Chapter 2
Innovative Materials for High-Performance Cladding: The Future of Green Urban Facades

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ABSTRACT

This chapter reviews high-performance cladding materials and facade systems for greener, climate-responsive urban buildings. It covers bio-based composites, smart and responsive materials, building-integrated photovoltaics, and vegetated facades, evaluating thermal performance, durability, lifecycle impact, carbon reduction, and urban environmental quality. It also examines the growing role of digital tools, including AI-assisted analysis, BIM, and predictive monitoring, in material selection, performance optimization, and long-term facade management. Case studies such as Bosco Verticale, The Edge, and Al Bahar Towers demonstrate how integrated facade strategies enhance energy efficiency, environmental performance, and design quality. Key barriers include high upfront costs, regulatory uncertainty, technical integration challenges, and maintenance complexity. Overall, the chapter argues that combining innovative materials with AI-supported design can advance net-zero and resilient urban development when guided by lifecycle thinking, supportive policies, and effective implementation.

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1. INTRODUCTION

Cities are developing at a pace never witnessed before with the projection that in 2050, over 70 percent of the world population will be living in towns and cities (United Nations, 2018). These gigantic urban sprawls put additional strain on infrastructure, energy as well as a built environment. The building sector is behind nearly 40 percent of the total energy-related carbon dioxide emissions worldwide because building consumes a huge amount of energy, as well as produces greenhouse gases (IEA, 2021b). Therefore, architecture, engineering and construction (AEC) sector is undergoing a paradigm shift in terms of sustainable business operation and processes and technology and facades and building envelope have received most attention.

Among the components of architectural design, the cladding system - and the facade in particular - plays a major role in shaping aesthetic character, thermal behavior, environmental impact, and weather resilience. Rather than functioning only as a protective outer layer, facade systems now operate as active interfaces between interior and exterior conditions (Addington & Schodek, 2005; Bran, 2014).

The current fashion of innovation in the design of the facade improves the implementation of the use of high-performance materials that are multifunctional: thermal efficient, energy generative, air purifying, durable and have low environmental costs. The following materials such as bio-composites, phase-change materials (PCMs), building-integrated photovoltaic (BIPV), and nano-engineered coatings have become the primary ingredients of the next generation of green architecture. They may find an application as the complementary steps in the broader measures of carbonization, circular economy, and climate-responsive design.

Where material science, environmental engineering, and architectural innovation intersect, facade design becomes a tool for urban ecological repair and climate-responsive performance. Advances in biomimicry, digital fabrication, and material innovation are widening the role of building skins as active environmental moderators rather than passive barriers (Ashby, 2013; Bran, 2014).

However, although the future of such advanced materials looks very promising, there is still a series of limitations to their large-scale implementation: economic affordability, technical demandingness, the absence of unified rules, and ignorance of long-term operation in various climates (Asdrubali et al., 2015). The only solution to narrow this gap is to emerge with a full-fledged knowledge about these new materials, their life-cycle effects, how to implement them on a practical basis, and how they can be integrated into current construction methods.

Concrete, glass and aluminum are traditional cladding materials that traditionally have dominated the design of the building envelope but these materials are highly lacking when analyzed in the context of modern-day sustainability objectives. Examples of materials with very high embodied energy and embodied carbon include

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