Sustainable Building Design for Tropical Climates

Niccolò Aste, Federico M. Butera, Rajendra Singh Adhikari and Fabrizio Leonforte

Abstract The "Handbook-Sustainable Building Design for Tropical Climates" considers the impact of the construction sector on climate change, estimating that the building stock that will be built in Sub-Saharan Africa by 2050 will be three times greater than the current overall building stock of Europe. The purpose of the handbook is to offer an easy-to-use tool that provides general guidelines and basic information on the physics of buildings, together with all of the practical tools necessary for designing a sustainable-energy building in a tropical climate. The contents of the handbook were tested and evaluated by means of a series of lectures and training sessions—during the training courses on "Sustainable Integrated Design" held in different East African countries. These courses were attended by professionals (including engineers and architects), entrepreneurs, university teachers and postgraduate students. Further, based on the handbook, two "Massive Online Open Courses" (MOOCs) have been developed for the dissemination of the knowledge among various stakeholders.

Keywords Building energy efficiency · Sustainable buildings · Tropical climate · East African community · MOOCs

1 Introduction

Roughly half of the world's population lives in urban areas, and this proportion is projected to increase to 66% by 2050, adding 2.5 billion people to the urban population. Over the next two decades, nearly all the world's net population growth is expected to occur in urban areas, with about 1.4 million people added each week (GCEC 2014).

For such reason, the total building stock is expected to nearly double by 2050, at a rate of 5.5 billion square metres per year to almost 415 billion square metres in 2050, compared to the current global building stock of 223 billion square metres (GABC

N. Aste · F. M. Butera · R. S. Adhikari (✉) · F. Leonforte
Architecture, Built Environment and Construction Engineering—ABC Department, Politecnico di Milano, Milan, Italy
e-mail: rajendra.adhikari@polimi.it

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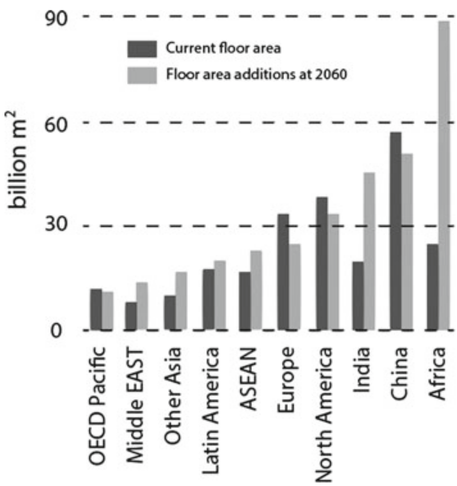
2016). The current building stock is asymmetrically distributed among countries, as well as the estimated new building construction. Roughly 1 billion buildings are expected to be built in addition to the current 1 billion existing building, mainly located in OECD countries and China as shown in Fig. 1. The African continent, as well as India, still has less buildings than North America and Europe, but the total number of new buildings in the two regions is expected to overcome developed countries within 2050, with more than 50 billion m^2 and 30 billion m^2, respectively. In fact, by 2050, it is expected that the population of Africa will double, reaching 2.5 billion inhabitants. Thus, 700,000 new homes, 310,000 new schools and 85,000 new clinics are expected within 30 years, as well as additional facilities and infrastructures. Thus, the issues of the unsustainability of building sector growth and its impact on social, economic and environmental well-being have been addressed since the preliminary phase of the design process.

Currently, buildings represent an estimated 36% of global final energy consumption and 39% of the global energy-related carbon dioxide emissions [the latter comprised of 28% operational emissions and 11% from materials and construction (IEA 2018)]. Growing population and income levels in emerging economies and developing countries represent the main driver for building stock increases, implicating an estimated increase of energy demand in building equal to 50% by 2050 if no action is taken (GABC 2016). The trend is still increasing, even if important measures have been worldwide implemented in terms of energy efficiency, especially in OECD countries.

The goal of total decarbonization of building sector passes through the construction of new building with zero or almost zero-energy consumption from fossil fuels, i.e. zero carbon buildings, and the total renovation of the existing building to the same net zero carbon standards.

Fig. 1 Global building stock



Current renovation rates account for about 1% of existing building stock each year (GABC 2016). While to achieve 100% zero carbon goal by 2050, it is necessary to ensure a renovation rate higher than 3% (WGBC 2017).

CO_2 emissions resulting from material use in buildings represent almost one-third of building-related emissions, as concrete and steel manufacturing requires high amount of energy and implies large process emissions. As buildings become more efficient and the grid decarbonizes, embodied carbon increases in significance and will be responsible for nearly 50% of total carbon emissions of global new construction from 2020–2050. In this context, construction industry is required to radically change its manufacturing structure, in order to abate this increasing embodied energy.

