CIRCULAR
DESIGN
ATLAS

BIMA MICROLIBRARY

Architect(s):
SHAU Indonesia

Year:
2016

Location:
Bandung, Indonesia

More info:
https://www.shau.nl/de/project/53

Scales:
Buildings

Resources:
Secondary

Design Approaches:
Modular design

R-Strategies:
Reuse

Aspects:
Resource flows
Stakeholders

TU Delft
BK Bouwkunde

Figure 1: Bima Microlibrary *Credits | Design: SHAU Indonesia | Photo: © Sanrok Studio*

Bima Microlibrary, located between a middle-class neighbourhood and an informal settlement in the city of Bandung, Indonesia, aims to increase the area's literacy rates by providing reading facilities in a safe community space (Ichioka, 2019). Initiated by SHAU Architects, this library was part of a larger initiative to connect poorer areas by creating multiple microlibraries that bridge the gap between the central city library and smaller mobile libraries (Archiroots, 2020).

The 80-square-metre building is constructed on top of an existing concrete platform, using a steel frame and concrete floors and roofs. The facade utilises 2,000 upcycled plastic ice cream tubs, laid out in a pattern of closed and open buckets, spelling out the message 'books are the windows to the world' in binary code (Archdaily, 2016). The use of plastic buckets is a cost-efficient and environmentally-conscious solution for letting diffused light into the building while allowing for sufficient shading and cross-ventilation. The circularity of the building was thus enhanced by this material choice, as it removes the need for air conditioning completely, and minimises the need for artificial lights during the day.

The unique design creates a sense of pride and identity for the local residents, contributing to the reduction of violence and criminal activity in the area (Ichioka, 2019). It provides a safe shelter for events and teachings organised by NGOs, as well as community gatherings initiated by the community.

Layers of Change and Lifecycle Duration

Site
The microlibrary is built on a concrete platform located in an open paved area, used as a playground and for gatherings. The library was built in 2016, but the platform had already been used by the locals in the neighbourhood. The lifecycle of the platform depends on what type of concrete was used but has an overall lifespan of 50 to 100 years (TNO, 2023).

Skin
The external skin is made of plastic ice cream buckets. UV light from constant exposure to the sun affects the material (polypropylene), as it attenuates the thickness of PP. It will then crack easily, making the white buckets turn yellow. Some of the buckets had already had to be replaced just three years after the library had been built because some of the buckets had become brittle (Archnet, 2019).

Structure
The main structure above the existing platform is made of steel beams with a concrete floor and roof. The steel beams will have a lifespan of at least 75 years (Nibe, 2023). Steel often lasts longer than other building materials such as wood and concrete, as it is more resistant to corrosion, moisture, etc. (Allied Buildings, 2023).

Services
Due to the small scale and experimental nature of the building, the library has very minimal services. There are no sanitary facilities, running water, or any mechanical ventilation. The only services installed are the rainwater drains and electrical lighting.
The electricity cables normally have a lifespan of 20 to 30 years (Electrotechnik 2023).

Space plan
The library is open-plan and has no internal walls. There are sliding polycarbonate doors behind the skin to prevent the interior from rain and wind. Some of the ice cream buckets are open, so the movable doors allow for cross ventilation. These sliding doors are made of aluminium and polycarbonate. Vendors give different indications for the lifespan of aluminium doors/windows, between 20 and 50 years (Milieu, n.d., Smith, 2020). The life span of PC also depends, among other things, on exposure to weather conditions. Suppliers indicate that it lasts between 10 and 20 years (Omnexus 2023).

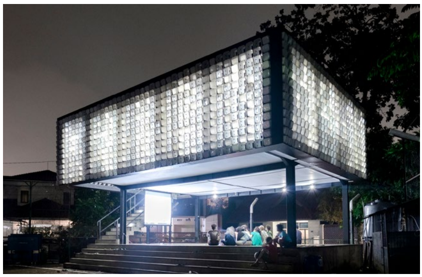
Stuff
The library has different kinds of furniture, all made out of the same type of wood. The furniture is probably made from teak (hardwood), which is very common in Indonesia. Furniture made of teak will have a lifespan of 50 to 75 years, although it can be longer under the right conditions and care (CYAN, 2023).

Site
Eternal

Skin
± 3 years

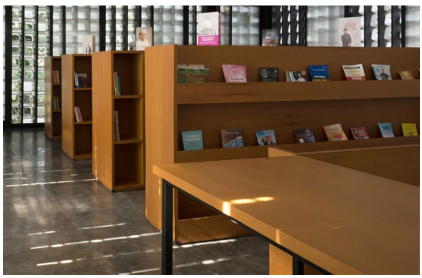
Structure
75 years

Services
20 - 30 years



Space plan
10 - 50 years

Stuff
50 - 75 years



Figures 2-7: Bima Microlibrary *Credits | Design: SHAU Iindonesia | Photo: © Sanrok Studio*

Carbon Footprint of Materials

The materials comprising a typical square meter of the facade are the reused ice cream tubs, made from polypropylene, the polycarbonate sliding doors designed to protect the interior in case of heavy winds, and the steel rods holding the tubs in place. The estimated carbon footprint of the facade was calculated using each of the materials' weight and global warming potential (GWP) values.

