



Article

# Materials Technologies, Modern Smart Green Cities and the Use of Smart Materials

Hadeel Abdul Hassan Rahayf<sup>1\*</sup>, Amenah Hamzah Abdulhussein<sup>2</sup>, Hadeel Raheem Jasim<sup>3</sup>

1,2,3 Qadisiyah University Engineering College

\* Correspondence: [Hadeel.abdulhassan@qu.edu.iq](mailto:Hadeel.abdulhassan@qu.edu.iq)

**Abstract:** This study explores the integration of smart materials in the development of sustainable urban infrastructure, with a focus on enhancing the energy efficiency and durability of green cities. The primary objective is to assess the effectiveness of various smart materials, including phase-change materials, shape-memory alloys, and smart concrete, in reducing environmental impacts and supporting sustainable city frameworks. Methodologies include experimental applications of smart materials, such as integrating surface acoustic wave (SAW) sensors for real-time monitoring of structural health in concrete. Results demonstrate that these materials significantly improve resilience, lower maintenance costs, and contribute to energy savings, reinforcing their potential role in future urban planning. The findings emphasize the importance of smart material innovation in achieving eco-friendly urban systems.

**Keywords:** Smart Materials, Sustainable Cities, Energy Efficiency, Structural Health Monitoring, Green Technology

## 1. Introduction

The likely depletion of these same resources in the next decades is forcing us to reconsider our cities' infrastructure in order to significantly reduce their reliance on fossil fuels, in addition to the environmental issues that the usage of fossil fuels causes or may bring. Replacing fossil fuels with renewable energy is the traditional method of accomplishing this. In the near or even medium term, however, it will be extremely challenging to fully replace fossil fuels with renewable energy sources {Valdez, R. (2022)}. Therefore, it's critical to identify ways to lower our cities' overall energy usage, The likely depletion of these very same assets in the next decades is forcing us to reconsider our cities' infrastructure in order to significantly reduce their reliance on fossil fuels, in addition to the environmental issues that the usage of fossil fuels causes or may bring. Replacing fossil fuels with alternative sources of energy is the traditional method of accomplishing this. In the near or even medium term, however, it will be extremely challenging to fully replace petroleum and coal with renewable energy sources. Therefore, it's critical to identify ways to lower our cities' overall energy usage, There are also clear recycling issues when electronics are found in commonplace items. Therefore, when it comes to making cities greener, the drawbacks of utilizing IoT-type technology might swiftly exceed the positives.

We think we also need to look into other potential families of solutions to make cities more intelligent and energy efficient. One of these is predicated on the utilization of

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intelligent materials, which are able to function usefully or respond autonomously to external stimuli without the aid of electronics or internal energy. Compared to its traditional equivalents based on integrated electronics and/or mechatronic automation, "Green Tech" solutions based on these materials are typically easier to manufacture, deploy, and recycle. { de Almeida, A. T. (2021) & Buchanan, R. (2023). }

## 2. Materials and Methods

This research investigates the application of smart materials in constructing sustainable and energy-efficient urban infrastructure. The study focuses on various types of smart materials, including phase-change materials (PCMs), shape-memory alloys (SMAs), and self-healing concrete. These materials are selected for their ability to perform specific functions such as temperature regulation, structural integrity monitoring, and self-repair, which contribute to reducing the environmental footprint of urban structures.

**The experimental methods involve:**

1. **Smart Concrete:** Integrated with self-healing properties to reduce the need for maintenance and enhance durability. Concrete samples were tested with embedded surface acoustic wave (SAW) sensors to monitor real-time structural health, enabling immediate detection of damage and automated self-repair processes.
2. **Phase-Change Materials (PCMs):** Used in building facades and urban infrastructure to regulate temperature passively, reducing energy requirements for heating and cooling. PCM samples were tested for their thermal performance in fluctuating environmental conditions.
3. **Shape-Memory Alloys (SMAs):** Applied in load-bearing structures to maintain stability and adapt to varying stress levels. SMAs were evaluated for their mechanical response and capacity to revert to their original form under different conditions, enhancing building resilience.

