Growing buildings

What are the benefits of techniques integrating living organisms in architecture?

Kamila Waszkowiak

Abstract

In recent years, architecture has shifted towards more sustainable and circular design. Scarcity of building materials and environmental awareness of the building industry generated a need for new techniques and developments, pushing architects and designers to increasingly turn towards biological and natural processes. Nonetheless, the elated insight is still scattered, whereas growth and development of new technologies are constantly accelerating. This paper aims at presenting and categorizing techniques integrating living organisms in architecture, along with their potential benefits in terms of sustainability and circularity. To provide clear classification and ease the comparison, each technique is described with the help of additional categories and catalogued by living organisms involved. To deepen the possibility of comparison, the outcome of the research is presented in tables, each focusing on different aspects which can influence the method choice. The results of the research, in form of a design tool, can be useful for architects and designers in making the decision of incorporating living organisms in their design.

Key words: circularity, biology in architecture, sustainability, living organisms in architecture

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“ [...]Wykonałem wszystko ściśle podług instrukcji: zakreśliłem z grubsza kwadrat (ciągnąc czubkiem buta po ziemi), otworzyłem hermetyczne opakowanie żywokrystu (serial “Altana - Wenecja”, o ile pamiętam; oczywiście autoletalna), odmierzyłem porcję ziaren na dłoń - i posiałem wzdłuż linii. Trochę jeszcze zostało, to dosypałem na rogach. Potem rzuciłem na wierzch przygotowane wcześniej dwa wiadra błota. Przez noc altanka urosła aż miło.[...]”

Jacek Dukaj, “Katedra” [w:] “W kraju niewiernych”, str. 429

‘[...]I have done everything strictly according to the instructions: I roughly circle the square (pulling the tip of the shoe over the ground), I opened a hermetic pack of the resins (the series “Gazebo - Venice”, as I remember, of course, autolet), measured a portion of grains on my hand - and sowed along the line. I had some left, so I’ve sprinkled on the corners. Then I dropped the two mud buckets I had prepared earlier. Through the night, the gazebo grew so nicely.[...]

Jacek Dukaj, “Katedra” [in:] “W kraju niewiernych”, p. 429

Introduction

Bridge in Rangthylliang (India). Source: Wikimedia Commons

As urban and suburban areas grow all over the world, so does the demand for materials and resources for them. Extreme, worldwide material flows bring profound consequences to our natural environment, economy and regional architecture identity. Scarcity of specific resources, along with lack of flexibility of existing building techniques, bring new challenges to modern architecture. The linear concept of production, usage, and disposal is no more viable: new techniques for building, maintaining and re-using our constructions and their parts must be created.

In search for better solutions, designers increasingly look at biology: including nature into the process of construction and maintenance of new buildings, means to incorporate or mimic cycles and processes which have existed from millennia, with perfect economy of energy and materials. However, including living organisms in architecture is not a new idea. One of the earliest mentions of vegetation used as an integral part of an edifice is the hanging gardens of Babylon[1], considered as one of the ancient seven wonders. Green roofs were used in Scandinavia, as an additional layer of insulation. Living organisms were also as a construction, in form of bridges created with roots of trees growing on the riverbank, like in Rangthylliang and Umshiang (India)[2,3].

Nonetheless, the idea of extensive usage of living organisms was not popular among modern architects until recently. Including plants, trees, fungi, algae or bacteria into the architecture can represent a new direction towards more sustainable, renewable and circular construction. New approach towards green architecture can be seen e.g. in Bosco Verticale project in Milan, by Stefano Boeri.[4] New technolgies and the development of our understanding of natural systems opens new possibilities for architecture, e.g. knowledge of plant microbal fuel cell allows to treat plants as a direct source of energy[5].

By mixing different techniques, small cycles of energy and materials can be achieved within one edifice or neighborhood, lowering the cost of maintenance and economizing resources. These concepts brought new, utopian ideas of human life and

1 Wikipedia (n.d.) Hanging Gardens of Babylon. Rietrieved 18.08.2018 from: https://en.wikipedia.org/wiki/Hanging_Gardens_of_Babylon

2 Wikipedia (n.d.) Sod roof. Retrieved 18.08.2018 from: https://en.wikipedia.org/wiki/Sod_roof

3 Poonam Binayak (2017) India's Amazing Living Root Bridges Will Blow Your Mind. Rietrieved 21.10.2018 from: https://theculturetrip.com/asia/india/articles/indias-amazing-living-root-bridges-will-blow-your-mind/

4 Boeri (n.d.) Bosco Verticale. Retrieved 21.10.2018 from: https://www.stefanoboeriarchitetti.net/project/bosco-verticale/

5 E-plant (n.d.) Information. Retrieved 07.01.2018, from: http://www.plant-e.com/en/plant-e-technology/

structures more connected to nature, including constructions uniquely based on natural materials, as in the Fab Tree House project by Joachim Mitchell.[6]

Surely, between conceptual ideas and real possibilities still lies a gap of knowledge, needed for the actual realization. Some architectural studios, combining research with design, try to provide realistic applications examples. For instance, the research about algae by ARUP lead to use them in the SolarLeaf project as shading system and energy source.[7] EcoLogicStudio presented several exhibition prototypes of using nature in architecture and urbanism, based on their research programme.[8] Some companies conduct researches about specific organisms, providing solutions not only for architecture but also for different usage, such as Ecovative Company producing isolation panels, as well as packaging grown from mycelium[9].

Several new methods are developed at the intersection between of architecture, biology, and art. Indeed, the best collections of possible solutions have been gathered by two museums, in a book titled "Bio Design. Nature, Science, Creativity" published by Museum of Modern Art[10], and in the exhibition "Biodesign. Exhibition on the Cross-Pollination of Nature, Science and Creativity" by Het Nieuwe Instituut, Rotterdam[11]. Another platform providing information about biology, design and engineering is SYN. DE.BIO, curated by the Bartlett School of Architecture, London.[12]

Clearly, implementing complicated and delicate environmental cycles is not the final answer for all problems, especially considering the current state of the art. Nonetheless, a design inspired by nature gives visible benefits and possibilities for further development. The knowledge of possible techniques which actively include living organisms (and, broadly speaking, biology itself) in architecture is scattered, hence the possibility of comparison or attempts of cross-application is limited. By collecting data from different sources - artist, designers, architects, biologist or other scientists - it is possible to unify and structure the current knowledge, with the aim to help in applying and further developing existing technologies, and also bringing more ideas in the future.

6 Mitchel Joachim (2008) Fab Tree Hab. Local Biota Living Graft Structure. Project description. Retrieved 18.08.2018 from http://www.archinode.com/fab-tree-hab.html

7 ARUP. (n.d.). Worldwide first façade system to cultivate micro-algae to generate heat and biomass as renewable energy sources. Retrieved 05.01.2018, from: https://www.arup.com/projects/solarleaf?query=hamburg

8 EcoLogicStudio. (n.d.). Office profile. Retrieved 12.01.2018, from: http://http://www.ecologicstudio.com/v2/about.php?mt=1

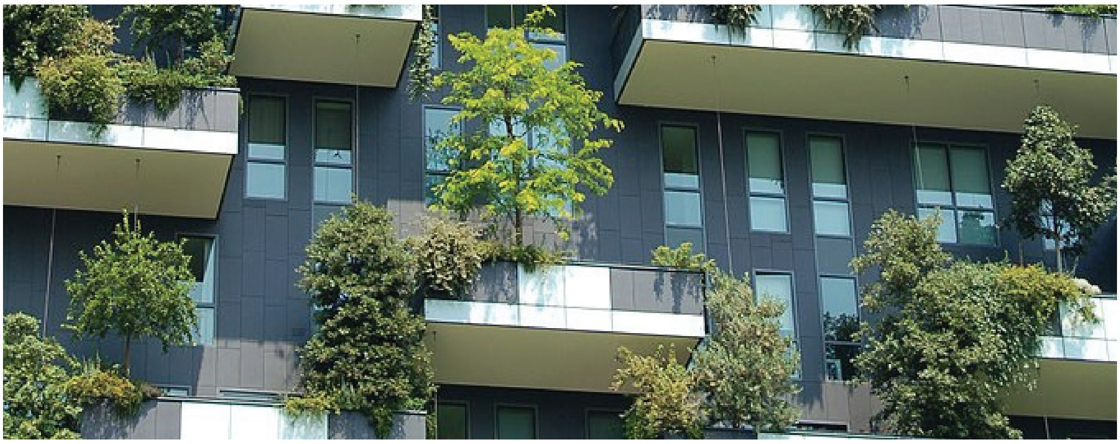
9 Ecovative (n.d.) Technology. Retrieved 18.08.2018 from: https://ecovativedesign.com/technology?ref=footer

10 William Meyers (2012) BIO DESIGN. Nature, Science, Creativity. The Museum of Modern Art, New York.

11 Het Nieuwe Instituut (2014), Exhibition on the Cross-Pollination of Nature, Science and Creativity, exhibition booklet.

12 Marcos Cruz, Richard Beckett (n.d.) Syn. De.Bio. About. Retrieved 18.08.2018 from http://syndebio.com/about/

What does it mean to be green?



Bosco Verticale (Milan). Source: Wikimedia Commons

Providing a healthy and pleasant habitat to its user is an idea old as architecture itself: Vitruvius himself, in the first century BC, was putting life quality in front of artist satisfaction. But the definition of good architecture constantly changes, bringing new challenges to the next generation of designers. Architecture is shaping our environment not only in a direct way but also indirectly, contributing with its design, usage, and maintenance to the global warming effect, urban heat islands or shortage of specific building materials. In the last decades, instead of talking about proportions, beauty or historical references, architects tend to talk more about biology, sustainability or circularity.

