From *anthropos* to *bios*: A new material paradigm

Experimenting the biological growth of
fungal mycelium composites on architectural scales

MASTER-/DIPLOMARBEIT

Vom Anthropos zum Bios: Ein neues Material Paradigma From Anthropos to Bios: A New Material Paradigm

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Manfred Berthold
Prof Arch DI Dr
Assisted by
Karl Deix
Ass.Prof. Dipl.-Ing. Dr. techn.

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Experimentieren mit dem biologischen Wachstum von Pilzmyzel-Kompositen in architektonischen Maßstäben

Experimenting the biological growth of fungal mycelium composites on architectural scales

Ludovica Breitfeld
[redacted]
Ceren Görgün
[redacted]
A 1040 Wien
Karlsgasse 13/1

[redacted]

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contents

Note to the readers:
To improve the readibility, this thesis has been conducted by two students. Each respective texts will be indicated by their initials: **Ludovica (L)** and **Ceren (C).**
Given the nature of their work, the structure of the thesis is comparted into two parts, **theory (I)** and **experiment (II).**

abstract

This Diploma Thesis is an applied research translated into a (1:1) design and build explorative pavilion that involves the experimentation of bio-cultivated fungal-mycelium composite materials. Underlying this, lies the need to shed light on today's construction industry use and depletion of materials and to propose a model of resilient and adaptive architecture in view of the current climate and resource crisis. How can one of the most impactful industries switch from an anthropocentric modus operandi to a more aware and resourceful cooperation with other species? Can the knowledge on new materials and construction methods expand and set itself on the future economic system? Considering current emission targets and climate mitigation actions, the practice of business as usual on material depletion and production is not promoting a closed loop system - whose goal is to produce goods and services sustainably, limiting consumption and waste of resources (raw materials, water and energy). Our century is on the other hand advancing in technological improvements, which can have an impactful role in the experimentation of emerging materials and construction methods for future global demands. Bio-based materials are successfully making their way as a prolific area of research in different sectors. Among them, fungal-mycelium composite materials are a recently implemented technology that fulfills the concept of such a circular economic system prospecting to minimize - or even avoid - emissions and waste. Mycelium is the complex root-like structure of the fungus, when bound together to organic substrates, living fungal mycelium becomes an active natural adhesive source. The composite made of fungal mycelium and the organic substrate is emission-free, non-toxic, low cost, and fully recyclable. Upon that, mycelium has proven to be an excellent material when it comes to insulating, acoustic absorbent, fire-retardant and water-repellant characteristics. Given the critical urgency of climate change, architecture must provide visionary solutions to the questions of over-consumption and sustainability. How can new forms emerge and new materials explored? In synthesis, this applied research explores the symbiotic relationship between architecture and nature, in order to investigate the relation between design and biology.
Can new materials contribute to an innovative, adaptive and sustainable built environment, and can the interaction between humans and the built environment become more sensorial, inspirational and engaging? A biomimetic approach is the catalyst of this Diploma, and to prove firsthand the nature of this material, the qualitative part of the research includes experimentation conducted during a time-span in the University laboratory. The journey from the bio-cultivation of a series of mycelium bricks, observations and empirical experiments to the digital and physical (preliminary and executive) prototyping of the 1:1 scale pure mycelium pavilion is provided through a lab-journaling method. By intersecting the microbiological scale of materials to the macro of architectural production, this thesis seeks to propose new trajectories for current agendas and future of design practices, where the role of the designer is not the one of the form-giver but rather replaced by the material enabler.

einleitung

Bei dieser Diplomarbeit handelt es sich um eine angewandte Forschung, die in einen (1:1) Design und Build eines explorativen Pavillons umgesetzt wird, bei dem mit biologisch kultivierten Pilz-Myzel-Verbundwerkstoffen experimentiert wird.
Dahinter steht das Bedürfnis, den heutigen Materialverbrauch im Bauwesen zu beleuchten und angesichts der aktuellen Klima- und Ressourcenkrise ein Modell für eine widerstandsfähige und anpassungsfähige Architektur vorzuschlagen. Wie kann einer der einflussreichsten Industriezweige von einem anthropozentrischen Modus Operandi zu einer bewussteren und ressourcenschonenden Zusammenarbeit mit anderen Lebensformen übergehen? Kann sich das Wissen über neue Materialien und Bauweisen erweitern und auf das zukünftige Wirtschaftssystem ausrichten? In Anbetracht der aktuellen Emissionsziele und Klimaschutzmaßnahmen fördert die Praxis des "business as usual" in Bezug auf Materialabbau und Produktion kein geschlossenes Kreislaufsystem, dessen Ziel es ist, Waren und Dienstleistungen nachhaltig zu produzieren und den Verbrauch und die Verschwendung von Ressourcen (Rohstoffe, Wasser und Energie) zu begrenzen. Andererseits macht unser Jahrhundert Fortschritte bei den technologischen Verbesserungen, die eine wichtige Rolle bei der Erprobung neuer Materialien und Baumethoden für den künftigen globalen Bedarf spielen können.
Biobasierte Werkstoffe sind in verschiedenen Sektoren erfolgreich auf dem Vormarsch und stellen einen wichtigen Forschungsbereich dar. Darunter sind Pilz-Myzel-Verbundwerkstoffe eine kürzlich eingeführte Technologie, die dem Konzept eines solchen Kreislaufwirtschafts Systems entspricht, das darauf abzielt, Emissionen und Abfälle zu minimieren oder sogar zu vermeiden. Myzel ist die komplexe wurzelartige Struktur des Pilzes, die, wenn sie mit organischen Substraten verbunden ist, zu einer aktiven natürlichen Klebstoff Quelle wird. Der Verbundstoff aus Pilzmyzel und organischem Substrat ist emissionsfrei, ungiftig, kostengünstig und vollständig recycelbar. Darüber hinaus hat sich Mycelium als hervorragendes Material erwiesen, wenn es um isolierende, schallabsorbierende, feuerhemmende und wasserabweisende Eigenschaften geht. Angesichts der Dringlichkeit des Klimawandels muss die Architektur visionäre Lösungen für die Fragen des übermäßigen Verbrauchs und der Nachhaltigkeit bieten. Wie können neue Formen entstehen und neue Materialien erforscht werden? Im Rahmen dieser angewandten Forschung wird die symbiotische Beziehung zwischen Architektur und Natur untersucht, um die Beziehung zwischen Design und Biologie zu erforschen. Können neue Materialien zu einer innovativen, anpassungsfähigen und nachhaltigen gebauten Umwelt beitragen, und kann die Beziehung zwischen Mensch und gebauter Umwelt sinnlicher, bewusster und ansprechender werden? Ein biomimetischer Ansatz ist der Katalysator dieses Diploms, und um die Beschaffenheit dieses Materials aus erster Hand zu prüfen, umfasst der qualitative Teil der Forschung Experimente, die während eines bestimmten Zeitraums im Labor der Universität durchgeführt wurden. Der Weg von der Bio Kultivierung einer Reihe von Myzelziegeln, Beobachtungen und empirischen Experimenten bis zum digitalen und physischen (vorläufigen und ausführenden) em-