As polypropylene and polycarbonate are both types of plastics, the resulting carbon footprint is relatively high, with approximately 156 $kgCO_{2eq}$ per m^2 of facade. The use of steel for the rods also adds to the high footprint, compared to other materials such as timber, which would produce a negative footprint.

However, as all of the 2,000 ice cream tubs used in the building are re-used, comparing this carbon footprint with a building using completely new materials would be misleading. The buckets, which would otherwise have been thrown away to be recycled, are given a second chance with minimal processing in between lives.

This shows that the carbon footprint calculations must be taken into consideration in conjunction with the R-strategies, as materials with higher CO_2 values do not necessarily mean a 'worse' building. If buildings with slightly higher footprints are more durable, require less energy-consuming maintenance and reuse existing materials, they may be alternative solutions to achieving a circular built environment.

Carbon footprint calculations

Material	**Area** (m^2)	**Thickness** (m)	**Density** (kg/m^3)	**GWP** ($kgCO_{2eq}/kg$)
Ice cream tub (polypropylene)	5.33	0.002	900	2.73
Sliding doors (polycarbonate)	1.00	0.016 (2 layers of 8mm)	1200	5.50
Steel rods	**Volume:** 0.00272		7900	1.12

Total ice cream tubs: 26.2 $kgCO_{2eq}$
Total sliding doors: 105.6 $kgCO_{2eq}$
Total steel rods: 24.1 $kgCO_{2eq}$

Total $1m^2$ of facade = **155.9 $kgCO_{2eq}$**

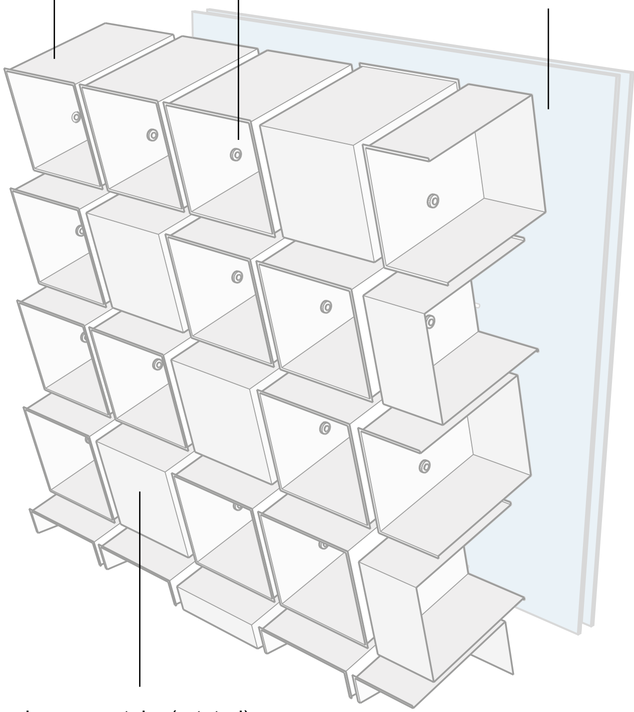


Figure 8: Facade axonometric
Modelled based on diagrams by Putri Irania Pangestu and Andika Citraningrum (n.d.)

Building Material Origin

Ice cream buckets

The neighbourhood surrounding the site is known for vendors selling steel, motors and plastic canisters (jerry cans). This led to the idea of applying reused materials for the façade of the microlibrary. Although the initial idea was to utilise old jerrycans for the facade at the time of construction, there were not enough of these available. Thus the current 2,000 used ice cream buckets were bought via an online vendor (Ichioka, 2019), but it is unknown where exactly they come from.

The ice cream buckets are technical materials, made of polypropylene, which is a type of plastic. Polypropylene is a tough, rigid, and crystalline thermoplastic that is made up of polymers (long chains of molecules composed of the same building blocks). Artificial polymers are usually obtained from the raw material petroleum (Omnexus, 2023), which is an unrenewable resource.

Steel structure

Indonesia ranks 10th worldwide among the largest steel importers. The country imports steel from over 85 countries, with China (56%), Japan (31%) and South Korea being the top three import sources (International Trade Administration, 2023). A distinction is made between types of steel products, namely flat products, long products, pipes and tubes, semi-finished and stainless.

In the façade, steel plates are used to attach the ice cream buckets. Flat products, like plates, are mostly imported from Japan, China and South Korea in order of frequency (International Trade Administration, 2019).