Biology and nature were always a source of inspiration for architects, for instance by applying the golden ratio to proportions, or by nature-inspired shapes and ornaments. The result of such inspiration might be very subtle: indeed, both Calatrava and Lloyd Wright claimed to be inspired by nature. An additional step is to mimic nature (instead of a simple inspiration), from which follows the name 'biomimicry'.[1] Biomimicry does not usually mean including nature or any of the natural processes into the design, but just recreating the natural processes or phenomena. Furthermore, not all use of biomimicry (or biology, in general) is applied with the goal to achieve a sustainable design - the two concepts can exist independently.

Sustainable architecture focuses on introducing buildings which can live in balance with our environment; it focuses on its influence on nature, carbon footprint, or limiting materials that could make harm to users or area around, during the building process, use, and demolition of the building. [2] One of the modern guidelines for sustainable design are certification systems, like LEED (Leadership in Energy and Environmental Design)[3] or BREEAM (the Building Research Establishment Environmental Assessment Method).[4] Sustainability does not affect only the shape of the edifice an environment around it, but also its influence on the community, resources used for transportation of building materials, together with the well-being of workers creating it.

Circularity, as a more specific way to achieve sustainability, focuses on re-use and recycle of materials used during the construction, as well as resources present during the utilization of the building. One of the most known approaches is 'Cradle to Cradle',[5] firstly introduced by Walter R.

1 Biomimicry Institute (n.d.) What is biomimicry? Retrieved 18.08.2018 from https://biomimicry.org/what-is-biomimicry/

2 Bennetts, H., Radford, A., Williamson, T. (2003). Understanding Sustainable Architecture. Chapter 1 - Sustainability. London: Taylor & Francis.

3 USGBC (n.d.) LEED. Retrieved 18.08.2018 from https://new.usgbc.org/leed

4 Building Research Establishment Ltd (2018) BREEAM. Retrieved 18.08.2018 from: https://www.breeam.com/

5 EPEA GmbH (2018) Cradle to Cradle. Retrieved 18.08.2018 from: https://www.epea.com/cradle-to-cradle/

Stahel and now popularised by the Cradle to Cradle Products Innovation Institute[6], which advocates for treating waste streams as a resource for new design. Circular architecture is optimized with the aim at future recycling, allowing prospective disassembly of the building and recycling or upcycling its parts.

Although these three terms - biology, sustainability, and circularity - are used interchangeably and might seem to have similar aims, they considerably differ. Achieving a design meeting all requirements of all categories is complex and requires extensive expertise. There are many available sources of knowledge about this topic, as well as many systems of certification trying to promote its use. Every year, new upgraded solar panels, wood construction technologies or ways to handle residue are launched and provided to designers. Nevertheless, in 2009, 23% of the total CO_2 emissions were produced by the construction sector.[7]

The aim of this paper is to seal the gaps between those concept and give insights into more specific typology of using biology in architecture, namely implementing living organisms directly or semi-directly into the design. Within this terminology, where can we place the usage of living organisms in architecture? It can be part of any of the described categories - or none, depending on the intentions in each specific design. Certiainly, the simple fact of living organisms being applied is not enough, since the paper is focusing mostly on benefits obtainable by executing enlisted methods. In some cases, applying those techniques can be based purely on easthetical or marketing purposes (e.g. greenwashing)[8]. Nonetheless, in this paper techniques implementing living organisms in architecture are evaluated mostly based on their sustainability and circularity. For this reason, biomimicry is not taken (directly) into consideration, being a method rarely depending on actual living organisms but rather imitating them.

Hopefully, providing additional knowledge in form of a analytical and comparable system will allow creating more sustainable and well thought-out green architecture with greater ease, facilitating architects and designers to struggle for beauty, balance and healthy impact on the environment.

6 Cradle to Cradle Products Innovation Institute (2018) About the Institute. Retrieved 18.08.2018 from: https://www.c2ccertified.org/about

7 Huang, Lizhen & Krigsvoll, Guri & Johansen, Fred & Liu, Yongping & Zhang, Xiaoling, (2018) Carbon emission of global construction sector," Renewable and Sustainable Energy Reviews, Elsevier, vol. 81(P2), pages 1906-1916.

8 Yuka Yoneda (2009) Top Five 'Green' Buildings That Defeat The Point of Being Green. Retrieved 21.10.2018 from: https://inhabitat.com/top-five-most-ridiculously-greenwashed-buildings/

Living organisms designing tool

Production of mycelium packaging. Source: Flickr

Possible applications of different techniques, including the use of living organisms, may vary depending on the possible aim. Architecture does not only care about building materials and their composition, but also about all possible appliances and systems, as much as orientation and surrounding of the design building, that can influence the user comfort and experience around and inside it. Each aim can be achieved by multiple means: each one of them brings additional values, as well as needs and disadvantages. There is not one universal answer to the question: "how to design?"; hence, the application of each method must be individually weighed, taking into consideration different aspects. Howbeit, to be fully aware of available possibilities, the knowledge must be systemized and categorized, to clarify the differences and emphasize the benefits of one method above another.

In this paper, 27 widely used techniques like green roofs, as well as novel ones, e.g. fungus thermal insulation, and other approaches towards implementing living organisms in architecture are presented in a short form of glossary, divided by the living organisms involved. For clarification, trees are being considered separated from plants: even if they technically belong to the same kingdom of living things, their application in architecture differs significantly.

There are multiple ideas of involving living organisms into the design, including theorethical projects, art pieces, biennale or festival displays, or commercial products. To narrow the scope and present only systems feasible in current state-of-art, theoretical usage is excluded from the research, so each technique presented is associated to at least one real-life application, leastwise in form of one physical, full-scale model. To restrict the field of the research, two boundaries are added: the paper takes under consideration building materials where living organisms play a crucial role in the production and are alive during that process (hence, not all bio-based materials), and techniques which rely on living organisms (alive during the entire time of use).

The research is a combination of literature study, case studies and interviews to designers and architects working with the proposed techniques. Most of the knowledge is based on research papers published by the inventors themselves, official websites of companies or individuals involved in the technique development. When the data is insufficient or unclear, questions were asked directly to developers or users of the method.

Even after limiting the scope of the research and defining its method, the variety of researched techniques and their dissimilarities in development created a problem in comparing them.
To provideconcise, comparable and homogeneous results, hence to structure them, additional research sub-questions are added:

1. What is the production process? (or)

Living Light. Source: Dutch Design Awards

What is the system composed of?
2. What are the advantages and disadvantages?
3. What are the quantities (time/space) needed?
4. What facilities are needed for production/maintenance?
5. What supplies should be provided?

To ease the understanding of the possibilities of different applications, for the sake of this paper, all techniques are divided into different categories, presented in the form of matrices:

1. Matrix A - Possible application in architecture
page 51

As previously mentioned, in this paper architecture is considered broader than its physical and technical characteristics. Hence, the categories taken under considerations are:
- Building materials and construction
    - Insulation and cladding
    - Energy production
    - Indoor environment
    - Food production
    - Cleaning and purifying
    - User well-being

2. Matrix B - Benefits
page 53

This matrix shows the advantages of the techniques over traditional materials and methods applied in architecture, as well as over other methods.
- User well-being
- Aesthetic quality
- Air quality
- Low carbon footprint
- Urban heat reduction
- Acoustics
- Biodiversity
- Circularity
- Thermal insulation
- Natural materials
- Low energy production
- Low maintenance

In this category costs are not taken under consideration, due to low development of some of the techniques, which makes cost estimation hard to obtain and non representative for the near future, when some of them will likely be more efficient.

Each benefit is given a 'relevance score': high (black dot) when achieving this particular benefit is the main aim of the application, and low (white dot) when the benefit is additional (so the method should not be mainly considered to obtain only this advantage).

3. Matrix C - Level of development
page 55

To give an idea of the actual possibility of applying the techniques, their level of development is compared and assigned to one of the following categories:

- Very well-known: many real-life examples, no need for specific knowledge

- Well-known: many real-life examples, need for specific knowledge
- Partially developed: several real-life examples
- Underdeveloped: only one real-life example
- Very underdeveloped: only exhibition examples

This particular matrix needs to be taken with caution since the knowledge about the techniques is in constant development, reason why this information can be soon out-of-date. Nonetheless, it gives a grasp on the reliability of the techniques at the moment.

4. Matrix D - Indoor/outdoor application
page 57

Due to the different restrictions about the requirements needed for each method, not all of them can be located outside (e.g. due to high temperature or humidity required), while some of them should be only placed outside (e.g. to provide enough sunlight). This matrix shows only the application of the system itself or the final product of the technique, assuming that in some cases the needed appliances could be detached from the biological system.

5. Matrix E - Time needed for the technique to be applied
page 59

Since most biological processes need a certain amount of time, and many of the techniques cannot be pre-prepared, pre-made or applied before providing specific conditions in the building, timing is truly important. This matrix shows the time-span needed to obtain the final product of each technique, or how long it is needed to wait for the organisms (mostly trees) to obtain the maturity needed for the technique. This matrix does not take into consideration the preparation of the systems which are needed to be 'pre-installed', those which should be prepared before the creation of the mentioned technique, whose construction is not bio-based.