In such a scenario, particularly, multifaceted and challenging are the role of the settlement design on minimizing energy consumption for cooling. This is a very critical issue, as energy consumption for cooling has been growing very steeply, and—according to the International Renewable Energy Agency (IRENA 2019)—will continue to grow, sustained by the climate change and the growing per capita income. For this reason, the issue of cooling must be specially highlighted.

Current models of human settlements are not designed to cope with the environmental challenges and are not sensitive to the rapid technological advancements from which our built environment could benefit. New real estate developments at the neighbourhood scale are producing a silent and uncontrolled Urban Revolution (Butera et al. 2018). The design of new building and urban developments is the key issue for coping with global warming and the quality of urban life, and, bearing in mind that urban design principles that apply to cities in tropical climates differ significantly from the principles that apply to cities in temperate climates, it is a burden shared by both developed and developing countries.

2 The Handbook of Sustainable Architecture in the East African Community

In such framework, the project "*Promoting Energy Efficiency in Buildings in East Africa*", an initiative of UN-Habitat in collaboration with the United Nations Environment Programme (UNEP), the Global Environment Facility (GEF), the governments of Kenya, Uganda, Tanzania, Rwanda and Burundi and Politecnico di Milano, was born. The first initiative of the project was aimed to the development of the "*Handbook of Sustainable Architecture in the East African Community*" written by Federico M. Butera as principal author (Butera et al. 2015). It offers an easy-to-use tool that provides general guidelines and basic information on the physics of buildings, together with all of the practical tools necessary for designing a sustainable-energy building in a tropical climate.

Fig. 2 Training session on handbook

The project team prepared an initial version of the handbook containing information on the various climates (building a climate map of the East African Community, defining six climate zones based on the impact of climate on the energy performance of buildings), the relations between the various climates and the energy response of buildings, their energy efficiency, design methods, the use of various technologies in the field of energy and zero-energy buildings and communities. The contents of the handbook were tested and evaluated by means of a series of lectures and training sessions—these too in provisional form—which were held in the cities of Dar es Salaam, Nairobi, Kampala and Kigali. The knowledge transfer was also extended to West Africa, through workshops in Douala, Cameroon.

The lectures were attended by professionals (including engineers and architects), entrepreneurs, university teachers and postgraduate students. The lessons included evaluation questionnaires on the handbook and training provided as well as discussion time sessions regarding the handbook and lessons (Fig. 2).

The evaluations and suggestions were used to improve the contents of the handbook and examine a number of issues in more detail, and to fine-tune the delivery of training in order to satisfy specific requests that emerged during the lessons. In addition to the above-mentioned subjects, the handbook (Fig. 3) contains five appendices: Principles of Building Physics, Principles of Thermal and Visual Comfort, Exercises, Case Studies and Integrated Design Applications. The handbook (Butera et al. 2015) is available as a free download on the UN-Habitat website (http://unhabitat.org/books/sustainable-building-design-for-tropical-climates/), allowing students, professionals and public administration technicians to consult, learn about and update their knowledge concerning the various themes connected with the building–energy relationship. Politecnico di Milano plays a particularly significant role in the potential for transferring knowledge that can have an impact on the national agendas—in this case the national energy agendas—of the East African Community countries, as

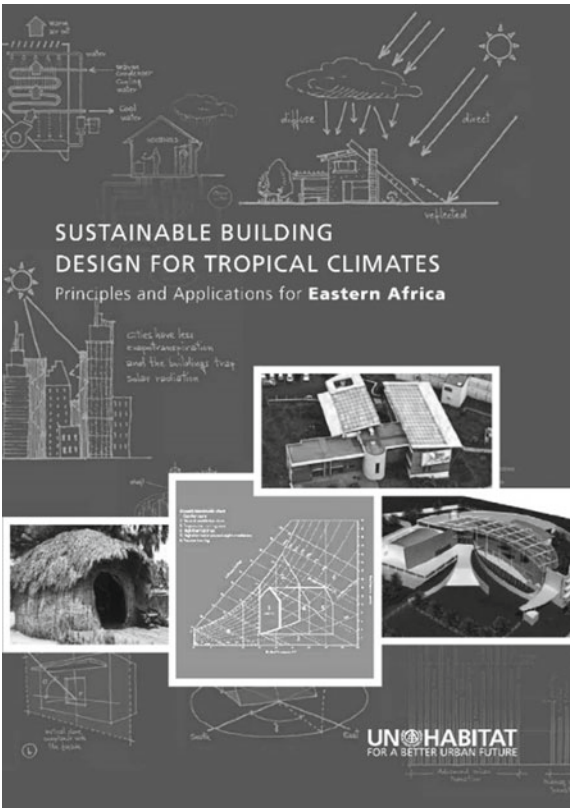


Fig. 3 Front cover of handbook

it is an internationally recognized institution with an extremely solid scientific reputation. The project has delivered two particularly important outcomes: firstly, the handbook has reorganized and disseminated a series of design-related information on tropical climates, providing dimensioning methods for the main parts of buildings in each of the different climate areas; secondly, it has produced a climate map based on building behaviour instead of the traditional ones based on vegetation.