pirischen Experimenten bis zum digitalen und physischen (vorläufigen und ausführenden) Prototyping des reinen Myzel Pavillons im Maßstab 1:1 wird durch eine Labor Journaling-Methode dargestellt. Durch die Verknüpfung der mikrobiologischen Maßstab von Materialien mit der Makroebene der architektonischen Produktion versucht diese Arbeit, neue Wege für die aktuelle Agenda und die Zukunft von Designpraxis vorzuschlagen, bei denen die Rolle des Designers nicht die des Formgebers ist, sondern vielmehr durch die des Materialermöglichers ersetzt wird.

I

introduction

> ***"In order to change an existing paradigm you do not struggle to try and change the problematic model. You create a new model and make the old one obsolete"***
> ***R. Buckminster Fuller***

We should stress that this diploma does not seek to directly solve the complexity of both global and environmental crises we are today facing, which might feel irreversible now.
It is rather an attempt to point out that we, future architects and practitioners, have to rethink what solving means and which are the necessary tools to trigger such reaction.

The nature of Ludovica and Ceren´s work combines theory and practice, similar to what was promoted in 1919 by the Bauhaus academy as a new radical pedagogical system.
Similarly to the Curricular structure[1] that the University proposed, the interest of the two students involves exploring new ideas through a holistic experimental approach.
Focusing on the intersection of biology, computation, and design, the two diplomands try to articulate three frameworks for harnessing living organisms for architecture: bio-processing, bio-sensing, and bio-manufacturing. It is therefore fitting to mention that the essence of this applied research, is intended to be a tool for experimentation on different scales, from the micro- to the macroscopic; from the biological lens of cells up to the physical dimension of architecture.
As architects, we have the responsibility to contribute to a new form of design that is nurtured by the complexities and challenges of modern times, making use of cross-disciplinary methodologies.
Combining design experimentation with scientific methods, we are seeking new modes of simulation and production and by exploring how advances in the fields of biology, material science, and digital fabrication are changing the future of design practices. Highly inspired by Prof. Oxman´s theories developed in her MIT Media Lab, the Israeli-American designer states that "biology plays a central role today and it goes beyond being a simple environmental regulator, model or inspiration; biology is in itself the medium of a multi-layered design approach that is materially and socially integrated[2]."
In her essay "Age of Entanglement" Prof. Oxman, proposes a map for four domains of creative exploration: Science, Engineering, Design, and Art, similar to what Bauhaus did with the different disciplines' interaction. Oxman attempts to represent the antidisciplinary hypothesis by stating that "knowledge can no longer be ascribed to, or produced within disciplinary boundaries, but is entirely entangled."

1 Gropius's 1919 manifesto had proposed a radical vision for a new institution that would erode distinctions between artists and artisans, it was the school's unprecedented pedagogy, represented in the circular curricular diagram.
Maristella Casciato, Gary Fox, and Katherine Rochester, "Principles and Curriculum," Bauhaus: Building the New Artist, June 10, 2019, https://www.getty.edu/research/exhibitions_events/exhibitions/bauhaus/new_artist/history/principles_curriculum/.

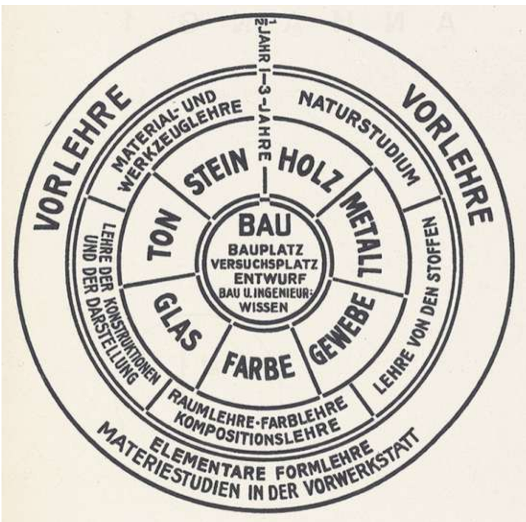
2 *Neri Oxman, "Age of Entanglement," Journal of Design and Science, January 13, 2016, https://doi.org/10.21428/7e0583ad.*