The whole glossary and the following matrices are prepared as a design tool: each benefit sought by the architect can be found in the 'Benefits' matrix, each desired usage in the 'Application' matrix. The glossary gives basic information about needs and possible drawbacks, to help exclude techniques not suitable for application (e.g. because of space requirements). Ultimately, the designer can have a full spectrum of practicable options, comparing all the factors shown in the matrices.

The glossary itself provides only basic information about each method. Since each design is unique, further research is needed before taking the final decision of implementing it. Nonetheless, this paper is not aimed at answering all application questions, but rather at showing the possibilities and helping with preliminary design decisions.

Conclusions

Baubotanik. Source: Archdaily

Each matrix, considered separately, not only allows for comparison between the techniques, but also contribute to the collective knowledge about them. Even though each technique presents distinctive features and diverges considerably, together they create a common essence of living organisms in architecture.

1. Possible application in architecture
page 51

Even if each technique is preliminarily designed to be applied in a specific way, many of them have at least one more secondary application. Certainly, some of them were created in that way, providing additional utilization methods, for example in algae panels technique, where an addition of biogas production allows to treat this technique as a source of energy, along cladding. Nonetheless in many cases, this occurrence does not appear by design, but it is rather a way to exploit the benefits associated with chosen living organism; for example, using trees in baubotanik allows to treat them also as air-cleaning factors, without any additional design. This proves, that applying living organisms in architecture can serve multipurpose solutions.

2. Benefits
page 53

Even if the techniques are primarily correlated with only one benefit, clearly each of them provides many additional values. To achieve supplementary gain, sometimes more requirements must be taken into consideration, for example only extensive green roofs are low-maintenance; however, most of the additional benefits can be obtained without any further design. It is clearly visible, that applying living organisms in architecture can bring a substantial amount of sustainable solutions and create more environmentally-friendly buildings, even if only a few techniques are involved. Also, many similar benefits can be achieved in multiple ways, creating opportunities for interesting and original design.

3. Level of development
page 55

The number of different application of given organisms is correlated with the level of development of existing techniques available nowadays. The most developed are those involving plants and trees, like green roofs or green walls - as stated in the introduction, this techniques are known for centuries; less developed, hence providing fewer variables, are techniques including mycelium, algae and bacteria. It shows, that there is still a potential of advancing in that field. More developed techniques provide not only more knowledge in the subject, but also more variations in application method, what makes them easier to combine in the design e.g. green roofs are possible to be applied on flat or tilted roofs, with diverse types of plants. However, underdeveloped techniques are already showing a potential, and can flourish in the coming future, for example mycelium thermal insulation might be a substitute for EPS, once the difficulties with production efficiency are solved.

4. Indoor/outdoor application
page 57

Techniques integrating living organisms in architecture are available indoors, as well as outdoors; nonetheless, to achieve optimal results, many environmental requirements must be met. That is why not many of the techniques are applicable both in- and outdoor. Likewise, each method has more explicit requirements about light, temperature or humidity, preferred for optimal development of the method, thus the location in the building is crucial for the proper performance, for example, to achieve repeatable and homogeneous properties of mycelium elements, highly controled environment must be provided, to assure unified growth and minimize contamination. Additionally, not all the techniques can be cross-implemented, due to interfering, conflicting climate conditions - for instance, in the Netherlands Living Machine System cannot be exposed directly to outdoor conditions, hence it cannot be utilized in for of a green roof.

5. Time needed for the technique to be applied
page 59

Biological processes might seem to be time-consuming and unpredictable; although, most of the techniques are designed to optimize the time-spawn needed for its application. When properly installed, most of them can create instant effects, e.g. air purifying, thermal insulation. Likewise, the production of building materials timewise can be competitive with traditional components. The only category of techniques requiring a significant amount of time is those depending on trees. While applying them, additional measures are required, for example, steel frames must support baubotanik construction, before trees become strong enough to carry the intendent load.

Certainly, the greatest challenge of applying living organisms in architecture does not lie the technical details, but rather in the change of mindset. In fact, some techniques do not practically influence the design itself (e.g. there is no difference between regular and bacteria brick), but nevertheless demand further awareness about additional specific requirements. Furthermore, biology is far less predictable than physics or chemistry, so including living organisms requires to take higher responsibilities for the created ecosystem, with the awareness that the results may not be always identical.

One of the possible advantages is the possibility of combining some of the methods. Some techniques have similar requirements but different outcomes: for instance, some plants listed by NASA in Clear Air research are also mentioned by e-Plant as a potential source of electricity. Combining those plants in form of a green wall, hence providing additional thermal insulation to the building, can triple the benefits within one design solution.

Building with living organisms requires more knowledge and sensibility than an ordinary construction. It might include creating a whole small ecosystem within the edifice or the neighbourhood. But the chance of creating a circular and sustainable building, with a lower carbon footprint with recyclable materials offers an encouraging reward in return. The currently available technology is suggesting great potential. This architecture can be slowly introduced without creating a sudden impact on the inhabitants, ultimately achieving a great change while avoiding a drastic variation in our lifestyles.

The form of glossary, supported by set of matrices is used not only for systematization, but furthermore to provide handy, clear and useful tool for architects. The appendix to this paper can be a stand-alone publication, used actively while making design desicions.

Further development of the tool

A bowl printed with algae-based bioplastic. Source: Atelier LUMA

The glossary, created as an addition to this paper was finished in July 2018. It clearly shows the potential of using living organisms in architecture; nonetheless, many of the examples are based on the early-stage development of different methods. Some of them, even if promising, are far from reaching the market. Some of them might never reach it. On the other hand, some of the described examples are being intensely developed at the moment, and in the near future the data provided in this paper might be outdated. In addition, in some cases, the data presented might seem too vague, due to limited examples and experiments. Nevertheless, the presented matrices - especially 'benefits' and 'possible applications' - should not get out of date soon, as the primary aim and purpose of each technique should stay the same.

Comparing different techniques, even within the same scope, can be difficult. Each one has a different purpose or way to achieve this purpose. Making them comparable means creating a systematization system, which may still be insufficient for some of the described examples. More developed techniques are complex enough to justify the creation of a similar glossary and set of matrices only for them. Though, analysing one particular typology of techniques more than others would make the overview unbalanced. Also, the difference between one particular method and a category of methods is blurrier than it might seem at first glimpse. If the glossary is to be extended, additional categorizations should be added, to emphasize the different variables of the proposed techniques, which may influence the overall performance of the method.

It is also worth to consider including more methods, existing on the fringe of architecture. Some usage of living organisms in other fields are promising enough to introduce them to the construction process, e.g. bio-plastic filament made out of microalgae, used for 3D printing. This material was never used in any real-life architectural example and was excluded from the glossary being detached from the field right now, but the potential exists and should be considered. Therefore, the glossary should be further updated with ongoing investigations and researches which might look promising.

Appendix
Glossary of methods

To make the comparison easier, each technique (except for short description and the author, if possible) is described using the following definitions:

PRODUCTION: Description of the process of creating specific materials, description of the components of the system and its aim, or explanation about the biological feature that plays a crucial role in the application of the technique.

ADVANTAGES: Additional benefit (e.g. economical or environmental), giving an advantage over traditional techniques.

DISADVANTAGES: Drawbacks that need to be taken into consideration while applying the technique.

QUANTITIES: Numerical information (e.g. efficiency, required space), helping to compare the techniques and to facilitate application.

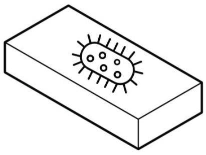
FACILITIES: Spaces or machines that are essential for production or maintenance (if necessary).

SUPPLY: Resources needed for production or maintenance (if necessary).

Bacterium

Bacterium (noun) plural bacteria
A member of a large group of unicellular microorganisms which have cell walls but lack organelles and an organized nucleus, including some which can cause disease.[1]

1 Bacterium. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/bacterium



Bacteria-grown bricks
building materials & construction

source: Archdaily

Technology developed my bioMASON, based on a well-known method in the biology cement production, used for example for creating mussels.[1]

PRODUCTION: For mass-scale production, a system similar to aquaponics is used: sand is mixed with *Sporosarcina pasteurii* bacteria in a special mold, and fed with calcium ions suspended in water. After 2-5 days the bricks are dried, to extirpate the bacteria.

ADVANTAGES: The biggest advantage is unnecessity of high temperatures, which allows not only to grow the material on the site, but also significantly lower the carbon footprint, compared to traditional brick production.[2]

D I S A D V A N T A G E S : The technology is new and underdeveloped.

QUANTITIES: 2-5 day for growing and drying. A pilot plant produces 500 bricks a week on average, with capacity for 1,500.

FACILITIES: To obtain the required precision, computer numerical controlled (CNC) deposition machine is required; existing machines can be used, with small additions and modifications, e.g. CNC from MultiCam company (Series 5000 Model 508).[3]

SUPPLY: An aqueous solution containing urea and calcium chloride, urease enzyme broth, loose aggregate material (sand).

