Sustainability in Architectural Design: Smart Systems and Traditional Materials

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Abstract. When discussing about sustainability in buildings we usually refer to the Brundtland Report, to the energy consumption that has increased dramatically, to the planet’s resources that are decreasing, to the wild life that must be preserved. We take into consideration the environmental – natural and anthropic - agents, resources – human as well as materials – life service of the building etc. Less is discussed about sustainability in architectural design and detailing, although the details are the ones that, beyond paper drawings, keep the building together and ensure the expected service life and the life cycle of the building. “God is in the details” – as Mies van der Rohe stated more than 50 years ago – applies to a less spectacular side of our profession but, nevertheless, the one that contributes significantly to the character of the architectural object (if applied in buildings, of course). This paper refers to sustainable architectural concepts and details and their history.

1. Introduction
Humans are not the only builders of the planet. They are only the most powerful. Throughout history, buildings have been the "mirror" of their time: they preserve the ideas, values, beliefs, culture of the era in which they were designed and built as well as the economic and technological levels of knowledge of the specific moment in time. Going to the core, the principles of construction have not changed and they can be identified in all the built heritage - from traditional homes to high-tech buildings, bioclimatic, eco or green buildings - due to the fact that, building on planet Earth, we need to consider natural and anthropic agents that act on the built environment.

While the anthropic agents can be considered subjective, Nature's laws can not be negotiated; these are basic elements that have to be respected (“we can not negotiate with a beetle” - Oren Lyons, "The Ice is Melting", October 2004) It therefore seems reasonable to use the forces of nature in the act of architectural creation and not to defy them. But so do the more humble creatures of the earth that are ingenious architects and engineers without diplomas. A comparison between the constructions carried out by the humble world and our present buildings or between building systems invented by our ancestors and our performant building systems might show that, in terms of principles, we did not evolve too much.

2. The dam constructors
Dams have been built for more than 5000 years, to hold back water, to prevent flooding and provide water for irrigation. The oldest (recognized) dam is in Jordan and was built around 3000 B.C. It is a gravity dam, in Jawa and it consists of a masonry building in a basalt desert that provided water for the proto-urban population and their herds during the hot summer months [1], [2].

It seems that the ancient structure was so well designed and built that the dam was intact until a few years ago, when the intentions of restoration managed to destroy it: "With all the appropriate scholarly attention that this site has got, it is unfortunate that the ancient water structures were partially ruined due
to physical intervention a few years ago. The cement additions that were built and failed to collect water, should have never been permitted.” [3]. In its prime, the Jawa Dam was 15 feet tall, 80 feet long, with a base of 15 feet. It created the Jawa Reservoir that had a capacity of 1.1 million cubic feet1.”

A different type of dam, composed of independent particles of mound of various compositions of soil, sand, clay or rock, bound together by friction and interaction between particles, is the embankment dam (see Figure 1). One example is the Gura Apelor dam, in Romania, that has a clay core and stone ripraps and is the largest dam made of embankment and clay core in Europe. Built between 1975 and 1986, it is 168 meters high, with a surface of the lake of 390 hectares and a total volume of 210 million cubic meters.

Figure 1. Gura Apelor (Mouth of the Waters) Dam – Romania. Photo: Ana-Maria Dabija

Nowadays the functions of the dam have increased and include the production of (clean) energy beside the ancient functions: restricting the water flow in order to create reservoirs for irrigation, human consumption, industrial use, aquaculture, and navigability as well as to control floods.

Humble constructors, the beavers, build their own dams as well. Less spectacular but nevertheless useful for the survival of their species. The building materials used by the beavers for their “embankment dams” are: mud, rocks, sticks and small logs, in order to flood the area that represents a food source for their families.