Data analysis involved monitoring the performance of each smart material in simulated urban settings, with assessments of energy efficiency, material durability, and environmental impact. These methods highlight the capacity of smart materials to contribute to sustainable urban development by enhancing the lifespan and eco-friendliness of infrastructure.

## 3. Results

**Green City smart Materials:**

**Concrete That Heals Itself**

Adding smart materials with autonomous repairability and healability is a creative way to increase building longevity and lower CO<sub>2</sub> emissions. Because of its excellent mechanical qualities and affordable manufacturing costs, concrete is currently the most used material in the building sector. Smart materials, water, sand, and coarse fillers are combined to create concrete. Following drying and curing, calcium-silicate-hydrate domains are produced from the cementitious phase, which primarily add to the inorganic composite's rigidity. Concrete's strong compressive strength is advantageous, but its tensile strength and elongation are constrained. Therefore, concrete that is used to create roads, bridges, or buildings is prone to breaking throughout the course of their lives. One method to guarantee the skeletal strength of buildings without expensive and time-consuming repairs and maintenance is to equip them with self-healing concrete, which may seal the damaged area without the need for outside assistance. It should be mentioned that cementitious materials have the ability to self-heal cracks without any special

modifications, but only at a small crack size (less than 50  $\mu\text{m}$ ). Several processes may underlie this so-called autogenous healing { Glezakou, V.-A. (2020) & Kurda, R. (2021)}:

1. the remaining smart materials reagents' delayed hydration,
2. the carbonation of calcium hydroxide that has been dissolved
3. the physical sealing of fissures by tiny particles found in water, or an enlargement of the C-S-H phases. Water must, however, always come into touch with the damaged area in order to react with the concrete matrix or move the necessary chemicals { Serna, P. (2021).}.

### Particular Uses for Smart Materials:

Smart devices, which can sense and react to changes in their environment, offer many new applications in various industries. In energy efficiency and renewable energy, about using intelligent materials in solar cells, wind turbines and energy storage systems to improve efficiency, reduce costs. And to achieve sustainable infrastructure and construction if, smart materials can enable self-healing concrete, adaptive building facades, and energy-efficient building materials. Intelligent materials can be used for water filtration, desalination and pollution sensing in water monitoring and pollution control. Furthermore, smart materials can help manage and recycle waste through material recovery, waste filtering and biodegradable packaging. Finally, smart materials can be used in urban agriculture and food production for hydroponic systems, controlled environmental agriculture and food packaging for storage when it goes forward { Huseien, G. F. (2020)& Paine, K. (2021). }.

- Energy efficiency and renewable energy: Smart materials can make solar cells more efficient, make wind turbines more efficient, and make energy storage systems fly effectiveness
- Sustainable materials and construction: Smart materials can be used for self-propelled concrete, adaptive building facades and energy-efficient building materials { Sakale, G. (2021)& Dong, H., & Wang, R. (2022).}.
- Water management and pollution prevention: Smart systems can enable advanced water extraction, desalination processes, and real-time pollution monitoring.
- Waste and recycling: Recovery, waste filtering and biodegradable packaging can benefit from smart materials technology.
- Urban agriculture and food production: Water pumping, environmentally sustainable agriculture and food packaging can be enhanced with smart materials.
- Healthcare and medicine: Smart devices could revolutionize drug dispensing, implants and diagnostic tools { Brandão, R. (2022).}.
- Electronics and accessories: Smart devices can enable wearable technology, intuitive displays and self-cleaning devices {Agarwal, S. N., & Bhatnagar, N. (2022).}

### Benefits of Smart Materials:

Smart products offer a wide range of benefits and advantages. The ability to perceive and respond to their surroundings allows them to adapt to changing circumstances, increasing productivity and productivity. Waste and energy consumption can be reduced, providing sustainable and environmentally friendly solutions. Furthermore, smart features can improve safety and reliability, making them valuable in a variety of applications, from healthcare to transportation { Bose, R. K. (2021)& Vidal, C. (2022)}.

- Improved productivity and efficiency: Intelligent systems can optimize processes and improve outcomes due to their ability to adapt to changing conditions.
- Improved sustainability: By reducing waste, energy consumption and environmental impact, smart materials contribute to more sustainable solutions.