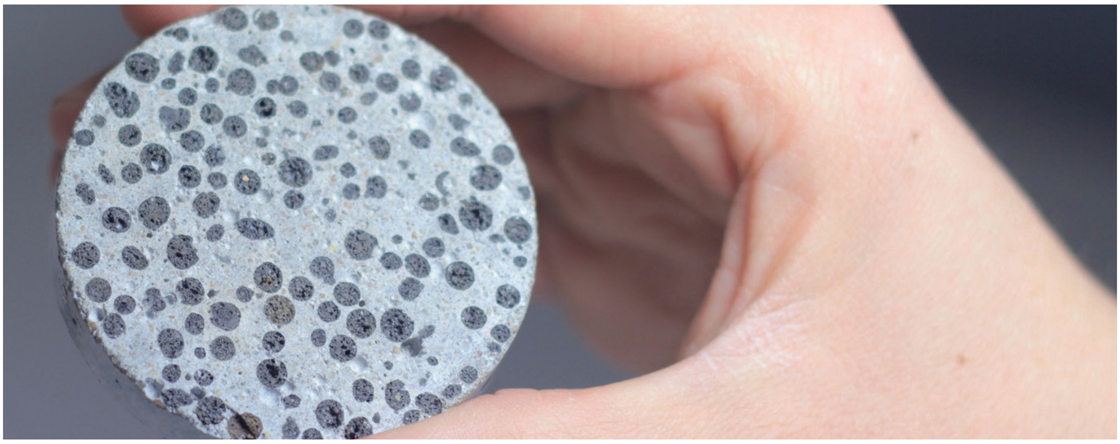
1 Source: https://biomason.com/ [Retrieved 05.01.2018]

2 Navy, K. (2015, October 12). How to grow bricks from trillions of bacteria, Wired. Retrieved 05.01.2018, from: http://www.wired.co.uk/article/bricks-from-bugs

3 Source: United States Patent nr US 9,199.880 B2, Dec. 1, 2015

Self-healing concrete

building materials & construction



source: Archdaily

Developed at TU Delft, in the Delft Center for Materials (DCMat), the technology employs calcite-precipitating bacteria to prevent cracks in concrete constructions. Furthermore, the research team is currently working on a liquid containing the mentioned bacteria, which could be applied on existing cracks in non-healing concrete constructions.[1]

PRODUCTION: Smaller than 2mm pellets with bacteria and nutrition mix are added to cement. The stagnated microbe can stay dormant for decades, but when the construction cracks, the penetrating water dissolve the pellets, activating bacteria. Limestone produced by them seals the crevices. [2]

ADVANTAGES: Self-healing of concrete makes this material much safer and easier to use. Preventive reinforcement adding could be neglected, and the thickness of elements could be smaller. Less frequent maintenance makes the construction cheaper and easier in case of hard-to-reach structures (eg. tunnels, bridges). [3]

DISADVANTAGES: Higher cost of production compared to conventional methods.

QUANTITIES: It takes only 3 weeks to seal any slit, no matter how long it is.

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 TU Delft. (2015, March). Self-healing of Concrete by Bacterial Mineral Precipitation. Retrived 10.01.2018, from: https://www.tudelft.nl/en/ceg/research/stories-of-science/self-healing-of-concrete-by-bacterial-mineral-precipitation/

2 TU Delft. (2016, Jun 13). TU Delft - Self-healing concrete for performance based infrastructures [Video file]. Retrieved from: https://www.youtube.com/watch?v=WUsDqArwEd8 [Retrieved 10.01.2018]

3 EPOfilms. (2015, April 21). Hendrik Marius Jonkers - Self-healing concrete containing bacteria [Video file]. Retrieved from: https://www.youtube.com/watch?time_continue=5&v=OXkW1q9HpFA [Retrieved 10.01.2018]

Fungi

Fungus (noun) plural fungi, funguses

Any of a group of spore-producing organisms feeding on organic matter, including moulds, yeast, mushrooms, and toadstools.[1]

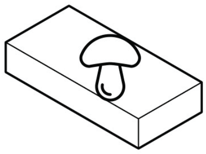
Mycelia

Mycelium (noun) plural mycelia

The vegetative part of a fungus, consisting of a network of fine white filaments (hyphae).[2]

1 Fungus. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/fungus

2 Mycelium. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/mycelium



Mycelium-grown brick
building materials & construction

source: Flickr

Low-energy material produced without any additional energy or waste, industrial and compostable. Used at MoMA PS1 Pavilion called Hy-Fi, designed by The Living.[1]

PRODUCTION: Low-value crop waste, firmly chopped, is mixed with mycelium. After few days, when the brick is solidified, it is heated up to 180-200 Celsius degrees, in order to kill the mycelium. The type of the production depends on the type of container where the mushroom is grown (tray culture, bag culture, slanted wall or a-frame culture, column culture, or bottle culture). For oyster mushroom cultivation (the most robust and practical type), vertical growth in columns or bags is preferred.

ADVANTAGES: Unnecessity of high temperatures significantly lowers the carbon footprint, compared to traditional brick production. Production is based on low-value waste materials and is fully biodegradable.

DISADVANTAGES: The technology is underdeveloped. A production plant needs a strictly-controlled environment (therefore the possible building materials proposed for its construction are concrete and plastic).

QUANTITIES: 3-5 days of growth + 5-10 days of drying. 75-125% biological efficiency (mass of crop waste needed for production compared to the mass of fungi provided). Preferable conditions for the mushroom farm are: a temperature of 15˚C to 20˚C; humidity of 80% to 90%; extremely sanitary conditions; light intensity of 750-1500 lux.[2]

FACILITIES: Three areas, providing an environment for each step of production:
- Substrate initial preparation area: space for substrate mixing, usually outside.
- Final preparation area: the substrate is pasteurized (in 55-60˚C for 0,5h, and then cooled down for 16-20 hours) and sterilized (in 250 ˚C for about 15 min, in a pressurized container).
- A spawning facility: area where mycelium is grown into substrate. To avoid contamination, this area needs to have a strictly-controlled environment.

SUPPLY: Low-value crop waste, in proportion around 1:1 to the mass of mycelium.

1 The Living. (n.d.). Hy-Fi. Retrieved 12.01.2018, from: http://www.thelivingnewyork.com/

2 Munira Z.Karimjee, (2014). Biodegradable Architecture. Finite Construction for Endless Futures, Azrieli School of Architecture and Urbanism, Ottawa, Ontario

Mycelium building frameworks

building materials & construction

source: Dezeen

One of the more developed mycelium construction is MycoTree, the structure designed and manufactured for Seoul Biennale 2017 by architect Dirk Hebel (Sustainable Construction unit at Karlsruhe Institute of Technology) and Philippe Block (Block Research Group at ETH Zürich). MycoTree is a self-bearing, tree-like construction created from mycelium components (from *Ganoderma Lucidum*) which support one another in compression, attached to each other with a system of bamboo and steel joints.[1]

PRODUCTION: Mycelium is first grown in pre-designed molds, and after the two weeks - when the element is fully formed and obtains the desired hardness - it is dried, to extirpate the organisms and stop the growing process.

ADVANTAGES: Unnecessity of high temperatures significantly lowers the carbon footprint. Production is based on low-value waste materials and is fully biodegradable.

DISADVANTAGES: The obtained material is brittle, so the construction needs to be carefully designed to obtain the right compression in each part. Although, the authors of the structure claim that this method could be used to create up to 2-stores high buildings.

QUANTITIES: 2 weeks of growth and drying. The material has a density of 440 kg/m^3 with 0.61 MPa of compressive strength (at 5% strain).[2]

FACILITIES: No extra facility is required.

SUPPLY: Low-value crop waste, in proportion around 1:1 to the mass of mycelium.

1 Dezeen. (2017, September 4). Tree-shaped structure shows how mushroom roots could be used to create buildings. Retrieved 06.01.2018, from: https://www.dezeen.com/2017/09/04/mycotree-dirk-hebel-philippe-block-mushroom-mycelium-building-structure-seoul-biennale/?li_source=LI&li_medium=bottom_block_1

2 Lee J., Javadian A., Hebel D., Design of a load-bearing mycelium structure through informed structural engineering. Presented at Conference: World Congress on Sustainable Technologies (WCST-2017)At: Cambridge, UK.

Mycelium sound insulation
indoor environment

source: Ecovative

The same process as growing mycelium-based brick could be used also in another way in architecture. Ecovative Design company is producing bio-based sound isolation mycelium-boards.

PRODUCTION: Low-value crop waste, firmly chopped is mixed with mycelium. After few days, when the brick is solidified, it is heated up to 180-200 Celsius degrees, to extirpate the mycelium.

ADVANTAGES: Production is based on low-value waste materials and is fully biodegradable.

DISADVANTAGES: Boards are fragile and easy to destroy.

QUANTITIES: Sound Absorption (NRC): 0.6. [1]

FACILITIES: Aerated Bed Reactor system, developed by Ecovative Design.[2]

SUPPLY: Low-value crop waste, in proportion around 1:1 to the mass of mycelium.

1 Ecovative (n.d.) MycoFoam™ Sinewave Acoustic Wall Tile. Rietrieved 09.03.2018 from: https://shop.ecovativedesign.com/products/sine-wave-wall-tile?variant=35862596929

2 Ecovative Design (n.d.). Our Pilot Plant. Rietrieved 09.03.2018 from: https://ecovativedesign.com/pilot-plant

Mycelium thermal insulation
insulation & cladding

source: Ecovative

Greensulate, developed by Ecovative Design, is an insulating material that is meant to replace styrofoam. [1]

PRODUCTION: Low-value crop waste, firmly chopped is mixed with mycelium, kept preferably in dark and moist conditions. After few days, when the brick is solidified, it is heated up to 180-200 Celsius degrees, to extirpate the mycelium.

ADVANTAGES: Compared to EPS, a 15% thicker panel of Greensulate is providing comparable thermal insulation, with 8 times smaller CO_2 emission, providing also better structural properties and fire resistance. The material is fully biodegradable.

DISADVANTAGES: Insulation layer must be thicker.

