The living building: integrating the built environment with nature evaluating the Bibliotheca of Alexandria according to the challenge imperatives

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Abstract
Over the last 20 years, ‘green buildings’ have grown to become one of the most significant and progressive trends in the building industry. Sustainability is an extremely important direction, which has been given great attention and progress in recent years, especially in engineering and architecture. The paper motivates green building designers to ultimately transform their projects and innovate new techniques while demonstrating that built and natural ecosystems can integrate with each other using current technology. The research illustrates the sustainable design elements according to ‘The Living Building Challenge’. In this context, a building should be ‘Living’ when it achieves some imperatives: it has to generate its own energy on site using renewable sources, capture and treat its own water, be constructed of non-toxic and sustainable sourced materials, use only previously developed sites and be beautiful and inspiring to its inhabitants. Looking at these multiple processes encouraged moving beyond the concept of responsive architecture so that a ‘Living’ building can interact and adapt to external stimuli, it has to also inspire and educate the people who deal with it. The Bibliotheca of Alexandria is reviewed as a case study according to Living building qualifications in its existing condition and also investigate the possible scores and their feasibility in the case of a redevelopment of the project.

Keywords: living building; responsive architecture; sustainability; green architecture

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1 INTRODUCTION

The living building is a philosophy that aims to achieve development at all scales, where buildings define the most advanced measure of possible sustainability in the built environment and act to bridge the gap between natural and artificial environments [1].

Obviously, the built environment has an important effect on the natural and human environment [2]. One of the ways to maximize environmental performance is adopting living building strategies. The bright side in the process is that these strategies can be integrated into buildings at any stage from design, construction, renovation and deconstruction [1]. However, the major benefits would be achieved if the design and construction team takes an effective step from the earliest stages of any building design to integrate these strategies [3]. Prospective benefits of living buildings could include the following [1, 4–6]:

1.1 Environmental benefits
- Improve and protect biodiversity and ecosystems.
- Enhance air and water quality.
- Reduce waste streams.
- Preserve and restore natural resources.

1.2 Economic benefits
- Decrease operating costs.
- Create, expand and shape markets for green products and services.
• Enhance occupant productivity.
• Improve life-cycle economic performance.

1.3 Social benefits
• Improve occupant comfort and health.
• Heighten esthetic qualities.
• Minimize strain on local infrastructure.
• Enhance overall quality of life.

Buildings achieving this level of performance can claim to be the ‘greenest’ anywhere and will sit as remarkable models for others that may follow. However, a more significant aspect of the living building challenge is to change the community buildings from being assessed on an individual performance and spread the challenge of these sustainable design principles to a whole neighborhood [1, 6].

On the other hand, the cost of making a living building and achieving net-zero energy buildings, is very expensive and can be especially costly [7]. This could be argued to be as one of the main impediments for investing in the living building concept. In addition, finding materials which can meet the sustainability standards is considered as a major challenge too [8], as commonly used materials often have harmful attributes. Builders are expected to use local materials where possible as it can lead to make efficient use of near natural resources. Nevertheless, costs will decrease when green materials, techniques and technologies become more commonplace within the general building industry [7].

The paper highlights seven areas of performance that contribute mainly in making a living building: place, water, energy, health and happiness, materials, equity and beauty [1] known as the seven petals (see Table 1). There are also 20 imperatives. These imperatives could be applied to nearly all possible projects types such as existing structures or new construction, infrastructure, landscape and community development. Approaches to create living landscapes, infrastructure, renovations, buildings or neighborhoods will differ widely by occupancy, use and construction type.

The methodology of this research is to review and examine the Bibliotheca of Alexandria against the Living Building Challenge qualifications as a case study in order to investigate to what extent it meets the challenge imperatives and identifies the possible recommendations and their feasibility in the case of the renovation of the building.

2 LIVING BUILDING THEORY

The concept of the living building is a new idea for design and construction and considered as a thinking paradigm shift for sustainable communities [1, 9]. It is defined as a building that generates its needed energy with renewable resources, captures and treats its required water, operates efficiently and shows maximum beauty [1]. Adopting the living building imperatives is attempting to raise the bar and identify the most advanced measure of sustainability (Table 1).

There are three development typologies, and it is essential to identify the one that aligns with the project to identify which imperatives would be applied:

(1) Renovation: this is for any project that does not form the substantial portion of a complete building reconstruction.
(2) Landscape or infrastructure (non-conditioned development): this is for any project that does not include a physical structure as part of its primary program such as open-air ‘park-like’ structures, restrooms, amphitheaters and the like. Projects may be as diverse as roads, bridges, plazas, sports facilities or trails.
(3) Building: this is for any project that encompasses the construction of a roofed and walled structure created for permanent use either new or existing.