Steel is a technical material because it is an alloy of iron and carbon, which are both naturally occurring materials. At this moment, most iron is made from ore and coal. In the furnaces, iron ore melts into liquid iron at a high temperature, and steel is made from the hot metal in the converter in the steel factory. Oxygen and used scrap steel pieces will be added. The steel is cast into slabs and further rolled out into thick and thin sheets in the hot strip and cold strip mill (Tata Steel, 2023).

Figure 9: Map of steel imports to Indonesia

R-Strategies

SMARTER USE &
MANUFACTURING:

Refuse
The design is kept simple, and all fragments/materials play important roles in the assembly. Thus, without compromising the performance of the building, no materials can be refused.

Rethink
Drilling holes into the buckets to connect them makes repurposing the products difficult, as the holes mean that the buckets have limited uses. Alternative ways of fixing them can be considered, such as wedging them tightly between vertical and horizontal steel members, so the buckets maintain their original condition. In this way, each individual tub can easily be taken out if it requires extra maintenance or needs to be replaced.

Reduce
The amount of steel used can be reduced by using a timber frame instead, minimising the carbon footprint and also allowing the building to reflect the Indonesian vernacular. This will reduce the production and transport emissions, because materials can be sourced from local manufacturers, with local methods of construction that are more familiar to the neighbourhood.

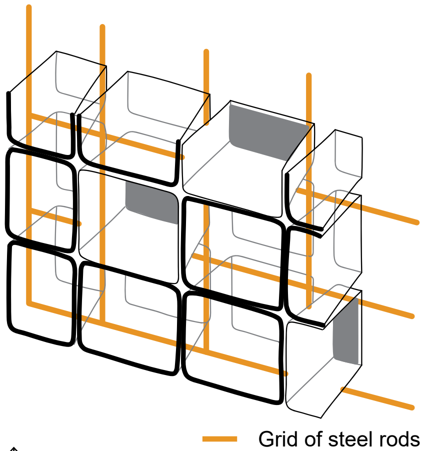


Figure 10: Rethink - fixing the buckets between a regular grid of rods will avoid having to drill holes into the plastic and allow for the reuse of the buckets

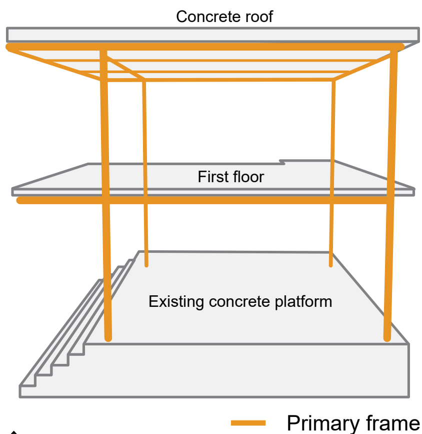


Figure 11: Reuse - by keeping the old concrete platform, first floor, roof and the primary steel structure, the building can be clad in any material again to be reused for different purposes

EXTENDING LIFESPAN OF PRODUCT AND ITS PARTS:

Reuse
The reuse of building components was already considered at the beginning of the project, where an existing stage on site was retained. The robustness of the concrete stage means that this can be retained at the end of the building life and be reused for new designs. The steel frame structure and light plastic tubs allow it to be disassembled and rebuilt; the rectilinear design means that it will be simple to construct with different dimensions to respond to a potential new site. SHAU is aiming to create more microlibraries around less-connected areas in Indonesia, so if the Bima library is to be deconstructed, the structure can be reused in other locations for similar purposes.

To be able to reuse the fragment components, the longevity of the materials must be designed from the start. Plastics can become brittle over time, and thus UV-coating and regular maintenance should be done in order to increase its lifespan and reduce the need for replacement. The steel beams and columns can be designed at regular dimensions according to the plastic tub sizes (e.g. 4 ‘tubs long’ etc.) to allow for a modular system that can be easily reconstructed elsewhere.

Repair
In the first three years after completion, many points for repair and extra maintenance have been identified. The plastic buckets had turned yellow and brittle after a few years of exposure to sunlight and thus some had to be replaced by new ones applied with UV-resistant coating. The old buckets were ‘disposed of properly, working with the city government’ (Ichioka, 2019), but questions remain as to how exactly they were disposed of, or if there were any opportunities for repurposing or recycling them.

Because the new facade is treated with the resistant coating, they can be expected to survive longer than the original, but repair or replacement will be inevitable in the future. To avoid them needing to be replaced often, regular maintenance is required to monitor the quality of the buckets, and reapply the coating at regular intervals. The benefit of the steel frame construction is that the buckets can be taken out easily for repair without compromising the primary structure. The works can be undertaken by local contractors, but can be costly - the repair in 2019 totalled about 19 million IDR (1,160 EUR) for new buckets, 21 million IDR (1,280 EUR) for UV-resistant coating paint and 45 million IDR (2,750 EUR) for labour, scaffolding and transportation costs (Ichioka, 2019).