3 The Krebs cycle is a closed-loop set of reactions in eight steps: The two-carbon acetyl CoA is combined with a four-carbon oxaloacetic acid and hydrolyzed to produce a six-carbon compound called citric acid or citrate. *"Krebs Cycle Overview," News-Medical.net, September 6, 2017, https://www.news-medical.net/life-sciences/Krebs-Cycle-Overview.aspx#:~:text=The%20Krebs%20cycle%20is%20a.*

4 *Neri Oxman, "Age of Entanglement," Journal of Design and Science, January 13, 2016, https://doi.org/10.21428/7e0583ad.*

The goal is to establish a tentative, yet holistic cartography of the interrelation between these domains, where one realm can incite (r)evolution inside another; and where a single individual or project can reside in multiple domains.
Mostly, this is an invitation to question and to amend what is being proposed". To the conventional Krebs Cycle´s carbon compounds[3], she replaces its content with the domains she believes are the fundamentals of knowledge "To each plot, a designated mission: to Science, exploration; to Engineering, invention; to Design, communication; to Art, expression (…) Each of the modalities (or 'compounds') produces 'currency' by transforming into another: the role of Science is to explain and predict the world around us; it 'converts' information into knowledge. The role of Engineering is to apply scientific knowledge to the development of solutions for empirical problems; it 'converts' knowledge into utility. The role of Design is to produce embodiments of solutions that maximize function and augment human experience; it 'converts' utility into behavior. The role of Art is to question human behavior and create awareness of the world around us; it 'converts' behavior into new perceptions of information, representing the data that initiated the KCC in Science (…) Some content is generated, other content is consumed, some are released and new content is formed[4]". By stating this, we wanted to get inspired by this anti-disciplinary approach to conducting our thesis. The search for a deeper understanding of the symbiotic relationship between architecture and nature, by establishing a framework through which architecture might successfully translate nature's wisdom into compelling design applications.

"it is a sine qua non worth spinning"
Oxman



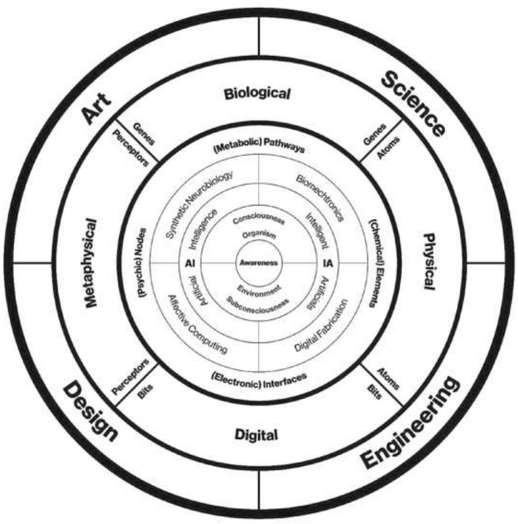


Fig.1 Diagram of the Bauhaus curriculum, Walter Gropius, 1922. Lithograph. 20.2 x 29.3 cm.

Fig.2 Krebs Cycle of Creativity III, Neri Oxman, 2020

a question of polarities

"That matter is secondary to shape constitutes the fallacy of design after craft. By nature, and in its rite, the material practice of craft is informed by matter, its method of fabrication, and by the environment"
Gottfried Semper

Fig. 3&4 Visconti Luigi, White silence, Excavators, Tavolini II, Carrara, Italy 2015

form/matter

If we epitomize the history of architecture, the design and production of the built environment have long been biased by the strict separation of form from matter - predicate and subordinate.
This chapter represents a brief introduction of form, told from the perspective of its predicate, the material.
Parallel to this, a focus is dedicated to the complex, and yet often unbalanced human-nature relationship, which can be interpreted as a possible catalyser of such polarity.
The ongoing tendency of positioning form over material in the traditional architecture practice, can be illustrated in a simple way when, in tender packages, form is illustrated in drawings while materials in mere words. Unlike craftsmanship, which prioritized, or better said, organically intertwined material and form, architectural design history has been characterized by a drastic division between form and matter and further distance form-finding as a process independent of its sources in material knowledge[5].
The debate between material and form and its consequently disconnection, can be found already in the Roman times, when in his book *De Architectura,* Vitruvius prioritized the form-finding process as the fundamentals of architecture invention, whereas materials had the responsibility of form´s consequence[6]. Materials used to be closed due to their structural performances or due to its accessibility. The same spirit continued during the Renaissance, where materiality gained importance for its aesthetic qualities.
"At least since the Renaissance, with the emergence of architectural theories, form generation has become somewhat of a self-directed and autonomous body of knowledge[7]."
It can be said that the past sublimation of form-finding became a norm for the subsequent contemporary architecture and design practices.
"With the exception of a few pioneering cases in contemporary design, the secularization and debasement of the material realm has become axiomatic. Materiality has become, within the logic of the modernist tradition, an agency secondary to form[ibid]". A turning point was marked with the first industrial revolution, when the relationship between form and matter was questioned by the introduction of material innovations. Steel, glass and cement were leaders in machine-based manufacturing and mass production. The creation of form had to follow the pace of powerful automatised industries.
This notion of materials new status as form giver was reinforced by the developments in architecture at the time in the shape of delicate iron-and glass creations where materials set the boundaries of form[8]. A countercultural promoter of the time was Gottfried Semper, who recognized the value of the material itself, and how each material had its appropriate form. In contrast to that, the materialism promoted by Adolf Loos and Frank Lloyd Wright attributed to matter a purely formal language.