Every project has to select a Living Transect category from the following options:

L1. Natural Habitat Preserve (Greenfield sites): it is defined as sensitive ecological habitat. It could not be developed except in limited circumstances related to the preservation of the landscape.
L2. Rural Agriculture Zone: land with a primary function for agriculture and development that relates specifically to the production of food.
L3. Village or Campus Zone: it includes relatively low density mixed use development found in rural villages and towns, and may also include college or university campuses.

| Table 1. The 7 petals and 20 imperatives of the living building challenge. |
|---|---|
| **Living building challenge** | **Pets** |
| **Imperatives** | **Place** |
| Limits to growth | Human-powered living |
| Urban agriculture | Net positive water |
| Habitat exchange | Net positive energy |
| Human-powered living | Civilized environment |
| Net positive water | Healthy interior environment |
| Net positive energy | Bio-philic environment |
| Civilized environment | Red list |
| Healthy interior environment | Embodied carbon footprint |
| Bio-philic environment | Responsible industry |
| Red list | Living economy sourcing |
| Embodied carbon footprint | Net positive waste |
| Responsible industry | Human scale + humane places |
| Living economy sourcing | Universal access to nature and place |
| Net positive waste | Equitable investment |
| Human scale + humane places | Just organization |
| Universal access to nature and place | Beauty and spirit |
| Equitable investment | Inspiration and education |

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**L4. General Urban Zone:** it includes light to medium density mixed use development found in larger villages, small towns or at the edge of larger cities.

**L5. Urban Center Zone:** it includes medium to high density mixed use development found in small- to mid-sized cities or in the first ‘ring’ of a larger city.

**L6. Urban Core Zone:** it includes high to very high density mixed use development found in large cities and metropolises.

### 2.1 Ideal conditions for a living building

#### 2.1.1 Place

The living building challenge is a conservation tool for the natural resource systems that support human health. It envisions a moratorium on the seemingly never-ending growth outward, and a focus instead on compact connected communities. In this context, the living building adopts that areas should be restored and nature’s functions should be invited back into a healthy interface with the built environment [1].

**Limits to growth.** In that case, the building can only be built on previously developed-sites, gray-fields and/or brown-fields [4] that are not one of the following [1]:

- **Wetlands:** the selected site should be located at least 15 m, and up to 70 m of separation.
- **Primary dunes:** the selected site should be located at least 40 m of separation.
- **Old-growth forest:** the selected site should be located at least 60 m of separation.
- **Native prairie:** the selected site should be located at least 30 m of separation.
- **Prime farmland.**
- **Within the 100-year flood plain.**

**Urban agriculture.** The building should integrate opportunities for agriculture appropriate to its scale and density using the floor area ratio as a basis for calculation by identifying how much square meterage should be given over to agriculture (Figure 1) [1].

**Habitat exchange.** In this context, an equal amount of land away from the development site needs to be set aside in perpetuity as part of a habitat exchange [1]. There is a minimum offset of 0.4 ha/1.0 acre per project.

**Human-powered living.** The building should participate toward making walkable communities. It is essential for the project to improve the ability of a community to support a car free lifestyle [10, 11]. The project should provide a mobility plan that addresses the interior and exterior of the building and demonstrates at a minimum the following:

- Protected storage for human-powered vehicles that provide facilities to encourage biking.
- Consideration of pedestrian routes, including weather protection on street frontages.

- Promotion of the use of stairs instead of elevators inside the building and quality of stairways.
- Facilitation of the uptake of human-powered transportation.
- At least one electric vehicle charging station.

For living community, it is essential to encourage the residents to reduce their transportation impact through car sharing, using public transportation, alternative fuel vehicles, or bicycles [4, 12].

#### 2.1.2 Water

Shortage of potable water has recently become a serious issue as many countries around the world face scarcity and compromised water quality [12]. In this context, the living building argued that all buildings, infrastructure and communities are configured based on the carrying capacity of the site: harvesting adequate water to meet their needs of a given population while respecting the natural hydrology of the land (Figure 2) [1]. Indeed, water can be used and purified and then used again, and the cycle repeats. The conservation and creative reuse of water are important.