According to the handbook, the following 30 strategies to consider in the design of sustainable building in the tropical climate can be outlined:

1. **Site analysis**: Assess the local context including the topography of the site. Collect data on temperature, relative humidity, wind's speed and direction, solar path and radiation.
2. **Building footprint**: The footprint of the building should ideally cover not more than 60% of the plot.
3. **Building orientation**: Design the long axis of the building to be along East–West to minimize direct solar radiation penetration in the building and reduce heat gain.

4. **Building shape**: Design it according to climatic zone. For hot-humid region, use narrow plans to maximize natural light, cross-ventilation and minimize heat gain. For hot-arid regions, use compact forms with courtyards to retain cold air in the building and minimize heat gain. Give preference to multi-storey building to increase density and maximize resources.
5. **Allocation of spaces within the building**: Services, e.g. toilets, starcases, lift, lobbies to be located on the East- and West-facing walls to act as buffer zones against heat gain but benefiting from daylighting.
6. **Opening**: Window sizing to be designed according to prevailing climatic conditions and placement preferably on North and South walls; window to wall ratio (WWR) should not exceed 40%. Glazing walls should be avoided, unless using special treated glass.
7. **Daylighting**: Design buildings according to climatic region, with openings on North and South walls, narrow plants to maximize daylighting, use light shelves in deep spaces. Window should be at least one-tenth of the floor area. The depth of the room should not exceed 2.5 times the height of the room.
8. **Solar protection**: Use sun shading devices, e.g. overhangs, vertical, horizontal shading elements, balconies, screens and vegetation to minimize heat gain.
9. **Natural ventilation**: Ensure that cross-ventilation is provided by the openings. Make use of roof vents and openings, thermal chimneys and clerestory windows. Make use of insulation materials under the roof sheet and design ventilated roofs.
10. **Cooling**: Integrate passive cooling systems by designing water bodies and features for evaporative cooling (just in hot and arid regions). Ensure that buildings using air condition appliances are well insulated to limit heat gains and reduce energy demand.
11. **Heating**: In highland region, enhance passive heat gain. Design passive solar heating strategies to ensure maximum sun penetration during cold season.
12. **Building envelope materials**: Always consider the carbon footprint content while choosing building materials. Give preferences to locally available building materials that are more appropriate with low energy content. Consider recyclable and reusable materials with low toxic emissions. Give preference to envelops (wall and roofs) with low U-value or low heat transmittance properties.
13. **External finishes**: Make use of light-coloured materials on external facades and roofs to reflect solar radiation in excess, while also incorporating green and living walls, vertical gardens provided with vegetation that grows on the facades.
14. **Renewable energy**: Integrate solar energy (thermal and electricity) such as photovoltaic and solar water heaters; wind energy, biogas and other available renewable energy systems into the building design.
15. **Water conservation and efficiency**: Design rainwater harvesting systems. Recycle grey water. Use water-efficient appliances and water-saving fixtures.
16. **Drainage**: Provide appropriate drainage technique to mitigate storm water run-off and facilitate replenishment of water table through rainwater infiltration.

17. **Sanitation**: In the absence of municipal sewage system, design on-site wastewater treatment facilities with production of biogas, compost and reused of water for irrigation.
18. **Solid waste management**: Design provisions for waste separation with on-site sorting facilities. Introduce innovative systems that encourage the 3R actions: reduce, recycle and reuse.
19. **Landscaping**: Design soft landscaping (greening site) with indigenous plants that require minimal irrigation and hard landscaping with paving materials that allow rainwater permeability. Limit paved areas around the building to reduce heat island effects.
20. **Energy-efficient appliances and energy demand management**: Incorporate energy-saving appliances in the building design. Make use of energy-saving bulbs, light level sensors, occupancy and motion sensors. Encourage behaviour change. Ensure that energy demand management principles are given top priorities by the building occupants.
21. **Well-balanced public spaces**: Fifty per cent of spaces should be allocated to streets, roads, public spaces, gardens and parks (30% far streets, 15% open space).
22. **Mixed land use**: Avoid zoning by combining economic, administrative and residential activities. This reduces the need to travel and ensures the use of public space.
23. **Mixed social structure**: Promote social integration and diversity. Encourage cosmopolitan values and the need to live together and avoid gated communities. Twenty to fifty per cent of residential space should be allocated to affordable housing.
24. **Adequate density and compact design**: High density neighbourhoods that are enough to trigger economies of scale and ensure livability.
25. **Connectivity**: Design street patterns and networks that connect the different parts of the city and ease the access to goods and services.
26. **Urban form matters**: Support mixed use, street life and walkability by designing compact blocks and buildings.
27. **Walkability**: Favour pedestrian mobility by emphasizing on walking distances, mixed use and public transport.
28. **Active mobility**: Street design should provide for pedestrians and cyclist lanes. Cycling extends reach of public transport.
29. **Promote the "shift"**: Encourage modal shift from energy-intensive modes, (cars) to walking, cycling and using public transport. Make cycling and walking safe and attractive.
30. **Promote vehicle efficiency**: Promote green transport by promoting the shift from fossil fuel-dependent vehicles to hybrid and electric cars.