QUANTITIES: Production process of one panel takes around than 2 weeks.
Physical properties:
- Density: 7 lbs/ft3
- R-Value: 3/in
- Flammability: very low
- Strength: 54 psi

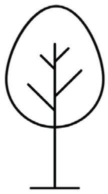
FACILITIES: Aerated Bed Reactor system, developed by Ecoative Design. [2]

SUPPLY: Low-value crop waste; preferable sawdust, in proportion around 1:1 to the mass of mycelium.[3]

1 Eduardo Mayoral González (2010), Growing architecture through mycelium and agricultural waste. Columbia University, GSAPP

2 Ecovative Design (n.d.). Our Pilot Plant. Rietrieved 09.03.2018 from: https://ecovativedesign.com/pilot-plant

3 FungiTalk, organized by BlueLab Rotterdam, 3.05.2018

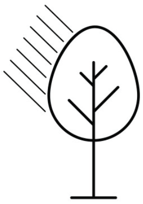


Tree

Tree (noun) plural trees

A woody perennial plant, typically having a single stem or trunk growing to a considerable height and bearing lateral branches at some distance from the ground.[1]

1 Tree. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/tree



Tree shading and cooling

indoor environment

source: Kelly Tree Farm

Trees, as well as bushes, vines and grass, are helpful to cool down the cities and to prevent heat island effect. This responsiveness is one of the easiest and the most natural way to maintain sunlight within the buildings if the tree is planted accordingly to the sun direction. Except direct sun energy blocking, trees cool down the air with a process called evapotranspiration, when water absorbed from the ground is transpired by leaves. [1]

PRODUCTION: Trees need to be planted according to the direction of the sunlight, within reasonable distance. The type needs to be chosen according to the climate, but also to the desired height.

ADVANTAGES: Lower energy consumption for cooling down and heating up.

DISADVANTAGES: Low influence on the results; long time needed for trees to obtain maturity and needed volume.

QUANTITIES: The sun exposure under the tree in summer reaches from 10% to 30%, while during the winter - 10% to 80%. The combination of shading and evaporation can lower the temperature up to 5°C compared to the area without any greenery.

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 United States Environmental Protection Agency (2008). Reducing Urban Heat Islands: Compendium of Strategies. Trees and Vegetation. page 3-5

Tree water management
cleaning & purifying

source: RTEC Treecare

The presence of trees and small greenery improves the water management during rainfall in the cities. The ability to absorb water lowers the need for complicated drainage systems. During small precipitation, all the water is intercepted, and during strong storms, the rainwater runoff is visibly reduced.[1]

PRODUCTION: Long tree roots infiltrate the soil, allowing water to soak down deeper and faster, compared to grass-covered area.

ADVANTAGES: The technique is natural, easy to maintain and provides many additional benefits (e.g. tree shading).

DISADVANTAGES: The best performance happens only during light to medium precipitation; during heavy rains, the rain runoff is only reduced.

QUANTITIES: 35% of rain can be absorbed.

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 United States Environmental Protection Agency (2008). Reducing Urban Heat Islands: Compendium of Strategies. Trees and Vegetation. page 8

Tree pollution reduction
cleaning & purifying

source: Gardening Channel

Ability to partially purify the polluted air by trees in several ways: by blocking airflow, PM (particulate matter) removal by tree canopy and re-dilution. [1]

PRODUCTION: The first process, airflow blocking, prevents the polluted air to pass.This could be a negative effect, because of PM densification upwind the tree; thus, to achieve a positive result, tree planting should be carried with consideration of prevailing winds.

The second process, PM removal by tree canopy, relies on dry deposition, when particles of pollution deposit themselves on a surface - in this case, the outer film of leaves. Part of deposited particles returns to the airflow, but it is also partially washed off. Efficiency depends on the PM concentration in the air, as well as the size and amount of leaves.

After being cleaned, the air keeps floating, re-diluting with the air passed above the tree. That is why the usual distance in which the drop of PM concentration is significant is around 30 meters, with a neglectable difference around 300 meters. The results differ due to air velocity, type of trees used or urban morphology.

ADVANTAGES: Low-energy and natural system.

DISADVANTAGES: The efficiency of the method depends on the prevailing wind direction. Long time needed for trees to obtain maturity and needed volume.

QUANTITIES: Within the impact zone, the result could vary from 15% up to 50% PM reduction.

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 The Nature Conservancy (2016). Planting Healthy Air. A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat.

Tree-shaping
building materials & construction

source: Wikipedia

A method of molding part of trees (or whole trees) into desired shapes, known and used for centuries, e.g. to construct Rangthylliang and Umshiang bridges.[1]

PRODUCTION: There are 3 main methods of tree-shaping:

- Instant tree-shaping - depends on bending prunes of young, 2-4m high trees by some molding device (eg. ropes, tutor). It is the easiest method, but the main drawback is the unpredictable reaction of trees.

- Gradual tree-shaping - when every branch of the tree is molded from the seedling to the mature tree. This method is predictable, but takes longer time and varies, depending on used species.

- Aeroponic tree-shaping - instead of molding branches, tree roots are shaped. Only complaisant species can be used. The method consists on planting the seeds in an aeroponic box to vaporize water and nutrient for around 1 year. Later the tree is planted on site, and roots are molded for the following several years.

ADVANTAGES: Even after finalization, the construction is still alive, growing, and is responsible for the atmospheric conditions.

DISADVANTAGES: Long waiting time.

QUANTITIES: 10-20 years of tree growth.

FACILITIES: No extra facility is required.

SUPPLY: Molding device (e.g. ropes, tutor).

1 Thomas Vallas, Luc Courardn (2017). Using nature in architecture: Building a living house with mycelium and trees.

Baubotanik
building materials & construction

source: ArchDaily

Engineering the building construction with living trees. To achieve this, the plants are connected with non-living elements into one system. The technology has been developed at Department of Architecture at the Technical University of Munich.[1]

PRODUCTION: Trees can grow together into one, compound structure, by merging with each other and with technical elements. To achieve one multi-tree system, plant addition is used: branches of individual trees, when kept pressed tightly together, after some time start to join (first with bark tissue, later with wood tissue), which allows them to exchange water and nutrition. When properly molded and provided initially with supporting construction, several independent trees with separated root systems can create self-bearing and bearing stiff construction, kept alive by just few roots.

ADVANTAGES: Even after finalization, the construction is still alive, growing, and is interacting with the atmospheric conditions. If treated as an external part of double-layer elevation, this could provide shading and pleasant microclimate to the inhabitants inside.

DISADVANTAGES: Long waiting time and a need for an additional bearing construction.

QUANTITIES: 10-20 years of tree growth.

FACILITIES: Additional steel construction, bearing the floor mass before trees are mature.

SUPPLY: No extra supplies are required.

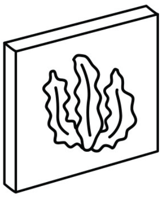
1 Baubotanik. (n.d.) Living structures. Source: Retrieved 09.03.2018, from: https://www.baubotanik.org/en/baubotanik/living-structures/

Alga

Alga (noun) plural algae

A simple, non-flowering, and typically aquatic plant of a large group that includes the seaweeds and many single-celled forms. Algae contain chlorophyll but lack true stems, roots, leaves, and vascular tissue.[1]

1 Alga. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/alga



Algae elevation panels
insulation & cladding

source: ARUP

In the SolarLeaf project by engineering firm Arup, algae (Chlorella Vulgaris) are located in glass elevation louvers. When algae are mature, they are collected, transformed into a pulp and fermented, creating the biogas.[1]

PRODUCTION: Each panel is connected to a common water circuit, which provides needed nutrients and carbon dioxide. The panels themselves are designed to maximize the efficiency and ease the maintenance - insulating argon-filled cavities on each side of the panel lower the heat loss, and small plastic scrubbers added to water keep them clean from the inside.

ADVANTAGES: This solution gives many benefits: by having the plantation on the site, the carbon footprint is reduced to the minimum; the plantation works the whole year, independently to the weather; no additional land-use is needed. Another advantage of this idea is responsiveness of the facade. In sunny days, algae colony visible grows, providing shading for inhabitants. The warmth of the water circulating in the system is also collected in the water tank, reducing the need for energy.

DISADVANTAGES: Algae colony limits visibility, not being fully transparent.

QUANTITIES: 10% efficiency of conversion from light to biogas, and 38% from light to heat.[2] The gain of algae biomass is 600 kg per year (129 reactors, 2,5mx0,7m, which gives 2,3kg/m^2/year)[3]

FACILITIES: Water pump, storage space for harvested algae, biogas plant, water tank.

SUPPLY: Water (max. 24L for each panel).[4]

1 Dezeen. (2013, April 15). Arup unveils world's first algae-powered building. Retrieved 05.01.2018, from: https://www.dezeen.com/2013/04/15/arup-unveils-worldsfirst-algae-powered-building

2 ARUP. (n.d.). Worldwide first façade system to cultivate micro-algae to generate heat and biomass as renewable energy sources. Retrieved 05.01.2018, from: https://www.arup.com/projects/solarleaf?query=hamburg

3 Jan Wurm and Martin Pauli (2016), SolarLeaf: The world's first bioreactive façade, arq (2016), 20.1, 73–79. © Cambridge University Press

4 ARUP. (n.d.). Worldwide first façade system to cultivate micro-algae to generate heat and biomass as renewable energy sources. Retrieved 03.05.2018, from: https://www.arup.com/projects/solarleaf?query=hamburg

Algae in ETFE cushions

insulation & cladding

source: EcoLogic Studio

One of the biggest benefits of algae is their ability of CO_2 reduction. This advantage was used in the first Urban Algae Canopy designed by EcoLogic Studio for Expo Milano 2015, later developed into Algae Folly v2.0, exhibited in Praça da República, Braga.[1]

PRODUCTION: This method develops the ETFE cushions technology. Microalgae are harvested within the outer layer of ETFE cushion. The amount of algae in each compartment (hence, the thickness of the shading layer) grows in sunny days. The pressure and fluid dynamic in the cushions allows to change their shape.