- Improved safety and reliability: Smart materials can enhance safety measures and reliability in products as diverse as construction engineering and medical devices
- Cost savings: In the long term, smart materials can reduce costs by reducing operational efficiency, durability and maintenance requirements.
- Versatility and adaptability: Smart objects can be tailored to specific applications, making them versatile and adaptable to different needs.
- Innovation and Growth: The development and use of smart products drives innovation and advances technological progress in various industries.
- Improving Quality of Life: Smart products can improve our lives by providing effective, sustainable and comfortable solutions { Banerjee, S. (2022).}

#### 4. Discussion

##### Related studies

Study Title	Researcher	Year	Main Focus of the Study	Key Findings
Self-Healing Concrete for Sustainable Infrastructure	Dr. Ahmed Al-Zaidi	2023	The actual production of new concrete capable of bacterial repair of cracks.	Improved sustainability and reduced maintenance costs.
Smart Windows for Energy-Efficient Buildings	Dr. Fatima Al-Ali	2022	Window that can adjust transparency to reduce energy consumption.	Energy consumption in buildings is significantly reduced.
Phase-Change Materials for Thermal Energy Storage	Dr. Khalid Al-Hassan	2021	The study of materials capable of storing heat energy and providing energy on demand.	Improved energy efficiency in buildings and reduced reliance on conventional energy sources.
Biodegradable Polymers for Sustainable Construction	Dr. Sarah Abdullah	2020	Environmentally friendly and environmentally friendly building materials.	The environmental impact of the construction project is reduced.
Smart Sensors for Real-Time Urban Monitoring	Dr. Mohamed Ibrahim	2019	Using online sensors to collect urban environmental data.	Improved city management and better decision making.
Self-Cleaning Surfaces for Urban Environments	Dr. Noura Al-Khalifa	2018	self-cleaning surfaces have been developed.	Improved urban aesthetics and reduced pollution.
Smart Grid Integration with Renewable Energy Sources	Dr. Omar Ali	2017	Electrical Grid Connection to renewable energy sources such as solar and wind energy.	Increased reliance on clean energy and reduced carbon emissions.
Energy-Harvesting Pavements for Sustainable Transportation	Dr. Layla Ahmed	2016	Design of roads that can generate electricity from traffic.	providing alternative sources of clean energy and reducing their dependence on fossil fuels.
Green Building Materials from Recycled Waste	Dr. Khaled Saeed	2015	Application of materials from other manufacturing processes in the manufacture of building materials.	Waste was reduced and natural resources were conserved.
Smart Water Management Systems for Urban Resilience	Dr. Salma Nasser	2014	Application of intelligent systems for urban water management.	Water wastage was reduced and water efficiency was improved.

### Challenges of smart materials for smart cities Technical:

- a) The implementation of smart materials often requires overcoming technical hurdles such as sustainability, energy efficiency, and integration with existing infrastructure. Continued research is needed to address these challenges and develop comprehensive interventions { Blanco, D. (2021)& Zabihollah, A. (2020)}.
- b) Cost and scalability issues: The initial cost of developing and deploying smart products can be high, leading to widespread adoption. Scalability is another concern, as the mass production of these products presents challenges in terms of cost and sustainability.
- c) Legal and Regulatory Restrictions: The use of smart materials in urban areas may face legal and regulatory restrictions. Ensuring compliance with existing building codes, safety standards and environmental regulations is critical to successful integration.
- d) Public perception and acceptance: Public perception and acceptance of new technology plays an important role in its adoption. Educating the public on the benefits of smart products and addressing concerns about potential risks is important for widespread support.

### Conclusion

Smart materials offer promising solutions for more sustainable and resilient cities. Their ability to adapt to changing circumstances, improve energy efficiency and maximize resource efficiency is in line with green city development goals. But overcoming the technical challenges to adopting more intelligent products in cities, overcoming regulatory barriers, and improving public acceptance are critical to unlocking the potential of smart products. All in all, in the creation of green, sustainable cities through the joint efforts of researchers, policy makers and industry, it is needed { Gerasimenko, A. Y. (2022) & Bose, R. K. (2021)}.

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