**Net positive water.** Building water use and release should work in harmony with the water flows in the building site and its surroundings. Of note, 100% of the water needed should be provided by picking up rain or any natural closed cycle water, or by recycling the water used in the building [1]. Water should be suitably purified without using chemicals [13]. In addition, 100% of water discharge and stormwater including gray and black water, should be treated and managed either through reuse or infiltration [4].

#### 2.1.3 Energy

Energy efficiency in a living building focuses on design that reduces overall energy needs, such as building orientation and glazing selection, and the use of climate appropriate building...
Strategies such as passive heating and cooling, and natural ventilation with smart controls further reduce a building’s energy use. The generation of renewable energy on the project site allows portions of the remaining energy consumption to be met with non-fossil fuel energy, lowering the demand for traditional sources. In this context, the living building demands a safe, reliable and decentralized power grid that is fully powered by renewable energy that would supply the inward and outward demand without negative impacts associated with combustion of fuel.

**Net positive energy.** One hundred percent of the energy required should be supplied by on-site renewable energy on a net annual basis, without the use of on-site combustion. In this context, on-site clean energy storage should be for resiliency.

**Civilized environment.** Operable and flexible windows need to be provided in every occupied space of the building to provide access for natural ventilation and daylight.

**Healthy interior environment.** Living buildings that promote good indoor air quality should meet the following:

- Entrances have to be provided by an external dirt track-in system and an internal dirt track-in system contained within a separate entry space.
- All kitchens, bathrooms, copy rooms, janitorial closets and chemical storage spaces have to be separately ventilated and exhaust directly to outside air.
- Ventilation rates should be designed to comply with ASHRAE and equipment should be installed to monitor levels of CO2, temperature and humidity.
- Smoking should be prohibited within the building boundary.
- Use cleaning products that comply with the EPA Design for the Environment label (or international equivalent).
Bio-philic environment. The building design should include elements that nurture the innate human–nature connection. Each of the six established bio-philic design elements has to be represented for every 2000 m\(^2\) of the project [1]:

- Environmental features.
- Natural shapes and forms.
- Natural patterns and processes.
- Light and space.
- Place-based relationships.
- Evolved human–nature relationships.

The building design plan should outline the following [6, 9]:

- Incorporating nature through environmental features, light and space, and natural shapes and forms.
- Incorporating nature’s patterns through natural patterns and processes and evolved human–nature relationships.
- Connecting to the place, climate and culture through place-based relationships.
- Sufficient and frequent human–nature interactions in both the interior and exterior of the building to connect the majority of occupants with nature directly.

2.1.5 Materials

The living building challenge demands a future where all materials in the built environment are replenishable and have no negative impact on human and ecosystem health [20]. The precautionary principle guides all materials decisions. In this context, the materials petal focuses on reducing the embodied energy and other impacts associated with the extraction, processing, transport, maintenance and disposal of building materials [21]. The requirements are considered to support a lifecycle approach that improves performance and supports resource efficiency.

**Red list.** The project cannot contain any of the following red list materials or chemicals [1]:

- asbestos
- cadmium
- chlorinated polyethylene and chlorosulfonated polyethylene
- chlorofluorocarbons
- chloroprene (Neoprene)
- formaldehyde (added)
- halogenated flame retardants
- hydrochlorofluorocarbons
- lead (added)
- mercury
- petrochemical fertilizers and pesticides
- phthalates
- polyvinyl chloride
- wood treatments containing creosote, arsenic or pentachlorophenol.

Embodied carbon footprint. The building should account for the total footprint of embodied carbon (tCO\(_2\)e) from its construction through a one-time carbon offset tied to the building boundary [8].

**Responsible industry.** The adoption of third-party certified standards to extract sustainable resources has to be advocated, using applicable raw materials such as stone, rock, metal, minerals and timber [1]. All projects have to use, at a minimum, one declared product for every 500 m\(^2\) of gross building area. For timber as an example, all wood has to be certified to Forest Stewardship Council (FSC) 100% labeling standards [8], from salvaged sources for the purpose of clearing the site for construction or maintaining the continued ecological function.

**Living economy sourcing.** The building should integrate place-based solutions and participate in increasing the regional economy based on sustainable practices, products and services [1]. In this context, the following restrictions should be adhered:

- 20% or more of materials construction budget should come from within 500 km of the construction site.
- An additional 30% of materials construction budget have to come from within 1000 km of the construction site or closer.
- An additional 25% of materials construction budget have to come from within 5000 km of the construction site.
- 25% of materials may be sourced from any location.
- Consultants have to come from within 2500 km of the project location.