The beaver’s building activities have an important impact on the environment, as their constructions bring in the same time benefits and create problems. Among the benefits of the beaver’s constructions are the invigorating of the wildlife habitat of the water and forest (as the ponds are available for the use of other animals as well) and a small flood control, one of the roles of any dam. Among the problems that the beavers’ constructions generate are flooding and destruction of croplands, destroying valuable timber, changing the riparian management of the area.

The beaver’s dams have a very clear purpose: to protect their lodges by water, so that predators can not reach them and their food cache. Therefore, they dig channels below the water line in order to access the “food cache” and the “lodge” (see Figure 2).

1 Transformed in meters, the dimensions of the Jawa Dam are: 4,5m heigh, 24 m long and with a base of 4,5m. The capacity is of 28317 m³
In fact so did the humans, throughout history: medieval castles were protected by the moat (the body of water that surrounds a medieval castle), to prevent the attackers from conquering them\(^2\).

\[\text{Figure 2. Beaver dam, pond and lodge.}, \text{Adapted from [4] (drawing by Ana-Maria Dabija)}\]

\[\text{Figure 3 Left: the beaver’s “castle” / lodge (Beaver’s Lodge in Wood Buffalo National Park, Canada) Photographed by Ansgar Walk in [5] and the medieval castle in Caerlaverock, Scotland, XIII-th Century, Photographed by Simon Ledingham in [6]}\]

Even if, at first glance, the comparison may seem slightly shocking, the principle, the means and the results are similar (see Figure 3), the need to protect the inhabitants against enemies.

3. The sky-scraper builders

Other “builders” of the humble world – still studies by specialists – are some types of termites, scattered on four continents of the Earth. Mound-building termites are living in sophisticated “buildings” that, compared to human buildings (and considering the scale of the “builders”), are higher than the highest sky-scrapers humans managed to build. “If we compare the height of an average termite nest with the size of a worker termite and adjust the scale to a human being 1.80 meters (5.5 feet) in height, the termite construction would be like a 960-meter (3,149-foot) skyscraper—higher than every human building in the world. For example, it is five times higher than the Great Pyramid of Egypt.”\(^7\)

\[\text{Different African, Australian, Asian and American termite mounds are examples of the logical approach of a less known ‘builder’ who needs to keep a constant temperature inside the nest, despite the large outdoor temperature gradient (see Figure 4).}\]

\[\text{\(^2\) In fact, it seems that the water protection was more subtle as it prevented tunneling under the fortification of the castle: any tunnel would collapse under the moat and fill with water}\]
The termite mounds are like high rise, multi-functional buildings, where all the aspects of life are carried out by the community, from birth to death: maternity hospital, kindergarten, working areas, dwellings, supermarkets (see Figure 5). Everything that is needed in a complex building which is designed to provide management of constant and controlled indoor climate (heat humidity and ventilation management, CO$_2$ ratio management) as well as waste management is accomplished by still unknown methods (although hypothesis and tests have been carried out for more than a century [10]).

The building materials used by the termite-builders are “bricks” of soil and any other material they can walk on or chew, bonded with saliva that acts like a mortar [11].

According to M Luscher$^3$ [10], the indoor climate is dependent on the size, shape, orientation of the construction, with a major role on the surface area-mass ratio. Luscher also identified two types of termitariums: closed and opened (with a chimney like top opening).

Luscher's original theory is known as the thermosiphon ventilation system. The warm air, containing CO$_2$ rises through the channels and, reaching the upper parts just beyond the mound envelope, pushes the denser, cold, clean air down to the core of the mound [12]. The loop closes and the cycle continues (see Figure 6).

Two decades later a new hypothesis was launched by C Noirot$^4$ [10], stating that the gas changes took place only by diffusion through the walls of the building in the closed termitarium. A later approach belongs to Cole, in 1973 [11], who considers that the wedge shape and NS axis orientation facilitate gas exchange, especially in the rainy season, as the porosity of the mound walls is reduced due to dampness.