5 *Katherine Lloyd Thomas, Material Matters : Architecture and Material Practice (London: Routledge, 2007).*

6 *Vitruvio Pollione, De Architectura, Libri X : Testo Latino a Fronte (Pordenone: Studio Tesi, Cop, 2008).*

7 *Neri Oxman, "Material Ecology," in MIT Media Edu (Material Ecology, MIT Press, 2010).*

8 *Simone Jeska, Transparent Plastics : Design and Technology (Basel ; Boston: Birkhäuser, 2008).*

Eventually, this non-material approach to design and construction automation would grow stronger under the command of computer-aided design and engineering[9].
The Digital Revolution, which marked the shift from analog to digital technology, has transformed the designer's drafting board into a digital canvas. Form, it seemed, was now divorced completely from the physical reality of its manifestation. This new design space afforded much liberation in formal expression, but it has also broadened the gap between form and matter, and made the hierarchical and sequential separation of modeling, analysis and fabrication processes infinitely more pronounced. The implementation and broad absorption of enhanced computational design tools in architectural practice has, since the early nineties, motivated a renaissance of the formalist project in architecture; geometrically complex shapes became emblems of creativity in digital design environments and supported the design mastery of complex geometries in form-generation. This formal and geometric design orientation has also addressed "free form" design and architecture along with their enabling technologies as part of the larger design phenomenon of "non-standard" form[10].
One can now question if industrialisation, modernisation and globalisation has been the biggest cataylzer when it comes to the form and matter controversy.
As Susannah Hagan states in "Material Matter", the industrialisation saw the "new" as a novelty[11].
This novelty was running at the same pace of the steam train. Notions of everlasting, resurrecting, never decaying and never-ending were the core of Modernism thinking. The "new" reality had to be complete and permanently in flux. A great example to that can be applied to the Modernism urban developments, where renewal was replaced by the so-called ***tabula rasa***.
Socio-economical developments further enhanced the notion of materials as subsequent to form. Technological advancements within material production together with the optimisation of logistics, infrastructures and trading, saw materials no longer connected to the vernacular.
This development created an illusion of endless resources[12].

9 *Charles Jencks, The Language of Post-Modern Architecture, Revised Enlarged Edition. (S.L.: Rizzoli, 1977).*

10 *Neri Oxman, "Material Ecology," in MIT Media Edu (Material Ecology, MIT Press, 2010).*

11 *Susannah Hagan, "The Good, the Bad and the Juggled: The New Ethics of Building Materials," The Journal of Architecture 3, no. 2 (January 1998): 107–15, https://doi.org/10.1080/136023698374224.*

12 *Gail Peter Borden and Michael Meredith, Matter : Material Processes in Architectural Production (New York: Routledge, 2012).*

Fig 5 Richard Serra, "Inverted",
New York, 2019

man/nature

> ***"we do not seek to imitate nature, but rather to find the principles it uses"***
> ***R. Buckminster Fuller***

Without going into too much detail about the relationship between man and nature in general, it is incumbent upon us to compendize some of the aspects that have characterized some of the most prominent architectural movements of recent centuries, to gain a better understanding on what lead architecture, becoming one of today´s prominent actors when it comes to environmental challenges.
The purpose of this chapter is therefore to, first of all clarify some cultural tendencies as well as to shed light on how we arrive at a concept of ecology in architecture when the architect used nature as a matter for designing.
For a long time, nature has been a source of inspiration for architecture. From the East to the West, its coexistence changed and evolved. From our ancestors´ need to claim territorial boundaries, nature has been a source of shelter, survival, means of development and at times even of pleasure. Man adapted itself to its natural environment, finding strategic solutions to build around nature and to protect himself from it or taking advantage of its resources.
It came at a time where nature became also essential for circumscribing rules, criteria and principles. And when humans studied the natural forms and the human body, abstracting them as geometry.
The similar set of rules can be found in the exemplary *Codex on the Flight of Birds*. 450 years ago, Da Vinci studied and published this branch of science, by observing the creation and to derive knowledge from it that could be later used in an innovative way.

> ***"The journey from prehistory to baroque is that of evolution and adoption. Man learned from nature, modified it, and beautified it. During prehistoric times, he was an amateur, his conditions led to some landscaping. However, as he evolved he learnt more about it and developed it further. The baroque style shows class and wealth. However, the ones in between show the evolution of man's relationship with nature. The relationship of man with nature is varying and complex[13]".***

An iconic example when architecture embodies nature notions is Antoni Gauidi´s development of his unique style, challenging the limits of Art Nouveau by combining neo-gothic elements. The most prominent example to it is the Sagrada Familia (1882) church in Barcelona, which contains many architectural elements inspired by the forces of nature, such as the branching columns imitating trees.

13 *Mithila Nimbalkar, "Relationship between Man and Nature," RTF | Rethinking The Future, July 9, 2021, https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a4529-relationship-between-man-and-nature/.*

14 *Louis H. Sullivan, "The Tall Office Building Artistically Considered" (Essay, 1896), https://www.pca-stream.com/en/articles/the-tall-office-building-artistically-considered-48.*