**Net positive waste.** Reduction or elimination of the production of waste during design, construction, operation and end of life in order to preserve natural resources (Figure 4). In this context, a Material Conservation Management Plan which identifies how the building optimizes materials should be adopted in each of the following phases [22]:

- design phase, including the consideration of appropriate durability in product specification,
- construction phase, including product optimization and collection of wasted materials,
- operation phase, including a collection plan for consumables and durables,
- end of life phase, including a plan for adaptable reuse and deconstruction.

![Figure 4 Wasted material levels.](https://academic.oup.com/ijlct/article-abstract/12/3/244/3078573)
| Surface Cover | L1 | L2 | L3 | L4 | L5 | L6 |
|---------------|----|----|----|----|----|----|
| Maximum dimension of surface parking lot before a separation is required on all four sides | 20 m x 30 m | 20% | 20% | 15% | 5% | 0% |
| Total area of surface parking lot allowed. All other parking requirements must be handled in structured or underground parking. | |

| Transect | L1 | L2 | L3 | L4 | L5 | L6 |
|----------|----|----|----|----|----|----|
| Maximum street width, measured either shoulder-to-shoulder or curb-to-curb | 5 m | 7.5 m | 10 m | 15 m | 22.5 m | |
| Maximum street width before driving lanes must be separated by a pedestrian strip and planting median. Additional lanes may be included on the other side of median to a maximum of 22.5 m total width of driving area | Not applicable |  |  |  |  | 15 m |
| Development of this kind is not permitted in a Natural Habitat Preserve or Rural Agricultural Zone |  |  |  |  |  | 7.5 m |
| Minimum overall width of sidewalks and planting median |  |  |  |  |  | 1/3 street width |
| Maximum distance between trees in furnishing zone and planting median |  |  |  |  |  | 9 m |
| Maximum distance between circulation routes |  |  |  |  |  | 45 m |
| Access way must be 5 m wide minimum to qualify |  |  |  |  |  | 60 m |
| Maximum street block size |  |  |  |  |  | 60 m x 120 m |
|  |  |  |  |  |  | 120 m x 120 m |

| Transect | L1 | L2 | L3 | L4 | L5 | L6 |
|----------|----|----|----|----|----|----|
| Number of freestanding signs per development | 1 |  |  |  |  |  |
| Maximum dimensions of freestanding sign(s) | 2 m x 2.5 m | 2.5 m x 3 m | 3.5 m x 6 m |  |  |  |
| Maximum elevation of sign’s bottom edge above ground | 2 m | 3 m | 6 m | 9 m | 12 m | |

| Transect | L1 | L2 | L3 | L4 | L5 | L6 |
|----------|----|----|----|----|----|----|
| Maximum single family residence size | N/A | 425 m² |  |  |  |  |
| Maximum distance between façade openings | N/A | 30 m |  |  |  |  |
| Maximum footprint for any building with a single use, single owner or single tenant. Acceptable to provide additional floor area for tenant on upper/lower floors(s) | 3750 m² excludes floor area of atriums, courtyards and daylight shafts |  |  |  |  |  |
| Provision of places for people to gather and connect internally and/or with the neighborhood | 1 | 1 | One every 1000 m² (10,760sf) |  |  |  |
| Provision of elements along the project edge that support the human scale of the larger neighborhood, such as seat walls, art, displays, or pocket parks. Single Family residences are excluded | 1 | 1 | One every 4000 m² (43,000sf) |  |  |  |

**Figure 5.** Design guidelines.
2.1.6 Equity
Equity means that communities should allow equitable access to all individuals regardless of age, physical abilities, sexual orientation or socioeconomic status [1].

Human scale + humane places. The building should be designed to be human-scaled rather than automobile-scaled building, so that the experience shows the best in humanity and promotes culture and interaction [1]. In this context, there are specific maximum and minimum requirements (Figure 5) for design elements such as paved areas, streets and block design, building scale and signage that contribute in livable places.

Universal access to nature and place. In order to create a living building through community, all facilities, transportation, roads and infrastructure should be accessible to all classes regardless of age, social and economic backgrounds, even homeless [4]. In this context, reasonable steps should be taken to ensure that all people could benefit from the project, with reasonable safeguarded access for those with physical disabilities. In addition, the design should not hinder access to, nor reduce the quality of, sunlight, fresh air and natural waterways for the society or adjacent regions [9]. The project should also appropriately address any noise audible to the public.