Refurbish
The tropical climate of the area, constantly staying around 28^{o}C and cooling down to around 22-24^{o}C at night means that there is no need for insulation or air

conditioning. Openings in the plastic facade create an efficient cross-ventilation strategy, thus reducing the need for electricity.

However, the building is not resilient to potential extreme temperatures in the future, as it currently runs on all-natural performances. Possible refurbishments include creating more/fewer openings in the buckets to respond to the temperatures and need for ventilation, adding more layers of UV coating to the plastics, or coating the plastic with antioxidants/stabilizers to help them maintain their strength and avoid cracks and discolouration. Changes in the climate may also require air conditioning, thus an addition to the 'services' layer of the building.

Remanufacture

The plastic buckets of the facade can be taken out with no damage to the rest of the facade, and remanufactured to be used again in a similar manner. In this case, close attention needs to be given to its quality and stability to ensure the safety of the building users. Steel components can be used again in their complete form, or resized to fit other building sizes and configurations.

Repurpose

The polycarbonate sliding doors come in rectilinear dimensions and thus can be repurposed easily for doors, facades or roofings. This will be especially useful for the

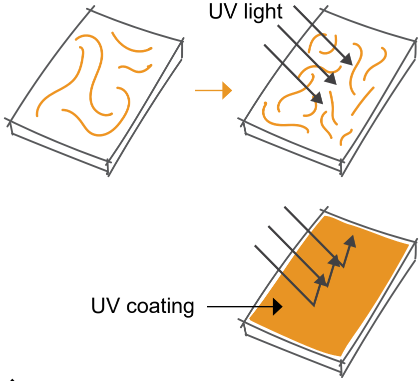


Figure 12: Refurbish - UV rays cause the molecular chains in the plastic to break, leading to cracking and reduction in mechanical properties. UV resistant coating reduces the damage of long-term exposure to sunlight

Figure 13 + 14: Repurpose - (top) slums in Indonesia using patches of discarded materials, (bottom) library project using small pieces of polycarbonate for the facade

Condition_Lab, Pigtan Book House Huaihua, China (2022) local informal settlements that use scrap materials for their houses. The ice cream tubs, however, are more difficult to repurpose because they are punched with holes on the sides and cannot be used for containers. Some alternative ideas for their usage would be as translucent interior screens, as lampshades or plant pots.

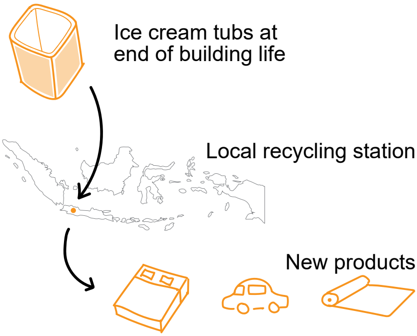


Figure 15: Recycle - common uses for recycled plastic in Indonesia include homeware engineered to Global Recycled Standard (GRS) standards, automotive parts, and geotextiles

END-OF-LIFE SCENARIO:

Recycle
Both polycarbonate and polypropylene can be recycled by shredding, granulating and moulding it into other forms - these can range from plastic containers, household items to building materials. With two plastic recycling facilities near the site in Bandung (Sinar Indah Plastic and Holis Usaha Plastic) (ENF Plastic, 2022), at the end of the building lifecycle, they can be brought there to be recycled locally, minimising its transport carbon.

Structural pieces of steel can be reused, so there is no need for them to be recycled. Scrap pieces, however, can be melted and processed into other steel projects. Recycled steel maintains its original quality and strength, making it an ideal material for recycling (U.S. Bridge, 2022).

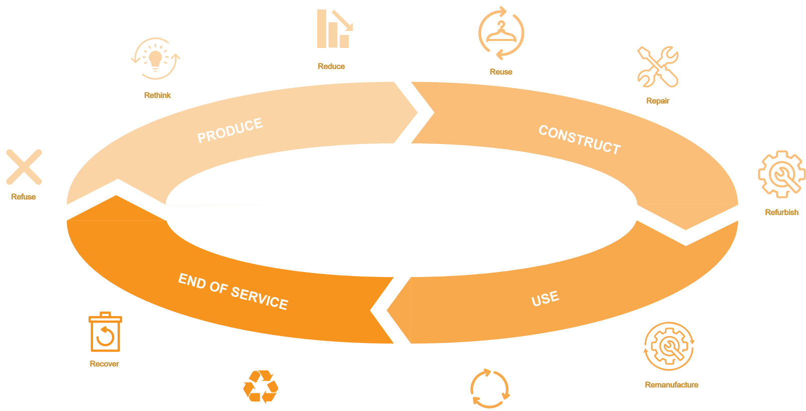


Figure 16: The circular design process

Adapted from: OpenCourseWare TU Delft (2023)

The NEW Nexus

Currently, the NEW Nexus is not incorporated into the design of the building, mainly due to the fact that the library is small-scale, with no plumbing and minimal use of electricity. Artificial lights are only required during nighttime, and even so, considering the long daylight hours and the majority of the building use being during the day, lights are rarely necessary.