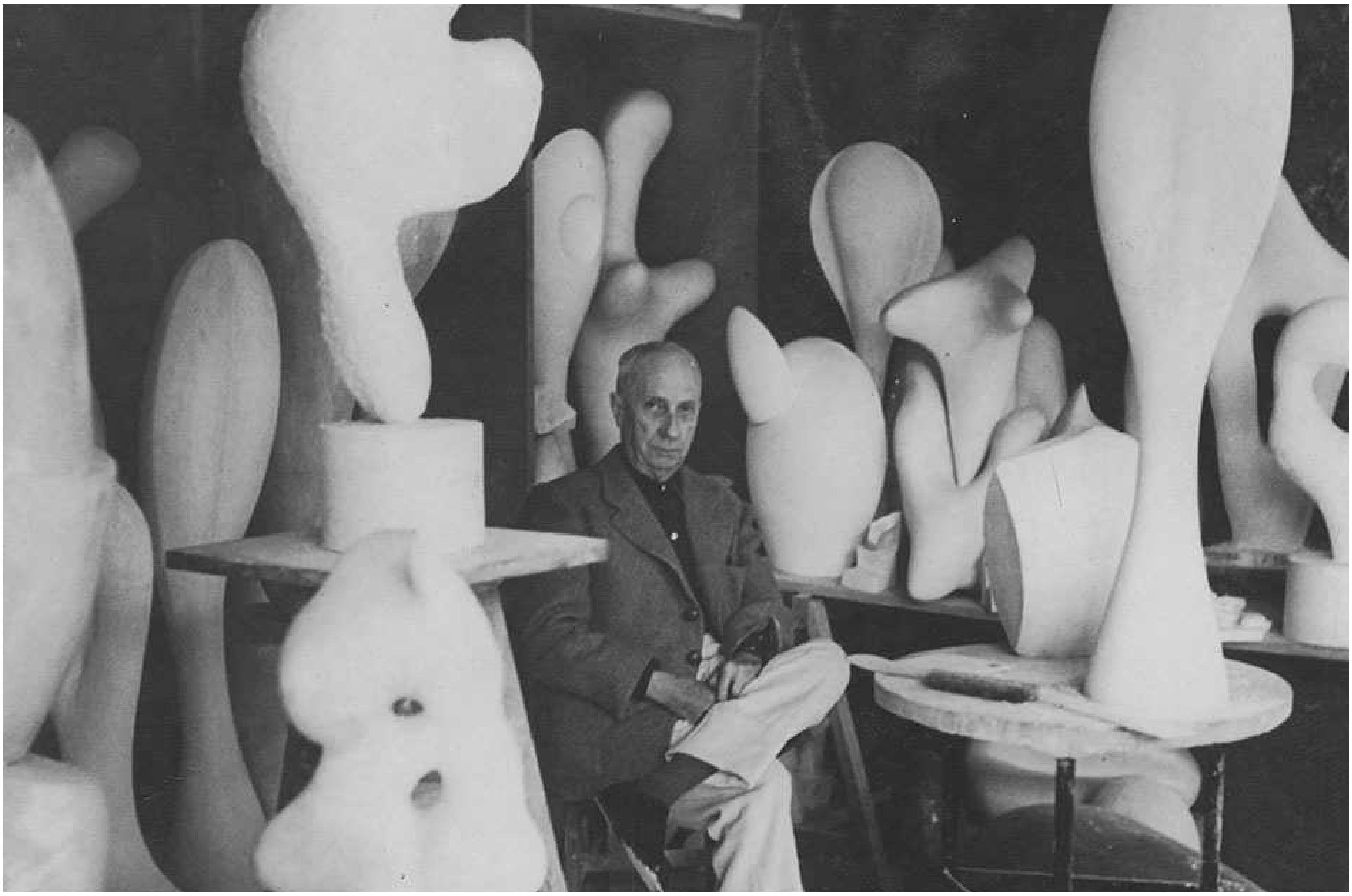
15 *Oliver Botar, "Biomorphism - Routledge Encyclopedia of Modernism," www.rem.routledge.com, 2016, https://www.rem.routledge.com/articles/biomorphism.*

In 1896, Louis Sullivan, pioneer of the organic architecture movement, states in one of his essays that "All things in nature have a shape, that is to say, a form, an outward semblance, that tells us what they are, that distinguishes them from ourselves and from each other. Unfailingly in nature these shapes express the inner life, the native quality, of the animal, tree, bird, fish, that they present to us; they are so characteristic, so recognizable, that we say simply, it is natural it should be so. […] Whether it be the sweeping eagle in his flight or the open apple-blossom, the toiling work-horse, the blithe swan, the branching oak, the winding stream at its base, the drifting clouds, over all the coursing sun, form ever follows function, and this is the law. Where function does not change form does not change. The granite rocks, the ever-brooding hills, remain for ages; the lightning lives, comes into shape, and dies in a twinkling. It is the pervading law of all things organic, and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of the head, of the heart, of the soul, that the life is recognizable in its expression, that form ever follows function. This is the law[14]". The real nature of each problem, therefore, contains and suggests the solution. A few years later Sullivan's famous phrase "form ever follows function" was reiterated by Ludwig Mies van der Rohe in the sharper version: "form is function[14]".

Those same tendencies of elevating nature were essential for the rise of the concept of "Biomorphism", when in 1935 Geoffrey Grigson used the term to refer to Henry Moore's sculptures[15].

In architecture, Biomorphism refers to a building inscribed in nature, its external appearance arises from its internal content and the rejection of the traditional laws of form.

Fig. 6 Jean (Hans) Arp, Biomorphic Sculptures in Studio, Ph. By André Villers at MoMa, 1958,