ADVANTAGES: Having the plantation on the site, the carbon footprint is reduced to the minimum; the plantation works the whole year, independently to the weather; no additional land-use is needed.

DISADVANTAGES: The technology is new and underdeveloped.

QUANTITIES: The pavilion provides nutrients and cleans the air - every day 35 g of Chlorella is harvested, 1,5 kg of CO_2 absorbed and 750 g of oxygen produced.[2]

FACILITIES: Water pump, storage space for harvested algae.

SUPPLY: Water.

1 EcoLogicStudio. (2015, May 1). Algae Folly. Retrieved 12.01.2018, from: http://www.ecologicstudio.com/v2/project.php?idcat=3&idsubcat=71&idproj=147

2 EcoLogicStudio. (2015, November 17). Algae Folly v2.0. Retrieved 12.01.2018, from: http://www.ecologicstudio.com/v2/project.php?idcat=3&idsubcat=71&idproj=148

Algae lamp
energy production

source: Thought Collider

In 2010, scientists from Yansei and Stanford University developed a method to obtain electricity from photosynthesis in algae; this technology was used by Mike Thompson to design Latro, a lamp powered by algae.[1]

PRODUCTION: 30-nanometre wide gold electrodes are inserted into chloroplasts of algae cells. The electrical current is weak but sufficient for powering low-energy lightbulb. To properly cultivate algae inside the lamp, CO_2 must be provided by breathing into the handle. The energy is stored in the battery at the bottom of the container, ready to be used any time.

ADVANTAGES: Energy produced without any pollution or by-products.

DISADVANTAGES: Algae need to be provided with a great amount of CO_2.

QUANTITIES: One day of loading provides energy for 3h of lamp operation.

FACILITIES: No extra facility is required.

SUPPLY: CO_2, water.

1 Thought Collider. (2010). Latro. Retrieved 18.03.2018, from: http://thoughtcollider.nl/project/latro

Plant

Plant (noun)
A living organism of the kind exemplified by trees, shrubs, herbs, grasses, ferns, and mosses, typically growing in a permanent site, absorbing water and inorganic substances through its roots, and synthesizing nutrients in its leaves by photosynthesis using the green pigment chlorophyll.[1]

1 Plant. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/plant

Hydroponics
food production

source: Food & Nutrition Magazine

A method of farming involving providing nutrition and water directly, without soil or any other medium (e.g. felt) to the rooots.[1]

PRODUCTION: They are several methods of hydroponics, e.g.:

Deep Water Culture (DWC) - used mostly for big-scale, lettuce farming - is based on floating, foam rafts, with holes in which plants are placed, so only the roots can be soaked.

Nutrient Film Technique (NFT) - used for plants that need some support (eg. strawberries) - plants are situated in holes made of plastic pipes, roots soaked in a stream of water inside the pipe. Useful for exploitation of unused spaces.

Vertical Hydroponics - the most efficient method. Plants are stacked into the vertical system, planted in a wicking material. Water with nutrients is pumped up and drips through the roots, directly into the fish pond. Perfect for leafy crops, without the need of an additional support.

ADVANTAGES: The technique is highly effective, and by applying water circulation system, resources can be saved.

DISADVANTAGES: The variety of crops is limited.

QUANTITIES: The exact amounts of crops varies, depending on type of plants or used method; in the Netherlands, the average reaches around 2,6 kg/m^2 per year[2]

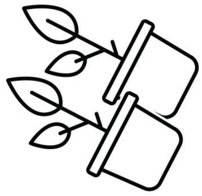
FACILITIES: Varies, depending on different method.

SUPPLY: Water, fertilizers.

1 The Aquaponics Source. (n.d.) What is aquaponics?. Retrivied 19.01.2018, from: https://www.theaquaponicsource.com/what-is-aquaponics/

2 Based on information obtained during meeting with staff of UrbanFarmers greenhouse in the Hague (11.05.2018)

Vertical farming
food production



source: NewsGram

A method of producing food by stacking the crops vertically, using Controlled Environment Agriculture (CEA) technology, that provides supervision over artificially supplied water, light, temperature, humidity or CO_2.[1]

PRODUCTION: The technique is similar to other methods of urban faming (aeroponics, hydroponics or aquaponics). The difference is in the presence of CEA technology. The crops are placed one above the other, illuminated with LED lamps.

ADVANTAGES: The production is more efficient (time-wise and space-wise), than traditional farming. Because of the strictly controlled environment, vertical farming has many possible placement solutions, also as part of a building with a different function: on the rooftop, on the elevation, inside the building, or even underground, in the basement. Therefore vertical farming could be used not only in a new design but also as an integrated retrofitting project.

DISADVANTAGES: Resulting from the need of artificial lightning and CEA technology, the system is more energy-consuming than traditional farming. Technical expertise is needed for maintaining the facility.

QUANTITIES: The exact amounts of crops varies, depending on type of plants or used method; Dutch company PlantLab claims its production around 73 kg/m2 per year[2]

FACILITIES: CEA sensors, automated watering system, heating system, LED lightning system.

SUPPLY: Water, fertilizer.

1 Vertical farm(ing) (n.d.) in Association for Vertical Farming. Retrieved 19.01.2018, from: https://vertical-farming.net/glossary-vertical-farming/#1507543882518-2356b485-609c

2 PlanLab. (n.d.) Radical New Plant Logic. Retrieved 11.05.2018, from: https://www.plantlab.nl/radical-new-plant-logic/

Green facade
insulation & cladding

source: fast.lunchrock.co

Type of vertical garden that relies only on climbing plants.[1]

PRODUCTION: Vines climbing directly on the wall (direct green facade), or on a system of supporters, like cables, metal mesh, and trellis (indirect green facade).

ADVANTAGES: Provides thermal insulation to the building, along with protection from the wind (which also influences the thermal performance), and helps to build the microclimate.

DISADVANTAGES: Long waiting time and need for an additional supporting construction.

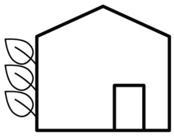
QUANTITIES: Depending on the type of plants, the greenery can reach 5, 10 or even 25 meters high; to reach superior heights or to support a wider range of vegetation, climbing boxes can be used.

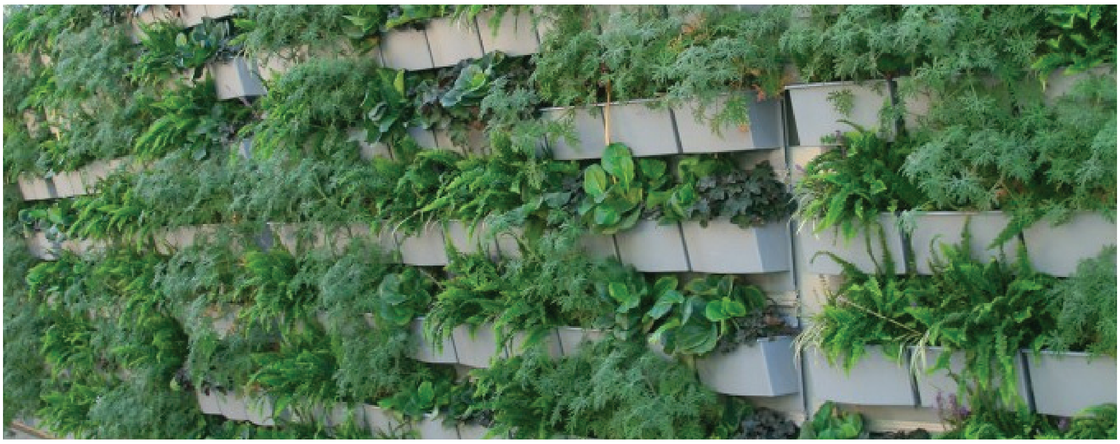
FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 Perini K, (2012). The Integration of Vegetation in Architecture, Vertical and Horizontal Greened Surfaces. International Journal of Biology Vol. 4, No. 2; April 2012

Living wall system
insulation & cladding





source: LiveWall

Type of vertical garden that provides support for non-climbing plants (eg. small evergreens)[1]

PRODUCTION: LWS is constructed with separated containers attached to the wall, each one comprehending soil (or another substrate, e.g. foam or mineral wool), with watering and nutrition system. Many systems were developed over recent years, giving more solutions and different characteristics, but two basic categories are: LWS based on planter boxes (HDPE), or constructed with several felt layers, playing as a substrate, with additional PVC sheet for waterproofing.

ADVANTAGES: This technique allows growing non-climbing plants, giving more freedom of design. Provides thermal insulation to the building, as well as protection from the wind (which also influences the thermal performance), and helps to build the microclimate.

DISADVANTAGES: The system is heavier than green facade (usually requires additional construction), necessitates of higher-maintenance and is more expensive. [2]

QUANTITIES: around 35-40 kg/m^2 (fully equipped and saturated HDPE), or 20-35 kg/m^2 (fully equipped and saturated felt LWS)[3]

FACILITIES: when the LWS cannot be watered manually, then watering system with a water pump needs to be provided.

SUPPLY: Water with balanced nutrient solutions, to provide all nourishment required.