Despite this, using the building to connect the elements of nutrients, energy, and water together can bring positive impacts on the local community. For instance, the roof can be used for rainwater attenuation, especially considering the long monsoon season from October to May - at the moment, the water is discharged through downpipes at the rear of the building, but this can be retained in a tank instead. Because of the small scale of the building and thus the amount of water collected, it would be unrealistic to say that this can irrigate crops for the local agriculture industry, but thinking on a smaller scale, the water can be used for watering plants in neighbouring community gardens instead, supporting the local food resources.

In a similar manner, solar PVs can be installed on the roof to generate electricity for the neighbouring buildings. The library is surrounded by local clinics and doctors that would require this energy to run their building and services/ equipment, so transferring the solar energy generated through a grid to the clinics would be a win-win for the community by investing in its healthcare system. The water collected can also be used in these buildings for their traditional squat toilets, where greywater stored in a bucket is used to ‘flush’ due to the lack of a plumbing system.

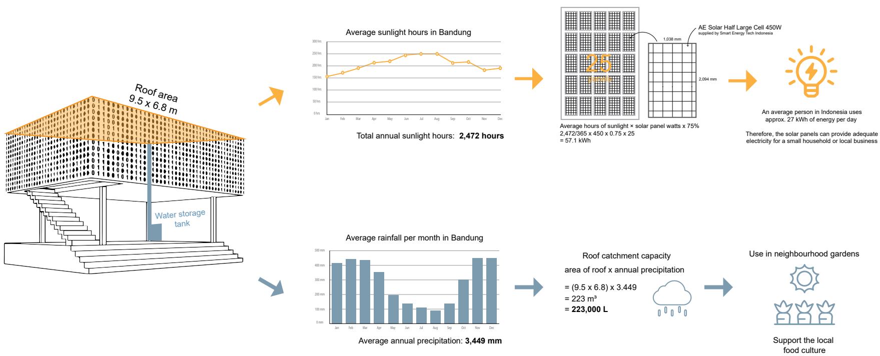


Figure 17: Use of roof for rainwater harvesting and solar energy production on site

Site plan 1:1000

Section AA' 1:1000

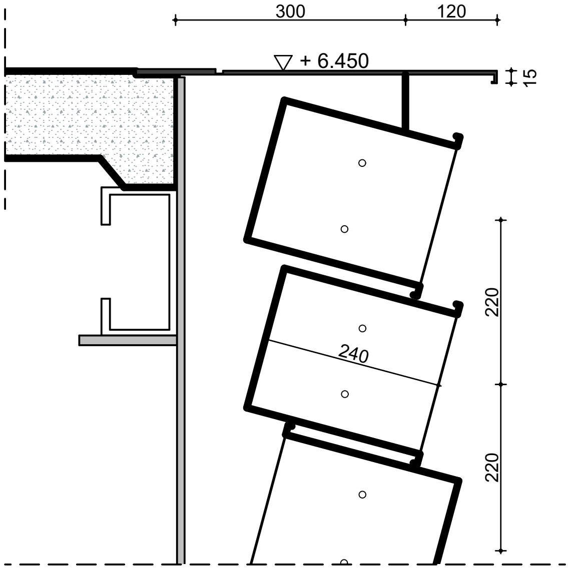
Credits | Diagrams: Thera Mulder and Sari Naito

Design Approaches

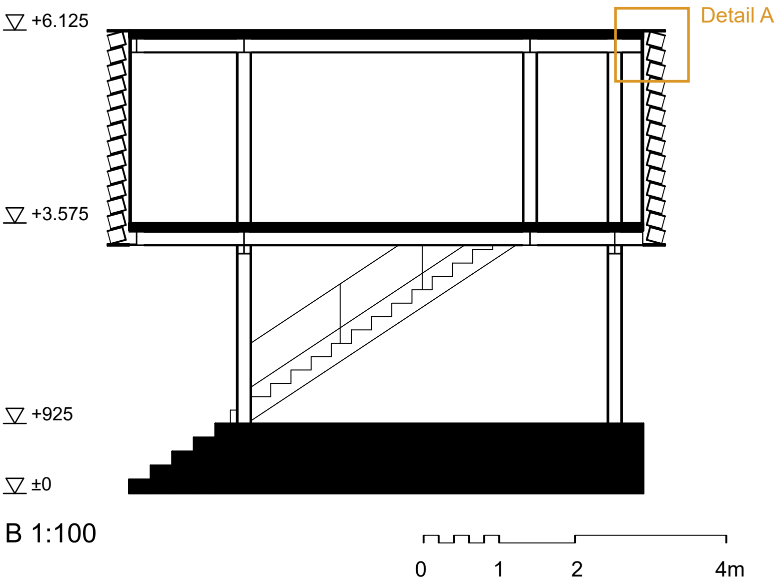
Issues in the building can arise when two or more different shearing layers directly intersect with each other, as the lifespan of the materials can be vastly different. When one layer has to be replaced or refurbished, it impacts the adjacent layers and makes the process complicated and ineffective.