3 Massive Online Open Courses (MOOCs)

In order to increase the dissemination of the knowledge developed in the handbook, two "Massive Online Open Courses" (MOOCs) have been developed. In detail, the "Massive Online Open Courses" (MOOCs) are online courses, implemented and issued with "open" logics, which generally involve a high number of participants, creating an equal community and which are distributed virtually on the global scale. These courses have spread rapidly since 2012 thanks to the launch of two international portals, Coursera and edX (http://www.coursera.org and http://www.edx.org), founded thanks to the encouragement of prestigious universities such as Harvard, Princeton, Stanford and MIT. All the initiatives connected with the Open Educational Resources, of which the MOOCs are an increasingly important pillar, playing a strategic role in redesigning the models of production and reproduction of knowledge and offering universities excellent occasions to test new forms of integration and share with the community on the local or global level.

The MOOCs—thanks to their being "open" and "massive"—are excellent channels through which to share ideas in local and global contexts and may therefore offer a significant contribution in this direction, but they also offer great networking opportunities. This potential develops in two dimensions; in the design phase: designing a MOOC allows the creation of flexible work groups that collect experts from different contexts in cultural, organizational and geographic terms, focusing on them with a short-term common goal and encouraging them to share the contents, opinions, etc.; in the execution phase: the global dimension of the MOOC facilitates the collaboration between the people interested in specific social themes fostering the creation of relationships on the global scale.

In this sense, the developed MOOCs called "*Sustainable building design for tropical climates: principles and guidelines for EAC*" and "*Sustainable building design for tropical climates: integrating design of buildings and technology systems*" aim to widely spread the basic skills for the design of sustainable buildings especially in tropical developing countries which, due to the exponential growth of their consumption, over coming years will prepare themselves to carry out a decisive role in the world's future energy scenario.

The courses are organized into different weeks and modules. At the end of each module, a quiz which checks the understanding of knowledge has been carried out (Fig. 4).

4 Conclusions

In conclusion, all the above-mentioned initiative aims to boost a technological change that implies also a cultural change. In order to face the issue of climate change, the culture of designers, architects, city planners, citizens, entrepreneurs and politicians has

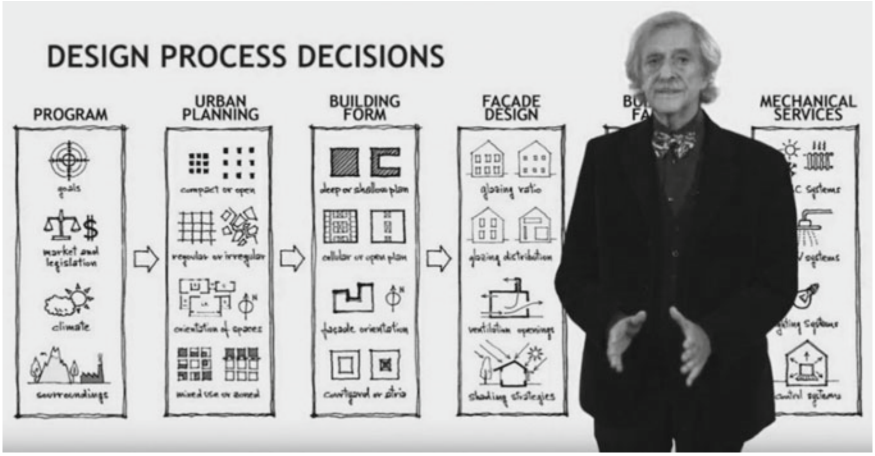


Fig. 4 Screenshot of MOOC developed based on handbook

to be changed. An unprecedented radical transformation of the methods of designing building and cities, especially in African countries, is required. The challenge for the new generations of designers is open.

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