1 Perini, K. (2012). Vertical greening systems: contribution to thermal behaviour on the building envelope and environmental sustainability, Eco-Architecture IV

2 Perini K. (2012). The Integration of Vegetation in Architecture, Vertical and Horizontal Greened Surfaces. International Journal of Biology Vol. 4, No. 2; April 2012

3 J.H.M. Wagemans. (2016). Modularity of living wall systems, TU Delft

Green roof
insulation & cladding

source: sokszinuvidek.24.hu

Roof of a building that is covered with vegetation.

PRODUCTION: Many available types could be divided into 3 categories: intensive, semi-intensive and extensive. The main difference between them is the thickness of the exterior layer - substrate, which indicates the possible option for plant growth. Intensive green roofs' substrate layer is at least 30 cm thick and can host all types of plants, including trees; it requires an irrigation system and medium maintenance. Semi-intensive roof gardens' substrate layer is usually 15-30 cm thick; it requires irrigation and periodical maintenance, allowing to plant small shrubs or lawns. Finally, the extensive (5-15 cm substrate layer thickness) allows only to grow lawns and sedum, but it is still popular, due to its low-maintenance, low-cost and lightweight.

ADVANTAGES: One of the main advantages of using this system (especially intensive and semi-intensive) is surface temperature reduction, and help with storm-water management. They can be applied not only to flat but also to inclined roofs (from 10° for even over 30° when special technical solutions are applied).[1]

DISADVANTAGES: Additional load of the green roof; extra maintenance.

QUANTITIES: 70 - 170 kg/m^2 in case of extensive roof, 290 to 970 kg/m^2 for intensive roof.[2]

FACILITIES: Irrigation system.

SUPPLY: Water with balanced nutrient solutions, to provide all nourishment required.

1 Perini K. (2012). The Integration of Vegetation in Architecture, Vertical and Horizontal Greened Surfaces. International Journal of Biology Vol. 4, No. 2; April 2012

2 Obendorfer, E. Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Kohler, M., Liu K.K.Y. and Rowe, B. (2007) Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services, BioScience, 57(10):823-833. 2007

NASA Clean Air Study Plants
cleaning & purifying

source: Wikipedia

Result of a research led by the National Aeronautics and Space Administration (NASA) in order to discover natural methods of air cleaning. The first list of air-filtering plants was published in 1989. In this research, NASA is checking the ability to neutralize three VOCs (volatile organic components) chemicals: benzene (present in inks, oils, plastic, used in the manufacture of different detergents), trichloroethylene (metal degreasing and dry-cleaning industries) and formaldehyde (consumer paper products, household cleaning agents).

PRODUCTION: Among plants that brought the most promising results, are English Evy (Hedera helix), Ficus (Ficus benjamina), Janet Craig (Dracaena deremensis "'Janet Craig"). Other plants can also influence the quality of air indoors. A study by Virginia Lohr proves that the presence of plants (especially hairy ones) has a great impact on the amount of dust.[1]

In addition, the root-soil connection was pointed out to be the most effective element of the plant in air purifying (because of root-based microbes that also take part in purifying), which should be taken into consideration during planting.[2]

ADVANTAGES: the system is low-energy and natural.

DISADVANTAGES: It is only applicable indoors.

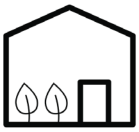
QUANTITIES: From 20% up to 90% removal in 24h cycle.

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 Lohr, V.I. et al (1996). Particulate Matter Accumulation on Horizontal Surfaces in Interiors: Influence of Foliage Plants.

2 Wolverton, B. C., et al. (1989) A study of interior landscape plants for indoor air pollution abatement: an interim report. NASA.



Plantscaping
user well-being


source: Wikipedia

A design field aimed at introducing plants into interiors. The primary goal is to enrich the tools of spatial design, but the appearance of plants indoors has a visible influence on users. [1]

PRODUCTION: Plants are introduced indoors as a part of integrated design; they can play a purely aesthetic role, but also space-orienting (e.g. as divider for different zones within a room), or for health purpose.

ADVANTAGES: Plants indoor have huge stress-reducing effects, can raise work effectiveness and contentment of the room perception.

DISADVANTAGES: The plants need to be maintained, and require certain light condition (depending on species).

QUANTITIES: No specific quantity apllied.

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 Andrew Smith, Matthew Tucker and Michael Pitt (2010) Healthy, productive workplaces: towards a case for interior plantscaping. School of the Built Environment, Liverpool John Moores University, Liverpool, UK

Constructed wetland (CW)
cleaning & purifying


source: Wikipedia

An artificial system constructed to utilize the abilities of wetland vegetation (macrophyte plants) and microbial population to sanitize water. The classification of CW depends mostly on the flow regime (surface or subsurface flow), type of plants used (submerged, free-floating or floating-leveled) and filtering material (sand or gravel). [1]

PRODUCTION: Wastewater (or gray water) is pumped into a system of pipes, distributed evenly over a flat surface, buried in sand or gravel, where cleaning plants are planted, providing conditions for microbial growth. Treated water falls to the bottom, where it is collected in separated piping system.

ADVANTAGES: This technology is low-tech, low-maintenance, and may not include open air water, which could attract mosquitoes.

DISADVANTAGES: The main drawback of the technique is the great area needed; subsurface CW could be used as a part of the green roof garden, although this method is relatively new and still has multiple problems.

QUANTITIES: Area needed for constructed wetlands varies, depending on used type of water flow, as well as the annual average temperature, between 1,2 - 3 m^2/p.e. (in warmer climate) and 4-8 m^2/p.e. (in moderate climate).

FACILITIES: Necessary, basic (or preferable) conditions to design CW are: full sunlight situation, climate with longer freezing periods is preferable, plants adapted to grow partially submerged, flat and horizontal surface. The cleaning field should be secured with water-resistant membrane.

Before introducing water to the system, it should be preliminary cleaned from solid waste (e.g. septic tank or mechanical grids).

SUPPLY: No extra supply is required.

1 Hoffmann, H., Platzer, C., von Münch, E., Winker, M. (2011). Technology review of constructed wetlands - Subsurface flow constructed wetlands for greywater and domestic wastewater treatment. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, Germany

Living Machine System
cleaning & purifying

source: Wikipedia

A water treatment system, concluded with set of tanks hosting wetland plants, microorganisms and small animals (eg. snails or insects).[1]

PRODUCTION: They are two main types of LMS: Tidal Flow Wetland and Hydroponic.

The first one, Tidal Flow Wetland, contains several ponds with plants that are periodically flooded and drained (hence the name). The micro-ecosystem within each 'cell', composed of wetland plants and bacteria living in the roots, removes solids and nutrient. The last stage is filtration and disinfection, providing clean and safe water. The whole cycle is invisible to the observer; ponds could be installed outdoors, as well as inside the building.

The second one, Hydroponics, can be located only indoors (in a building or a greenhouse). In this one, the wetland ponds are filled with textile material, and the air is provided through bubble diffusers. This method provides conditions for the microbial population to grow, as well as beneficial insects and other organisms. [2 3]

ADVANTAGES: Water is purified with low-energy cost, without any pollution, chemicals or by-products.

DISADVANTAGES: The system needs a considerable amount of space, usually indoors.

QUANTITIES: 1m^2 has capacity to clean around 250l of wastewater.

FACILITIES: Before introducing water to the system, it should be preliminary cleaned from solid waste (by anaerobic reactor, anoxic reactor and/or closed aerobic reactor), and additionally after the treatment, by clarifier (additional tank for separating remaining solids from the water).

SUPPLY: No extra supply is required.

1 Living Machine (n.d.) Living Machine® Technology. Rietrived 15.01.2018, from:: http://www.livingmachines.com/About-Living-Machine.aspx

2 Living Machine (n.d.) Tidal Flow Wetland Living Machine System. Rietrived 15.01.2018, from:: http://www.livingmachines.com/About-Living-Machine/Tidal-Flow-Wetland-Living-Machine-System.aspx

3 Living Machine (n.d.) Hydroponic Living Machine System. Rietrived 15.01.2018, from:: http://www.livingmachines.com/About-Living-Machine/Hydroponic-Living-Machine-System.aspx

Photosynthesis lamp

energy production

source: TreeHugger

Concept of generating electricity from living plants, by Plant Microbal Fuel Cell, designed by Marjolein Helder from Wageningen University.
Another product that exploits the same technology is a modular wall system designed by IaaC student Elena Mitrofanova and biochemist Paolo Bombelli. The system contains hollow 'bricks' of moss planted inside. The designers believe that this solution could be used on walls with exposure not sunny enough to install PV panels.[1] [2]

PRODUCTION: The technology is based on the observation that a great part of the matter produced by plants during the process of photosynthesis is excreted into the soil through the roots, where it is broken by bacteria. Electrons released in that process could be captured by cathode and used for lighting a LED lamp.[3]

ADVANTAGES: Provided in this way, energy is clean and without any pollution or by-products.

DISADVANTAGES: Even if the technology is already available on the market, the final product produces a small amount of energy.