The library design makes sure that each layer is independent, minimising the consequences of this. For instance, the facade cladding is lightly attached to the concrete floor/roof and steel frame with screws, so that they can be detached and replaced/refurbished if necessary.

However, some conflicts between material lifespans can be seen within a single shearing layer. For instance, the rows of steel plates in the facade used to fasten the ice cream buckets together last longer than the buckets themselves. Steel has a lifespan of at least 75 years, and although the lifespan of the ice buckets is still unknown and yet to be confirmed, a few had to be replaced within 3 years of completion of the building already. However, the ice cream buckets are connected to the steel plates with screws, which makes it easy to replace them at the end of their lifespan.



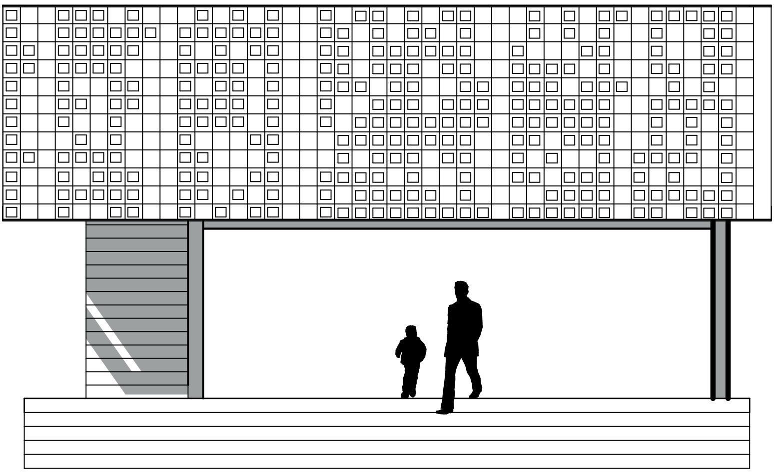
Detail A 1:10



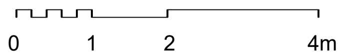
Section B 1:100

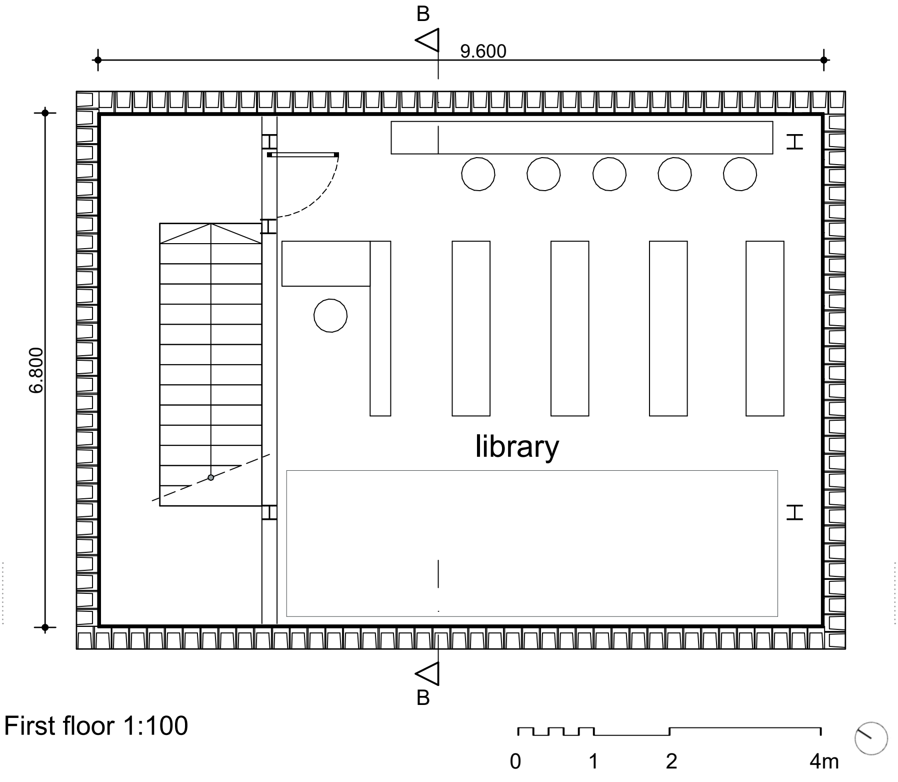
Credits | Diagrams: Thera Mulder

Design Approaches



Front elevation 1:100





First floor 1:100

Credits | Diagrams: Thera Mulder

Stakeholders & Value Chain

Circular design greatly influences the role of architects in the design process, as it challenges the architects' roles as liaisons between multiple stakeholders and requires them to constantly understand all aspects of the design, from the conceptual stage, construction, to disassembly.