There came a time, where nature´s rules became a source of investigation for structural engineering solutions aswell. One of the most prominent *biomimetic* approaches is given by the italian engineer Pier-Luigi Nervi´s *Palazetto dello Sport* in Rome (1957). Here, Nervi tries to recreate the leaves of the giant Amazon water lily. To achieve a highly innovative use of cement, his *ferro cemento*[17] pushes the limits of concrete by adapting to any given form, need, or stress. Here, it is said that his ability to shape a material into a highly performative structure is very similar to how in biology, a muscular and skeletal body works.
Looking back in time, one of the first examples of biomimicry that our civilization ever saw can be found in silk making (4000 BC), making it one of the first fabrics invented by humans[18]. It is said that Chinese were the first civilisation learning from nature itself, from the unique works of silkworms
A more recent research, which embodies notions of nature and technological advancements under the term of Biomimicry, is the MIT - Media Lab´s “Silk Pavillion”. In 2013 “a three-meter wide dome, constructed over three weeks with a flock of 6,500 live silkworms assisted by a robotic arm. Each silkworm spun a single silk thread filament that is about 1 km long. Combined, the silkworms produced a dome-shaped thread as long as the Silk Road. By studying how the silkworm’s spinning behavior is informed by spatial and environmental conditions, we were able to guide the silkworm’s movement to spin two-dimensional sheets rather than three-dimensional cocoons[19]”.
Countless are the examples in architectural history adopting their own set of rules relating to nature which found their own specific stance toward nature and architects continue to define a relationship with nature.
Despite the new line of thinking that the Modern Movement undoubtedly fostered to our sense of connection with nature, its leading exponents, people like Alvar Aalto, Wright and Le Corbusier, all sought to emphasize this connection in their own way.
Architects and builders have always drawn inspiration from nature. Countless analogies can therefore be found. It is yet hard to identify if nature has always been a source of investigation, a meter of comparison and an inspiration rather than an integration within design practices.
Few investigated the overlaps between architecture and nature.

16 Biomimetics or biomimicry is the emulation of the models, systems, and elements of nature for the purpose of solving complex human problems. *Wikipedia Contributors, “Biomimetics,” Wikipedia (Wikimedia Foundation, April 27, 2019), https://en.wikipedia.org/wiki/Biomimetics.*

17 Ferrocement was conceived and patented, around the 1940s, by Pier Luigi Nervi; during the fascist period, in fact, the use of reinforced concrete was prohibited in Italy because it was “non-Italian”: both steel and wood for formwork were imported from abroad. *Wikipedia Contributors, “Ferrocemento,” Wikipedia, January 13, 2022, https://it.wikipedia.org/wiki/Ferrocemento#:~:text=Il%20ferrocemento%20fu%20ideato%20e.*

18 *Wikipedia Contributors., “Biomimicry: Man-Made Nature,” Self Care Awakening, 2021, https://www.selfcarehub.com/blog/biomimicry.*

19 *Neri Oxman, “Silk Pavilion I,” Silk Pavilion I, 2013, https://oxman.com/projects/silk-pavilion-i.*

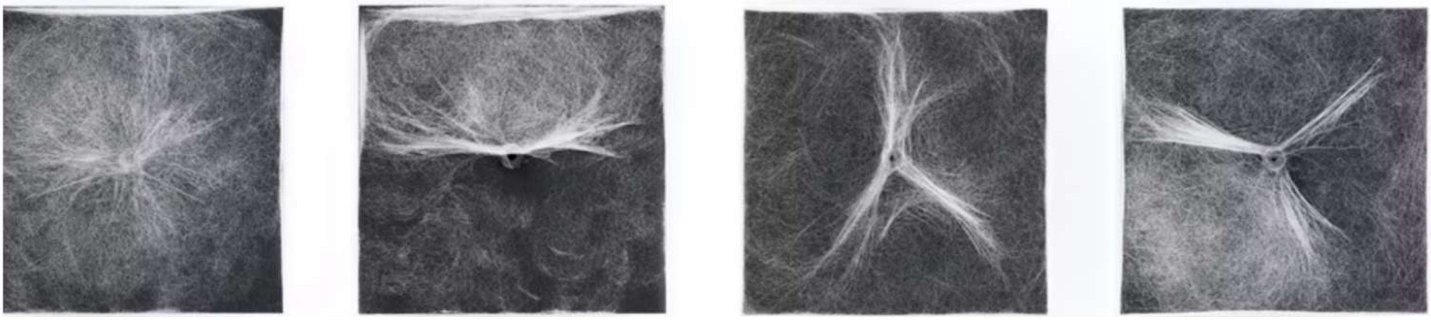


Fig. 7 Neri Oxman, “Silk Pavilion II”, Initial Experiments in robotic silk deposition, MIT Lab, 2020

20 *Klaus Teichmann and In Architektur, Prozess Und Form "Natürlicher Konstruktionen" Der Sonderforschungsbereich 230 (Berlin Ernst, 1996).*

21 *D'arcy Thompson and John Tyler Bonner, On Growth and Form (Cambridge: Cambridge University Press, 2014).*

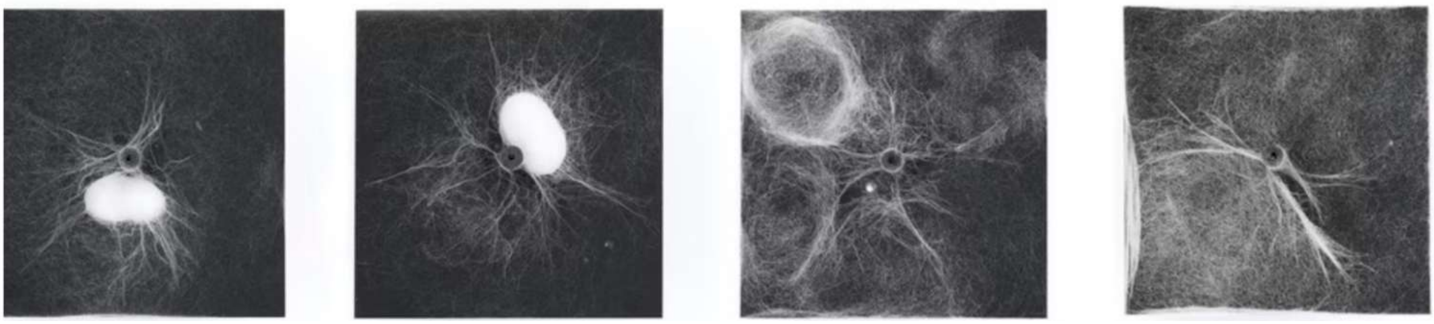
"Not until the principle of imitating nature is understood as an integrated part of a cycle, or better: part of a hermeneutic-poietic spiral, whose complementing section is the constructivist conditionality of every knowledge- or activity seeking observation of nature, one can attribute a relative right to the postulate of imitation. that the opposing interpretations of the formula nature's constructions' [nature constructed as representation of god, or man constructs the reality of nature] could at the same time be held and correlated to each other and that both incorporated theses are at the same time right and valid...We grasp nature by constructing it according to the role model delivered by our inventions. We explain nature by interpreting it according to the composition of our inventions. In this sense nature is a product of our culture[20] ".