Equitable investment. For every dollar spent of total building cost including land, soft costs, hard costs and even furniture, the development has to put aside and donate half a cent (or equivalent) or more to a charity of its choosing or contribute to ILFI’s Living Equity Exchange Program, which directly funds renewable infrastructure for charitable enterprises. The charity should be located in the country of the project [1].

Just organization. The building should help in creating a more JUST, equitable society through the transparent disclosure of the business practices of the key organizations involved [1]. At least one of the project team members (architect, landscape architect, MEP engineer, interior architect, structural engineer, owner or developer) should have a JUST label for their organization; project teams are also required to send JUST program information to at least 10 project consultants, sub-consultants or product suppliers as part of ongoing advocacy.

2.1.7 Beauty
In this petal, it is argued that an effort should be made to enrich people’s lives with each square meter of construction on each building. In this aspect, there is a need to create and organize programs for educating the public about the environmental qualities resulting from their living building challenge projects. The need for beauty as a harbinger to concerning enough to preserve, conserve and serve the greater good.

Beauty and spirit. The building should contain features promoting human amusement and the rooting of culture, spirit and place appropriate to its function [4].

Inspiration and education. Educational documents about the buildings operation and performance should be provided to the public to share successful solutions and to motivate others to make change toward more living buildings [1].

In this context, buildings should offer the following:

- An annual open day for the public.
- An educational website sharing information about the design construction, and operation of the building.
- A simple brochure that describes the design and environmental topographies of the project, as well as recommendations for occupants to optimize building function.
- A copy of the operations and maintenance manual.
- Informative signage that explains visitors and occupants about the building.
- A living building case study to be published on the institute website.

In addition, non-sensitive areas of the building should be open to the public at least 1 day per year to facilitate direct contact with the building.

3 CERTIFICATION OPTIONS

3.1 Living certification
A building attains full living certification or living building certification by achieving all imperatives identified to its typology. All the 20 imperatives are mandatory for buildings, 15 for renovations and 17 for landscape and infrastructure projects.

3.2 Petal recognition
Although attaining ‘Living’ status is the ultimate goal, meeting the imperatives of multiple petals is a substantial success in and of itself. For this reason, the living building challenge offers petal recognition. This certification option develops a platform for a development to inform other efforts throughout the world and accelerate the adoption of restorative principles.

In this aspect, petal certification oblige the attainment of at least three of the seven petals, one of which must be either the water, energy or materials petal. Imperative 01, limits to growth and Imperative 20, inspiration and education are required.

3.3 Net-zero energy certification
Net-zero energy certification mainly obliges four of the imperatives to be achieved: 01, limits to growth, 06, net positive energy (reduced to 100%), 19, beauty and spirit and 20, inspiration and education.

The requirement for Imperative 06, net positive energy is reduced to 100%, while 105% is required for petal and living building certification only.
As with living, building and petal certification, net-zero energy certification is based on an actual performance rather than modeled outcomes.

4 CASE STUDY

'The Bibliotheca of Alexandria'

The Bibliotheca Alexandria (Figure 6) construction in Alexandria City (Egypt) has revived the role and spirit of the ancient library building as a center of learning and communication. Its design main concept is defined as ‘the world’s window on Egypt—Egypt’s window on the world’. It is considered as a library for the new digital age [23].

4.1 Architectural form

The library design is prepared by the Snøhetta Arkitektur Landskap architects as ‘a cross barriers of Politics, religion, culture and history’. With the intention to accommodate this main challenge, they suggested a strong, symbolic iconography that may address basic human circumstances that sound effects the society, for example the passage of time, our relationship to the planet that we live on and the people we live with.

First, the circular form that is the object found in all cultures representing human’s first understanding to the passage of time and its relation with the movement of the sun, moon and stars. Hence, to express the concept of time passage, the building is designed as a gently rotated disc passing into the earth. As it passes into the earth it enters the past world, then it passes above the ground to enter the future, then it settled upon the ground at the present to be felt as a frozen moment in time [24].

Second, the tilting disc (Figure 7) is surrounded by a circular wall embracing 4000 carved garnet blocks (Figure 8) which could earn the library the title of ‘the Fourth Pyramid’. The main reading hall is one big open space when past, present and future connect symbolically in a unique space [24].

Third, the planetarium (Figure 9) is a hanging sphere next to the pedestrian bridge at the edge of the plaza, along with 12 olive trees, forming the central view of the plaza along the corniche (Figure 10) [24].

4.2 Project description

The project includes two main parts: the main library and the planetarium. They are linked at basement level, under the open

Figure 6. Bibliotheca Alexandrina.