In the Bima Microlibrary, this is especially evident, as the architects worked with the local community and government to understand why the site requires a library, and how the current site can be enhanced to solve the issues regarding illiteracy, social integration and participation.

Designing an environmentally circular building by using reused materials also creates a more complex network of stakeholders, as the architects need to cooperate with a supplier to make sure quality materials are obtained. The maintenance of the building to ensure its sustainability also requires excellent communication between architects (who have knowledge of the building) and the local community and government who will be responsible for the physical tasks. At the end of the building lifecycle, the repurposing/ relocation of the materials must be considered again - who needs them, or where can they be reused? - further expanding the number of stakeholders in the design process.

SHAU's vision to create a network of microlibraries throughout cities to bridge the gap between mobile libraries and city libraries also challenges the communication between architects and local authorities, by making sure that each district has access to a library and that they work collaboratively with one another.

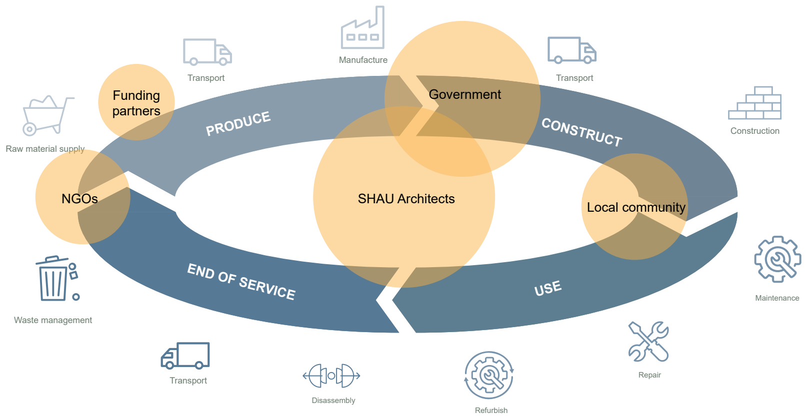


Figure 18: The role of stakeholders in the circular design process
Adapted from: OpenCourseWare TU Delft (2023)

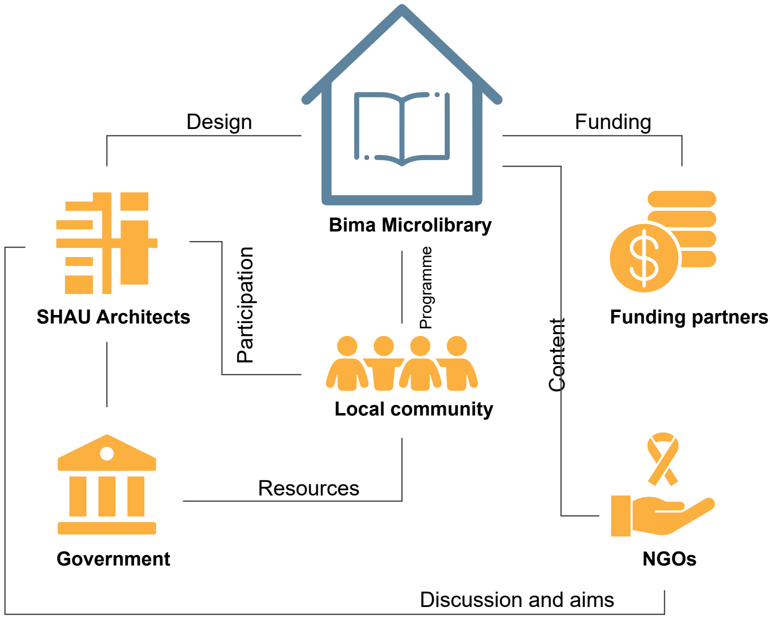


Figure 19: Diagram of interactions between different stakeholders in the Bima Microlibrary
Adapted from diagram by Archiroots (2020)

Architects
By engaging with the locals and taking a bottom-up approach, the architects design a site-specific library that relates closely to its environment and users.

Local community
The local community participates in the design process, helping create the library programme and advising on its uses. The local youth organisation also voluntarily manages the library.

Government
While interacting with the architects, the city of Bandung provides the resources necessary to build the library, such as land and materials (Ichioka 2019). They are also responsible for keeping an overview of the building.

Funding partners
Dompet Dhuafa, a humanitarian charity organisation based in Indonesia, provides support and funds the scheme (Ichioka 2019).

NGOs and media
NGOs educate the architects about issues regarding illiteracy and social development, outlining the overall aims. Using this as a starting point, architects set their own goals for the building. Media coverage also helps promote these initiatives and inspire similar projects in the future.