To link again the axioms form-matter, man-nature, the contribution of both nature and matter it emerges that both are evidently treated as pure subordinate to their predicates.

One can of course question if today it is still an essential point of architectural discourses the topic about form and function as entities per- se. Given the critical times we are today witnessing, a reconsideration over the complex origins and causes of long established tendencies might positively contribute to a new understanding of how *bios* can be an integral part of architectural discourses, hence practices.

"As in Nature, when creation begins with matter, morphogenesis, or the generation of form, is a process engendered by the physical forces of Nature[21] "

Fig. 8 Neri Oxman, "Silk Pavilion II", Initial Experiments in robotic silk deposition, MIT Lab, 2020



“of all things man is the measure”

In the 1700s, Carl Linnaeus[23] classified nature in an attempt to bring rigor, order and logic to his perceived chaos of biological life.
“However Linnaeus’s system must now be understood as a constructed hierarchy closely tied to European colonial expansion and power.
It placed ‘man’ at the pinnacle, and in control of the biological pyramid.
The legacy of this view underpins the modern industrial system inherited today[24]”.

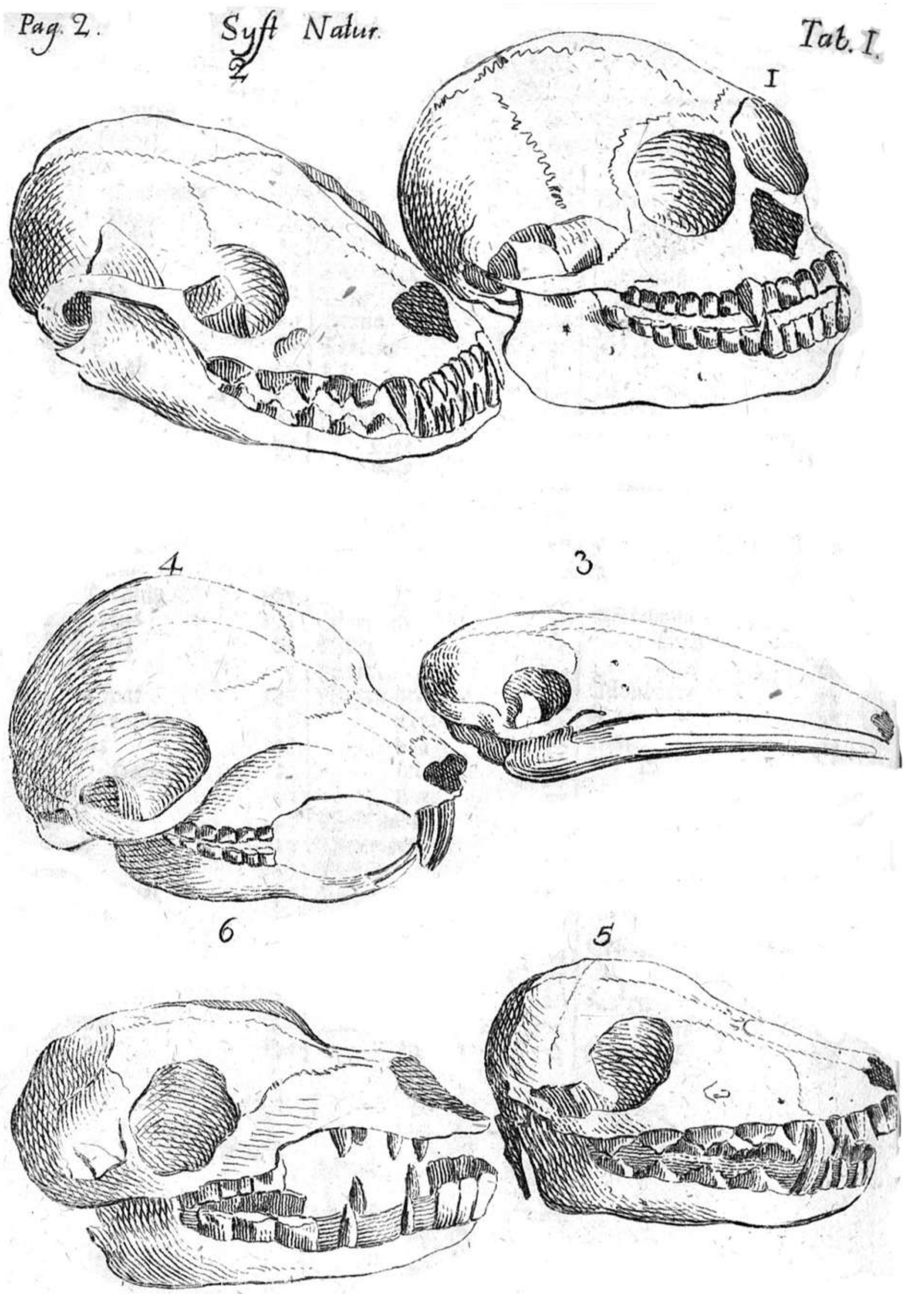
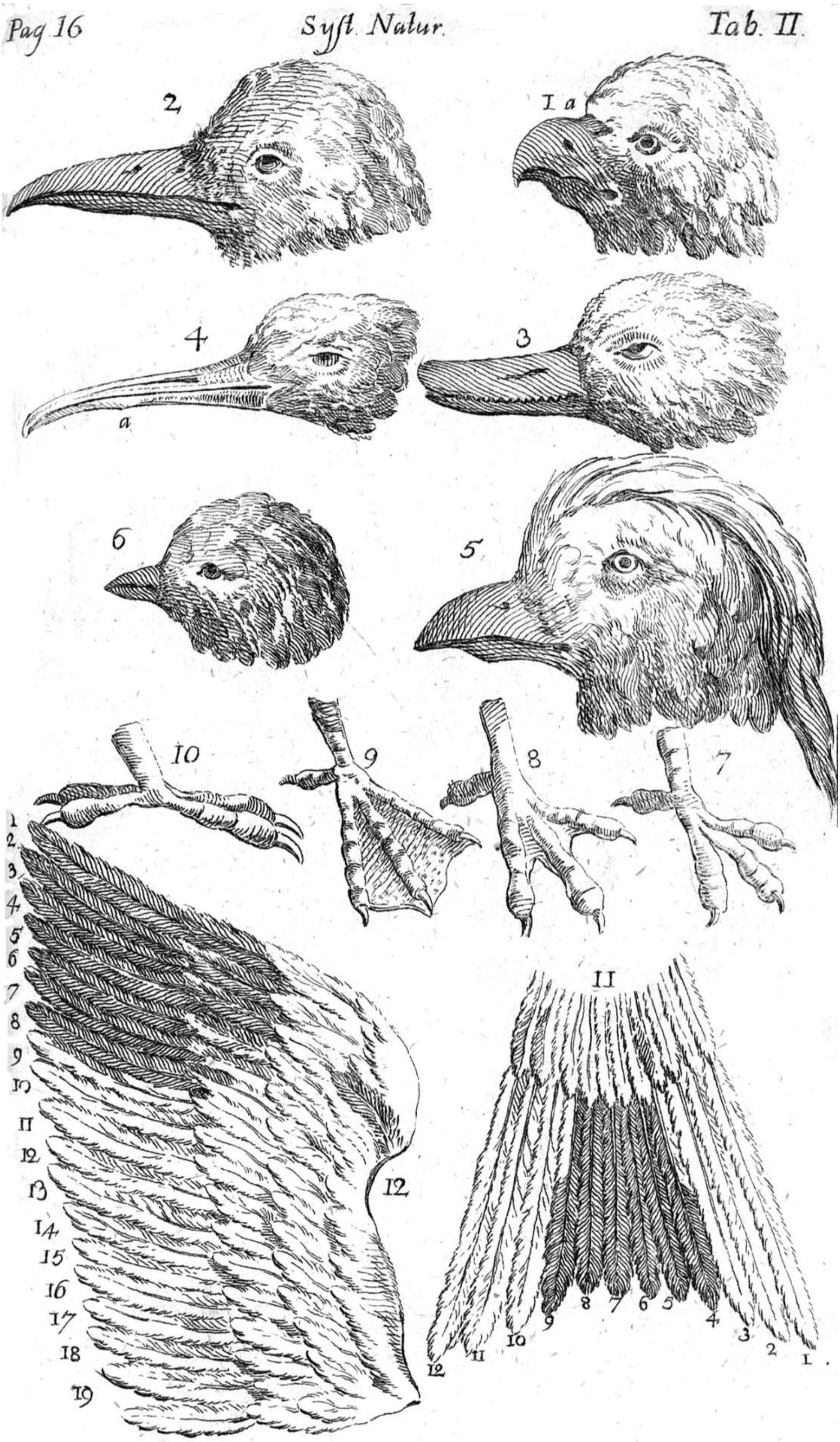


Fig. 9 Carl Linnaeus, Systema Naturae Plate I: Quadrupedum Crania Secundum Ordines, Ut Dentes Primores Facilius Perspiciantuar, 1748.