Figure 7. The library’s tilting disc.

Figure 8. The round walls covered in 4000 granite panels carved with alphabets from throughout history.

Figure 9. The library’s planetarium.
plaza, to the existing conference hall while a pedestrian bridge links the plaza with the university and the corniche (Figures 11 and 12).

The library comprises of the main reading room, which seats 2000 readers (13 625 m²) and 6 specialist libraries: the children’s library, young people’s library, multi-media library, Taha Hussein library for the visually impaired, microfilm and special collections, and rare books and manuscripts. There are also three museums, for antiquities, manuscripts and the history of science. There is the internet archive and seven research centers: the center for special studies and programmes, the center for manuscripts, with restoration facilities, the arts center, the center for the study of writing and calligraphy, the Alexandria and Mediterranean Research Center, international school of information science, and the national center for the documentation of cultural and natural heritage (CULTNAT). In addition, three permanent galleries are housed: the Shady Abdel Salam gallery, impressions of Alexandria gallery and the science of underwater archaeology, with space for various temporary art exhibitions. There is also the nobel peace hall, and an exploratorium was added by converting part of the original parking area. A cafeteria, offices and other services and facilities support the library. Outside the library building, the planetarium seats 99 people and the refurbished conference hall can seat a total of 3000 in 4 halls and 1 auditorium. The conference building also includes three restaurants that can be used by the staff. The outdoor plaza is 8500 m² and the reflection pool is 4600 m². The Library covers 11 floors, comprising 4 levels below ground and 7 above. The building rises to a height of 33 m and the site area is 45 000 m². The ground floor is 23 900 m² and the total floor area is 85 405 m² [25].

4.3 Project analysis against living building challenge

4.3.1 Place

Although the library is almost a new building, the idea of it dates back to 1974 when a committee set up Alexandria University nominated a plot of land to build a new library between the campus and the sea front and to be close to the ancient library place. The selected site is a part of the town’s center, opposite to the Eastern harbor. In the North, there is the Corniche and in the South, there is Port Said street. In the East and West, there is the Maternity hospital and two residential buildings, respectively (Figure 13).

The main plaza is supposed to be a place for meditation and observation. It has little seating area and no designed planting areas. Recently, some pots of geraniums have been placed in the middle of the concourse. The pool that surrounds the building on three sides makes a connection between the ground and the sky by reflection. Papyrus plants along Port Said street represent alongside with olive trees the native vegetation and agricultural past of the region. The plaza is pedestrianized, with
limited vehicular access (controlled by retractable stainless steel bollards) on the southern and western sides.

4.3.2 Water
The collection of rainwater from the main building roof which is then filtered and pumped to the roof for cleaning is the only system of water treatment designated in the project.

4.3.3 Energy
The use of natural daylight is one of the most successful features in the sustainability process (Figure 14). For the library, sunlight is the main lighting source for the main reading halls. The shape of the building is designed to harvest sunlight via skylights to produce appropriate, comfortable lighting. In the main reading area, lights are switched on only after 6 pm. In addition, electric lighting systems are extremely efficient and controlled to be used only when conditions mandate supplemental light.

The orientation of the main building roof panels was studied and designed carefully to introduce maximum daylight without direct sunlight. Glare was dealt with in the design of the glass shading over the windows. The library is mainly air-conditioned throughout a facility that is controlled by the management system.

4.3.4 Health and happiness
The building functions very well for both the general visitors and users, as it has clear and well-organized spaces. However at the buildings entrance, there is no provision for waiting under the strong sun or rain, and increased security checks mean longer queues. While light wells provide natural daylight into the common spaces between offices in the basement, the underground offices themselves have no natural daylight. Moreover, the interior uniform gray color has clearly been identified to need softening as can be seen by the introduction of potted plants in the public spaces of the building.

Plants in public areas are the biological wastewater treatment system removing carbon dioxide and other gases while producing oxygen indoors and outdoors. Overall, daylighting, natural ventilation and views are attained. Operable windows are provided in each occupied space for both the health and enjoyment of guests.

4.3.5 Material
Materials selected for the construction of the building are durable and require little maintenance. The structure of the building is of reinforced concrete. The capitals and beams of the roof are precast and the structure of the planetarium and bridge is steel. The roof panels of the building consist of anodized aluminum sandwich panels with double-glazed glass panels. The planetarium’s main infill panels are made of glass reinforced concrete and the bridge’s are precast concrete. The wall of the building is covered with gray granite panels, 15 cm thick, that vary in size from $(1 \times 1)$ m to $(2 \times 1)$ m.