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$^3$ M. Luscher Air-conditioned termite nests, Scient. Am. 205, 1961, p. 134-45, in [6]

$^4$ C. Noirot, The nests of termites in Biology of Termites, Eds. K. Krishna & F.M. Weesner, Vol 2, p. 73-125, Academic Press Inc New York, in [6]
Cole launched the hypothesis according to which the gas changes occur during a convection air movement. The theory is supported in the case of mounds with “chimneys”, that evacuate the warm air in the exterior.

**Figure 5.** Cross section of a termite mound adapted from J. Korb [14] (drawing by Ana-Maria Dabija)

According to King and his collaborators [13], the thermal stability (and indoor air quality) is achieved due to a set of vertical channels – buttresses called “flutes” - that become warm while the central chimney is cold, thus leading to convection and gas change.

**Figure 6.** The thermosiphon flow theory, adapted from Martin Luscher (drawing: Ana-Maria Dabija)
A different theory of how mounds actually work was proposed in 2008 [14]. The authors compare the mounds with the human lungs that are multi-phase gas exchangers. In the first phase gas exchange is dominated by forced convection driven by the respiratory muscles. Deeper, in the alveoli and alveolar ducts of the lungs, the gas exchange is dominated by diffusion. “Sandwiched between these phases is an extensive region of the lung, which includes the fine bronchi and bronchioles, where neither forced convection nor diffusion dominates flux. This mixed-regime region is the site of the overall control of lung function” [15].

Whatever makes the mounds work, one thing is clear: studied for more than a century and with questions – yet – unanswered, the termite mounds have been an inspiration for architects in the effort of obtaining good indoor air quality by passive means and sometimes with local materials. One of the best-known buildings is the Harare Eastgate building, authored by Mick Pearce and the engineering firm Arup and completed in 1996. The architect declared that he tried to incorporate the thermosiphon principle by providing a tube system within the walls and floors that move air through the building. As in the case of the mound, the heat generated by the activities inside the building as well as the heat stored within the structure draws the air up and into the large chimney stack and eliminated it through the roof (see Figure 7).

![Figure 7. Eastgate Centre, Harare, Zimbabwe. Arch. Mick Pearce. Photo copyright: Michael Denne, Cross section drawing Ana-Maria Dabija](image)

While appreciating the smart design that decreases the use of HVAC systems – thus reducing the use of traditional energy means – it should be noted that the chimneys are aided with fans, in order to increase the evacuation of the air. The same idea is applied by Mick Pearce in the design of the Council House 2 in Melbourne, a decade later (see Figure 8).
The cool air enters at the lower part of the room and rises as it gets warmer, to the upper part of the room from where it enters in the chimneys and is evacuated outside, with the contribution of the yellow fans that are part of the façade expression.

More than in the Harare building, Mick Pearce makes the most of the elements of construction that belong to the HVAC field (fans, ducts, tubes, showers), transforming them in specific features of the building façades.

The idea of expressing pipes and equipment is not new, in fact it represented a style in architecture – the high-tech - in the ‘70s. The best example is the Beaubourg / Georges Pompidou Center in Paris, designed by Renzo Piano and Richard Rogers.

The high-tech buildings emphasize the state-of-the-art in technology; the contemporary sustainable principles of building support the idea that the response to natural hazards and rules should be a part of the design and adapt the shapes and volumes in order to meet and emphasize these requirements.

From the termite mounds to the wind towers of the Middle East that cooled the buildings using the stack effect, or to the ordinary chimneys that ventilate hot gases or smoke, the distance is less than one may think (Figure 9): ventilation is naturally achieved, by passive design, without the use of active means.
Figure 9. Left: Tower of Silence, Wind Towers and Ice Chamber, Yazd, Iran Photo copyright: Julia Maudlin. Right: Chimneys of the Casa Batllo, architect Antonio Gaudi 1877 Photo: Ana-Maria Dabija

In fact, it is the principle according to which buildings with atrium have been designed: a central space acting as a huge stack takes over the air flowing from the floors and evacuates it at the top of the building. One interesting example is the Commerzbank in Frankfurt, designed by Sir Norman Foster, where the incoming air is filtered through green-houses at different levels and pushed towards the center of the building, the stack effect in this case bringing clean, fresh air to the floors, instead of evacuating it in the atrium (see Figure 10).

