH: Weinheim, Germany, 2009; pp. 141–179.
23. Stimmel, L. Carol. Building Smart Cities: Analytics, ICT, and Design Thinking; CRC Press: Boca Raton, FL, USA, 2016; pp. 6–46.
24. The Washington Post. Available online: https://www.washingtonpost.com/archive/realestate/1990/11/03/smart-homes-wave-of-the-90s/5d69abfe-b115-4edb-92da-5af81699d05f/?utm_term=.6eba30f49602 (accessed on 20 June 2021).
25. Gassmann, O.; Böhm, J.; Palmié, M. Smart Cities: Introducing Digital Innovation to Cities, 1st ed.; Emerald Publishing Limited, Howard House: Bingley, UK, 2019; pp. 5–65.

26. SIEMENS. Smart buildings: New Criteria for a New, Smart Building Era; Article no. SI_0183_EN (Status 11/2019); Smart Infrastructure Global Headquarters; Siemens Switzerland Ltd.: Zug, Switzerland, 2019; Volume 2.
27. Francis, A.; Cristian, G. Natural Ventilation in the Urban Environment. In Building Ventilation: The State of the Art; Santamouris, M., Wouters, P., Eds.; Earthscan: London, UK, 2006; pp. 1–35.
28. Bavaresco, M.V.; D’Oca, S.; Ghisi, E.; Lamberts, R. Technological innovations to assess and include the human dimension in the building-performance loop: A review. Energy Build. 2019, 202, 109365.