Lessons Learned

LAYERS OF CHANGE AND LIFECYCLE DURATION

The Bima Microlibrary is built in a minimal way, mainly consisting of concrete, steel beams and columns, ice cream buckets, electrical services, aluminium sliding doors and teak wooden furniture. The different layers have different lifespans, and as a result, it is convenient to make the layers independent of each other as much as possible. For example, in the past years, some ice cream buckets already needed to be replaced. The steel plates, on the other hand, will last at least 75 years. This is important to consider when choosing materials so that each layer is designed separately and keeps maintenance or demolition as simple as possible.

CARBON FOOTPRINT OF MATERIALS

All facades of the library are similar to each other, making it easy to view a representative part of the 1m² facade. As the main material used for the facade is plastic, the resulting carbon footprint is relatively high, with approximately 156 kgCO2eq per square meter of the facade. The use of steel rods also adds to the high footprint. However, as the plastic buckets are reclaimed and repurposed, this needs to be taken into consideration when comparing the values with other projects.

BUILDING MATERIAL ORIGIN

For the building material origin, the ice cream buckets and steel plates between them have been investigated. Indonesia imports steel plates mostly from Japan, China and South Korea. The used ice cream buckets are bought via an online vendor. It is unknown where these are made, but both materials are technical materials because they require a technical process to make. Investigating the source of the material creates awareness as to what kind of journey products have to take. A lesson learned from this project is to try to use as many local materials as possible in future projects to reduce transport carbon emissions and support the local industry.

R-STRATEGIES

Within the R-strategies, there is a division between three scenarios, in order of preference: ‘smarter use & manufacturing’, ‘extending lifespan of product and its parts’, and the ‘end-of-life scenario’. Some key strategies that can be implemented in future projects will be described below:

Reduce - using a timber frame instead of steel will reduce the carbon footprint of the building.

This will further reduce production and transport emissions, as materials can be sourced from local manufacturers.

Reuse - a light steel frame structure and a facade cladding that is detachable allows the entire structure to be disassembled and rebuilt elsewhere; rectilinear and regular designs mean that it will be simple to construct with different dimensions to respond to a potential new site.

Recycle - although the building uses large amounts of plastics with high carbon emissions, the material can be recycled by shredding, granulating and moulding it into other forms, extending its lifespan. Creative uses for these can be explored, such as more plastic containers, household items or innovative building materials.

THE NEW NEXUS

Currently, the Nutrients-Energy-Water Nexus is not incorporated into the design of the building, because the library is small- scale and experimental, with minimal services. However, considering the future impact of the building on the site, using the building to connect the NEW elements together can bring positive impacts on the local community. For instance, the roof can be used for rainwater attenuation. Although the impact of any of the outputs generated by the library may not be large, the water can be used for water plants in the surrounding neighbourhood, for instance. Solar PVs can also be installed on the roof to generate electricity for the other buildings.

DESIGN APPROACHES

The drawings in the Design Approaches section display how the library is structured. One of the takeaways from this is to separate the different building layers and ensure that they act independently, so there are no conflicts between them and can be refurbished/ replaced separately without any disruptions to the other layers.
In the microlibrary, however, it was seen that in the ‘skin’ layer, the lifetime of the ice cream buckets is shorter than that of the steel plates. Fortunately, it was concluded that as the ice cream buckets are connected to the steel plates with screws, the buckets can be replaced when necessary without too much interference with the other parts of the facade.

STAKEHOLDERS & VALUE CHAIN

This analysis has shown that designing an environmentally circular building by using upcycled materials creates a more complex network of stakeholders, as the architects form a fundamental part of the entire research, design, and building process. The microlibrary project involves architects, the local community, government, funding, NGOs and media.

Colophon

Student(s):
Thera Mulder
Sari Naito

Studio:
Urban Architecture

Tutor(s):
Georgios Karvelas
Joost Woertman

Image credits:

Fig. 1-7: Sanrok Studio. (2016). *Bima Microlibrary / SHAU Indonesia* [Image]. https://www.archdaily.com/790591/bima-microlibrary-shau-bandung

Fig. 8: Pangestu, P.I., Citraningrum, A. (n.d.). Pengaruh Material Bekas Pada Fasade Bangunan Terhadap Kenyamanan Visual (Studi Kasus: Microlibrary, Bandung)

Fig. 13: Pixelrz. (2023). *Jakarta Indonesia Slums*. [Image]. https://hotcore.info/babki/jakarta-indonesia-slums.htm

Fig. 14: Zhao, S. (2023). *Condition_lab Pingtan Book House*. [Image]. https://divisare.com/projects/475435-condition_lab-sai-zhao-pingtan-book-house

Fig. 16 + 18: OpenCourseWare. (2023). *3.1.2 Life-Cycle of a Building*. [Image]. https://ocw.tudelft.nl/course-readings/3-1-2-life-cycle-of-a-building/

Fig. 19: Archiroots. (2020). *Bima Microlibrary*. [Image]. https://archiroots.net/project/bima-microlibrary/418c8199-906c-4f52-a985-2a4bde04b0eb

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