Figure 10. Commerzbank Frankfurt. Arch. Norman Foster Photo by Epizentrum in [16]
"Borrowed" from the traditional architecture and interpreted in a contemporary register and technological means, building scale chimneys appear in the Queen College of De Montfort University - Arch. Short and Associates - providing air ventilation with less use of conventional energy as a part of a sophisticated – but logical – study of cross ventilation design (see Figure 11).

![Figure 11. Queen College of De Montfort University - Arch. Short and Associates. Photo copyright: Stephan Richards in [17] Cross section: courtesy Prof. A.C. Short](image)

### 4. Space and time in Architecture

Traditional architecture is perennial: the same principles of construction have been respected for centuries: the environment of the site, the neighborhoods, the orientation, the climatic agents (sun, wind, water, soil etc.), vegetation, building materials have all been considered and used in the design principles in the most appropriate way, refined in millenniums of improvements.

It is, therefore, natural that buildings located at great distances from each other look (roughly) the same, since the basic principles according to which they are constructed, as well as the materials used for building them, are similar. As an example, we present two vernacular houses, built at about 10,000 km apart, one in Romania and one in Japan (see Figure 12). The same requirements for protection against natural agents (including seismic hazards) and the use of similar building materials lead to similar looking houses, despite the distance, in km/miles between them.

![Figure 12. Perennial architecture. 10,000 km apart, the example on the left is in Japan (XVII-th Century), in the Yamanashi Prefecture while the example on the right is in Romania (XVIII-th Century). Photo: Ana-Maria Dabija](image)
Taking a critical and historic look at the principles of designing architectural components and assemblies throughout history, it is established that millenary principles are being used (viewed from contemporary angles) and are reinterpreted in the architectural design according to the moments’ needs.

The contemporary buildings where these systems are integrated are clearly different from the ancient ones, but the basic principles can be identified, thus proving that the "discovery" has been discovered some time ago and what is "new" for us was new thousand years ago also.

The history of construction systems is full of examples of building principles that "come back to fashion" once a new technical or functional requirement revitalizes them. The radiant floor heating systems, for instance, are not new. Their history goes back millennia ago [18] and it developed in different parts of the world, wherever there was needed to warm houses. The idea is the same: fire outside the spaces that needed to be heated and a system of raised floors that conducted the hot smoke in the plenum and from there to the flues of the chimneys.

The Chinese kang foregoes the Greek and Roman radiant floor heating systems and there is no documented information that ancient Greece or the Roman empire adopted it from Asia. Rich villas and baths (see Figure 13) were using the system, as it was too expensive for regular population While after the fall of the Roman empire the system was abandoned, in Asia – China – it is still in use [19].

![Figure 13 Bath in the city of Pompei, Italy. Photos Ana-Maria Dabija](image)

A different historic requirement may lead to - in principle - a similar technological solution: raised floors are used as technical floors, sheltering cables and ducts, in contemporary office buildings. The idea, however, emerges from the ancient radiant heated floors of the villas and baths (as seen in Figure 14)

![Figure 14. Left: Floor heating system in ancient Israel Photo copyright: Dennis Jarvis, Right: Technical office floor. Source: Knauf [20]](image)
5. Conclusions
The use of technologies - new or old - and materials new or old do not represent targets of their own. They are only the means that transform the concept of a building to a real building. Innovative architectural and engineering design, the reinterpretation of everlasting principles as well as the use of the appropriate technologies lead to an individual identity of buildings that represent the built heritage that we provide for the future generation, that provides not only shelter but well being. As architect Yoshio Taniguchi stated, “Architecture is basically a container of something. I hope they will enjoy not so much the teacup, but the tea.”