The roof panels were made in Austria and were assembled in Egypt. This allowed technology transfer to the construction industry in Egypt. The internal stone walls are quarrying of the gray granite from south of Aswan. The black granite was imported from Zimbabwe. All the timber flooring come from abroad.

4.3.6 Equity
The project allows the presence of the sea with a public square along the corniche. The design also respects the urban environment behind it and retains the scale of the street. However, the public plaza is very barren and gray and the users obviously felt this. In addition, the project provides ease of access to the site and access for the disabled users; compactness to minimize the movement of staff and books; extendibility within the building and internal flexibility. Safety and security considerations were accommodated and all systems had to be centralized for efficiency.

4.3.7 Beauty
The project presents a center of excellence in the production and dissemination of knowledge and a place of dialogue, learning and understanding between cultures and peoples.

4.4 Project summary

| Place                      | Current conditions                              | Action needed |
|----------------------------|------------------------------------------------|---------------|
| Limits to growth           | The Bibliotheca is inaugurated near the site of the ancient library | Achieved |
| Urban agriculture          | The main plaza has no designed planting areas  | Not achieved (‘limited’) |
| Papyrus plants are grown in planters, along with olive trees | More planting areas needed |
| Habitat exchange           | The site area is 45 000 m$^2$; the ground floor occupies 23 900 m$^2$ | Achieved |
| Human-powered living      | The plaza is pedestrianized, with limited vehicular access | Achieved |

Figure 14. Natural daylighting through the roof panels.
(Continued)

| Water          | Current conditions                                                                 | Action needed                                                                 |
|---------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Net positive  | Rainwater is collected from the roof to be treated and used for cleaning the roof  | Not achieved. 100% of water required should be provided by a natural and renewable resources. More water strategies can be used for example: sea water desalination. |
| Energy        | The main reading area is naturally lighted during daytime                            | Not achieved. Solar cells can be used to save energy for night illumination.   |
| Health and happiness | Civilization environment                                                            | Not fully achieved. Provision for waiting areas is needed in the entrance spaces. Operable windows are needed to achieve natural ventilation. |
| Healthy interior environment | The users enjoy the clean air, daylighting and a deep connection with nature provided by the slope of the roof toward the sea. The building is air-conditioned. Smoking is prohibited. | Achieved. |
| Biophilic environment | A strong, symbolic iconography that would address basic human conditions that affect human society. | Achieved. |
| Materials     | Red listed materials are avoided. Zero Carbon footprint                               | Achieved. |
| Responsible industry | The roof panels were made in Austria and assembled in Egypt. This allowed technology transfer to the construction industry in Egypt. | Achieved. |
| Living economic sourcing | Although the internal partitions stone of the gray granite came from south of Aswan (within 1000 km of the construction site). The roof panels were made in Austria. The black granite came from Zimbabwe and all the timber flooring was imported. | Not achieved (limited). |
| Net positive waste | Structural and finishing materials used are durable and require little maintenance. All furniture were finished and designed for comfort and durability. | Achieved for design and operation phase. Not achieved during construction. |

(Continued)

| Equity       | Current conditions                                                                 | Action needed                                                                 |
|--------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Human scale + humane places | The building is designed to be a human-scaled rather than automobile-scaled building. | Achieved. |
| Universal access to nature + places | Ease of access to the site. Access for the disabled user to all its sections. | Achieved. |
| Equitable investment | The total cost of the building (including furniture) was donated by Arab and foreign countries. | The Library is exempt from this requirement. |
| JUST organization | No one of the following project team members has a JUST label for their organization. | Not achieved. Owner/developer should attempt to have a JUST Label for their organization. |
| Beauty        | Beauty + spirit | The library has become an agent of socialization that is shaping Alexandria’s sense of self and social identity. | Achieved. |
| Inspiration + education | The library is considered as a center of production and a place of dialogue, learning and understanding between cultures and peoples. | Achieved. |

5 CONCLUSION

The Living Building Challenge is the built environment’s most rigorous performance standard. It calls for the creation of buildings that operate as cleanly, beautifully and sufficiently as nature’s architecture. To be certified under the challenge, projects have to meet a series of determined performance requirements, including net zero energy, waste and water, over a minimum of 12-month period of continuous occupancy. It may seem to be aspirant to simultaneously achieve all of the requirements of the Living Building Challenge.