QUANTITIES: One Unit of Mitrofanova panels is giving 0,4 – 0,5 Volts. $2m^2$ is needed for one LED light bulb. [4]

FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 Dezeen. (2017, November 15). Living Light is an off-grid lamp powered by photosynthesis. Retrieved 07.01.2018, from: https://www.dezeen.com/2017/11/15/living-light-ermi-van-oers-microbial-energy-photosynthesis-lighing-lamp-good-design-bad-world-dutch-design-week/

2 Elena Mitro (n.d.) Moss Voltaics. Rietrieved 26.01.2018 from: http://elenamitro.com/my-product/moss-voltaics/

3 E-plant (n.d.) Information. Retrieved 07.01.2018, from: http://www.plant-e.com/en/plant-e-technology/

4 Elena Mitro (n.d.) Moss Voltaics. Rietrieved 26.01.2018 from: http://elenamitro.com/my-product/moss-voltaics/

Sound diminishing plants
indoor environment

source: Wikipedia

Plants can be used indoors as soft and open material to shorten reverberation time and absorb noise. Houseplants as Ficus benjamina or Kentiapalm can have a positive influence on noise control. Furthermore, green wall systems are considered useful in sound diminishing, although the performance depends on many aspects, e.g. type of vegetation or thickness of substrate.[1]

PRODUCTION: Indoor, plants with big leaves lead to the best result, preferably evenly distributed around the room in small groups. The best effect is achieved in small, rectangular and regular rooms.

Outdoor, green facades, green roofs, but also tree belts and other vegetation barriers can be implemented.

ADVANTAGES: Low-energy, natural system.

DISADVANTAGES: There is no clear list of plants with best performance, due of the large differences between individual plants.

QUANTITIES: Green facades can diminish the noise up to 10 dB. Outdoor barriers (eg. tree belts) can reduce noise levels between 5dB and 15 dB[2], hence indoor living walls - 15 dB.[3]

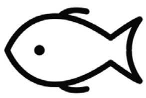
FACILITIES: No extra facility is required.

SUPPLY: No extra supply is required.

1 Ruben Smits (2012), *Designing with plants.* TU Delft

2 Arup Deutschland GmbH (2016). Cities Alive. Green Building Envelope. page 15

3 Azkorra, Zaloa & Pérez, G & Coma, Julià & Cabeza, Luisa F. & Burés, Silvia & Álvaro, Juan E. & Erkoreka, A & Urrestarazu, Miguel. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. Applied Acoustics. 89. 46-56. 10.1016/j.apacoust.2014.09.010.



Fish

Fish (noun)

A limbless cold-blooded vertebrate animal with gills and fins living wholly in water.[1]

1 Fish. (n.d.) In Oxford Living Dictionaries. Retrieved 13.02.2018, from https://en.oxforddictionaries.com/definition/fish

Aquaponics
food production

source: Wikipedia

A method of farming where water-based plants are introduced into the same ecosystem with fish and microbes. The system is based on the following cycle: waste from fish production (ammonia) is converted by microbes into nitrates, fertilizing the plants. Then, solid fish waste is used as a compost. Plants are used for filtering water for fish.[1]

PRODUCTION: The water from the containers in which the fish are raised is collected daily, and then (after separating solids and examining whether the amount of nutrients is sufficient) it is pumped into the plant watering system. Depending on the type of plants grown, an additional fertilizer (10% to 30%) must still be added to the water. After watering, the water is collected again, and after another test, pumped back into fish containers.

ADVANTAGES: Chemical fertilizers are redundant.

DISADVANTAGES: The system must be strictly controlled, including temperature, humidity and amounts of nutrients in the circulating water.

QUANTITIES: By keeping that water-nutrition cycle closed, aquaponics uses only 1/10 of water in comparison to traditional soil-based farming. Fish harvest: 3,8 kg/m^2 per year.

FACILITIES: Fish tanks, equipment controlling and pumping water between tanks and hydroponics (if applicable), hydroponics.

SUPPLY: fodder for fish (1,2 kg for every 1 kg produced), fry, seeds.

1 Based on information obtained during meeting with staff of UrbanFarmers greenhouse in the Hague (11.05.2018)

Appendix
Matrices

	bacteria		fungus			
	Bacteria-grown bricks	Self-healing concrete	Mycelium-grown brick	Mycelium building frameworks	Mycelium thermal insulation	Mycelium sound insulation
building materials & construction	●	●	●	●		
insulation & cladding	○	○	○		●	
energy production						
indoor environment						●
food production						
cleaning & purifing						
user well-being						

	tree					alga		
	Tree-shaping	Baubotanik	Tree shading and cooling	Tree water management	Tree pollution reduction	Algae lamp	Algae elevation panels	Algae in ETFE cushions
building materials & construction	●	●						
insulation & cladding								●
energy production						●		○
indoor environment	○	○	●				●	○
food production	○	○	○	○	○			○
cleaning & purifing				●	●			○
user well-being	○	○	○	○	○			

	plant												fish
	Green roof	Living wall system	Green facade	Plantscaping	Hydroponics	Aeroponics	Photosynthesis lamp	NASA Clean Air Study Plants	Living Machine System	Sound diminishing	Vertical farming	Constructed wetland	Aquaponics
building materials & construction													
insulation & cladding	●	●	●										
energy production							●						
indoor environment								●		●			
food production	○	○			●	●					●		●
cleaning & purifing									●			●	○
user well-being				●				○					

Matrix A

Possible application in architecture

	bacteria		fungus				tree					alga			plant												fish
	Bacteria-grown bricks	Self-healing concrete	Mycelium-grown brick	Mycelium building frameworks	Mycelium thermal insulation	Mycelium sound insulation	Tree-shaping	Baubotanik	Tree shading and cooling	Tree water management	Tree pollution reduction	Algae lamp	Algae elevation panels	Algae in ETFE cushions	Green roof	Living wall system	Green facade	Plantscaping	Hydroponics	Aeroponics	Photosynthesis lamp	NASA Clean Air Study Plants	Living Machine System	Sound diminishing	Vertical farming	Constructed wetland	Aquaponics
user well-being							●	●	●	●	●				●	●	●	●	○	○	○	●	●	●		○	○
aesthetic quality	○						●	●	●	●	●	○			●	●	●	●	○	○	●	●	●	●	○	○	○
air quality							●	●	●	●		●	●	●	●	●	●	●	○	○	○	●	○	○	○	○	○
low carbon footprint	●		●	●	●	●	●	●	●	●	●	●	●	●					●	●	●	●	●	●	○	●	●
urban heat reduction							●	●	●	●	●				●	●	●							○	●	●	
acoustics							○	○	○	○	○				●	●	●	●				●	○	●			
biodiversity							●	●	●	●	●				●	●	●	●								●	
circularity	●		●	●	●	●	●	●	●	●	●	○	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●
thermal insulation															●	●	●										
natural materials	●		●	●	●	●	●	●	●	●	●		○	○	○	○	●	●	○	○	●	●	○	●	●	●	○
low energy production	●		●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●		●	●
low maintenance		●					●	●	●	●	●				○		●	○			●	●	○	●		●	

Matrix B

Benefits

	bacteria		fungus				tree					alga			plant												fish
	Bacteria-grown bricks	Self-healing concrete	Mycelium-grown brick	Mycelium building frameworks	Mycelium thermal insulation	Mycelium sound insulation	Tree-shaping	Baubotanik	Tree shading and cooling	Tree water management	Tree pollution reduction	Algae lamp	Algae elevation panels	Algae in ETFE cushions	Green roof	Living wall system	Green facade	Plantscaping	Hydroponics	Aeroponics	Photosynthesis lamp	NASA Clean Air Study Plants	Living Machine System	Sound diminishing	Vertical farming	Constructed wetland	Aquaponics
instant															●	●		●						●			
hours										●													●				
a day												●									●	●					
1-5 days	●												●	●												●	
~2-3 weeks		●	●	●	●	●																					
months																			●	●					●		●
1-5 years																											
5-10 years											●						●										
more than 10 years							●	●	●																		

Matrix C

Time needed for the technique to be applied

Group	Technology	Very well-known	well-known	partially developed	underdeveloped	very underdeveloped
bacteria	Bacteria-grown bricks			●		
	Self-healing concrete					●
fungus	Mycelium-grown brick					●
	Mycelium building frameworks					●
	Mycelium thermal insulation					●
	Mycelium sound insulation			●		
tree	Tree-shaping		●			
	Baubotanik			●		
	Tree shading and cooling	●				
	Tree water management	●				
	Tree pollution reduction	●				
alga	Algae lamp				●	
	Algae elevation panels				●	
	Algae in ETFE cushions					●
plant	Green roof		●			
	Living wall system		●			
	Green facade	●				
	Plantscaping	●				
	Hydroponics		●			
	Aeroponics		●			
	Photosynthesis lamp					●
	NASA Clean Air Study Plants		●			
	Living Machine System			●		
	Sound diminishing	●				
	Vertical farming		●			
	Constructed wetland		●			
fish	Aquaponics		●			

Matrix D

Level of development

		indoor	indoor/outdoor	outdoor
bacteria	Bacteria-grown bricks	●		
	Self-healing concrete		●	
fungus	Mycelium-grown brick	●		
	Mycelium building frameworks	●		
	Mycelium thermal insulation	●		
	Mycelium sound insulation	●		
tree	Tree-shaping			●
	Baubotanik			●
	Tree shading and cooling			●
	Tree water management			●
	Tree pollution reduction			●
alga	Algae lamp		●	
	Algae elevation panels			●
	Algae in ETFE cushions			●
plant	Green roof			●
	Living wall system		●	
	Green facade		●	
	Plantscaping	●		
	Hydroponics	●		
	Aeroponics	●		
	Photosynthesis lamp		●	
	NASA Clean Air Study Plants	●		
	Living Machine System	●		
	Sound diminishing		●	
	Vertical farming	●		
	Constructed wetland			●
fish	Aquaponics	●		

Matrix E

Indoor/outdoor application

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