References
[1] Tata and Howard, Unsurpassed Solutions in the Water Environment. “A History of Dams: From Ancient Times to Today”, 2019 [Online] Available at: <https://tataandhoward.com/2016/05/a-history-of-dams-from-ancient-times-to-today/>.
[2] India Celebrating, “First Largest Masonry Dam in the World”. 2019 [Online] Available at: <https://www.indiacelebrating.com/geography/first-largest-masonry-dam-in-the-world>.
[3] A. Khammash, Khammash Architects, Jawa - The dawn of water engineering, 2019 [Online] Available at: <http://www.khammash.com/research/jawa-dawn-water-engineering>.
[4] Washington Department of Fish and Wildlife, Living with wildlife, 2019 [Online] Available at: <https://wdfw.wa.gov/species-habitats/species/castor-canadensis/living>.
[5] A. Walk, Photo, “The beaver’s “castle” / lodge (Beaver’s Lodge in Wood Buffalo National Park, Canada)”, 1998 [Online] Available at: <https://commons.wikimedia.org/wiki/File:Wood-Buffalo-NP_Beaver%27s_Lodge_1_98-07-02.jpg>.
[6] S. Ledingham, Photo “The medieval castle in Caerlaverock, Scotland, XIII-th Century” 2007 [Online] Available at: <https://commons.wikimedia.org/wiki/File:Caerlaverock_Castle_from_the_air.jpg>.
[7] E. Hoyt, P. Schultz, Insect Life, New York: John Wiley and Sons. Inc., p. 160, 1999.
[8] B. Bradley, Photo, “Termite-mounds” 2007 [Online] Available at: <https://commons.wikimedia.org/wiki/File:Termite-mound-Litchfield.JPG>.
[9] B. Sarangi, Photo, “Termite-mounds” 2014 [Online] Available at: <https://pixabay.com/ro/dealului-termite-termitele-266587>.
[10] G. C. Grigg Some consequences of the shape and orientation of “magnetic” termite mounds; Australian Journal Zoology, 21, p. 231-7, 1973.
[11] V. Pendharkar, “A Method in the Madness: How Termites Build and Repair Their Mounds in”. The Wire 2017 [Online] Available at: <https://thewire.in/science/termites-mound-bolus-granular-hydrogel>.
[12] Termite Research, “The mound as a gas exchange device”, 2019 [Online] Available at: <http://www.esf.edu/efb/turner/termitePages/termiteGasex.html>.
[13] American Institute of Physics - Climate control in termite mounds. 2014 [Online] Available at: <https://www.sciencedaily.com/releases/2014/11/141125074646>.
[14] J. Korb Thermoregulation and ventilation of termite mounds, Naturwissenschaften 2002
[15] J. S. Turner and R. C. Soar, “Beyond biomimicry: What termites can tell us about realizing the living building First International Conference on Industrialized”, Intelligent Construction (IICON) Loughborough University, 14-16 May 2008.
[16] Epizentrum, Photo, “Commerzbank Frankfurt”, 2013 [Online] Available at: <https://commons.wikimedia.org/wiki/File:Frankfurt_Commerzbank-Turm.201309094.jpg>.
[17] S. Richards, Photo, “Queen College of De Montfort University - Arch. Short and Associates” 2011 [Online] Available at: <https://www.geograph.org.uk/photo/3120215>.
[18] R. Bean, B.W. Olesen and K.W. Kim, “History of Radiant Heating& Cooling Systems”, in ASHRAE Journal, History_of_Radiant_Heating_Cooling_Systems, January 2010.
[19] Y. Li, Z. Zhuang, X. Yang and B. Chen, Chinese Kang, Congress on Heating, Refrigerating and Air-conditioning, Belgrade, December 6-8, 2006.
[20] Knauf, “Technical office floor”. 2019 [Online] Available at: <https://www.knauf.ro/>