For the current case study, the Bibliotheca of Alexandria identified some credits that are difficult to be achieved. The certified rating of the existing condition of the Bibliotheca of Alexandria against living building challenge could be easily achievable for the ‘Petal’ rating, as the main characteristics of the Bibliotheca architecture and its urban pattern together with some easily achieved interventions in the area could score as well as a new development that would intentionally be designed to meet living building requirements.

More living strategies could be applied or integrated into the building as

- solar cells that can be used to save energy for night illumination.
- water strategies can be used to reduce using portable water for example: sea water desalination or harvesting rainwater.
Therefore, the project owner could be ready to submit their project for certification.

Finally, it is assumed that this particular type of architecture comprises the same basic principles like new urbanism and compact development, showing that when it could be combined with the recent green technologies, it could offer one of the most sustainable forms of sustainability.

REFERENCES

[1] International Living Future Institute, Living Building Challenge 3.0: A Visionary Path to a Regenerative Future, ILFI, 2014.
[2] Baker N. The Handbook of Sustainable Refurbishment: Non-Domestic Buildings. Earthscan, London, 2009.
[3] Jason FM. The Philosophy of Sustainable Design: The Future of Architecture. Ecotone Publishing, 2004.
[4] Haselbach L. The Engineering Guide to LEED: New Construction Sustainable Construction for Engineers. McGraw-Hill, New York, 2010.
[5] UN-Habitat. Conference on Promoting Green Building Rating in Africa, Nairobi, Kenya, 4–6 May 2010.
[6] Yudelson J. Green Building A to Z: Understanding the Language of Green Building. New Society Publishers, Canada, 2007.
[7] Gupta R. Special issue on sustainable energy technologies and low-carbon buildings: the case of UK and India. Int. J. Low-Carbon Tech. 2009;4:132–3.
[8] Reddy V. Sustainable materials for low carbon buildings. Int. J. Low-Carbon Tech. 2009;4:175–81.
[9] Yudelson J. Green Building Through Integrated Design. McGraw-Hill, New York, 2009.
[10] Haapio A, Viitanen P. A critical review of building environmental assessment tools. Environ. Impact Assess. Rev. 2008;28:469–82.
[11] Kyrkou D, Karthauss R. Urban sustainability standards: predetermined checklists or adaptable frameworks? Procedia Eng. 2011;21:204–11.
[12] Avlonas N, Nassos G. Practical Sustainability Strategies: How to Gain a Competitive Advantage. Wiley, 2013.
[13] Zuo J, Zhao Z. Green building research–current status and future agenda: a review. J. Renew. Sustain Energy Rev. 2014;30:271–81.
[14] Crawley D, Pless S, Torcellini P. Getting to net zero. ASHRAE J 2009;51:18–25.
[15] Ng T, Yau R, Lam T, et al. Design and commission a zero-carbon building for hot and humid climate. Int. J. Low-Carbon Tech. 2016;11:222–34.
[16] Kalogirou S. Building integration of solar renewable energy systems towards zero or nearly zero energy buildings. Int. J. Low-Carbon Tech. 2013;10:379–85.
[17] Li D, Yang L, Lam J. Zero energy buildings and sustainable development implications. J Energy 2013;55:1–10.
[18] Hernandez P, Kenny P. Net energy to zero energy buildings: defining life cycle zero energy buildings (LC-ZEB). Energy Build. 2010;42:815–21.
[19] Marszala A, Heiselberga P, Bourrelleb J, et al. Zero energy building - a review of definitions and calculation methodologies. J. Energy Build. 2011;43:971–9.
[20] Hossaini N, Hewage K, Sadiq R. Spatial life cycle sustainability assessment: a conceptual framework for net zero buildings. J. Clean. Technol. Environ. Policy 2015;17:2243–53.
[21] Gurgun A, Komurlu R, Arditi D. Review of the LEED category in materials and resources for developing countries. Procedia Eng. 2015;118:1145–52.
[22] Yeheyis M, Hewage K, Alam M, et al. An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability. J. Clean. Technol. Environ. Policy 2013;15:81–91.
[23] Zahran M. The New Bibliotheca Alexandrina: Reflections on a Journey of Achievements. Bibliotheca Alexandria, 2007.
[24] Serageldin I. A Landmark Building, Reflections on the Architecture of the Bibliotheca Alexandria. Bibliotheca Alexandria, 2007.
[25] The Aga Khan Award for Architecture, Bibliotheca Alexandria, Alexandria, Egypt, Technical Review Summary, 2004.