23 Systema Naturae is one of the major works of the Swedish botanist, zoologist and physician Carl Linnaeus (1707–1778) who introduced the Linnaean taxonomy.
Wikipedia Contributors, “Systema Naturae,” Wikipedia (Wikimedia Foundation, March 2, 2019), https://en.wikipedia.org/wiki/Systema_Naturae.

24 *Simone Le Amon, “History in the Making | NGV,” www.ngv.vic.gov.au, 2021, https://www.ngv.vic.gov.au/essay/history-in-the-making/.*

Fig. 10 Carl Linnaeus, Sistema Naturae Plate II: Avium Capita & Artus, 1748.



In architecture, the systems of classifications´s turning point came later in 1948, when Le Corbusier, one of the pioneers of Modernism, set the rules for a universal anthropometric scale of proportions. Modulor´s purpose was the one of embodying "a range of harmonious measurements to suit the human scale, universally applicable to architecture and to mechanical things[26]".
The idea of placing the man at center of everything is nothing new, 2,000 years ago, Da Vinci defined architecture in proportion to the human body with his Vitruvian man. An ideal building, according to him, had to represent the ideal size of a man.
Here, the bodily ideal of perfection was multiplied into a range of architectural values: The Vitruvian Man was built around this notion of idealized ratios for both body and architecture.
Today such anthropocentric, indeed male body-centered design, seems questionable, if not fallacious. Not only because of its socially non-inclusive nature but also because of its antithetical character toward the environment.

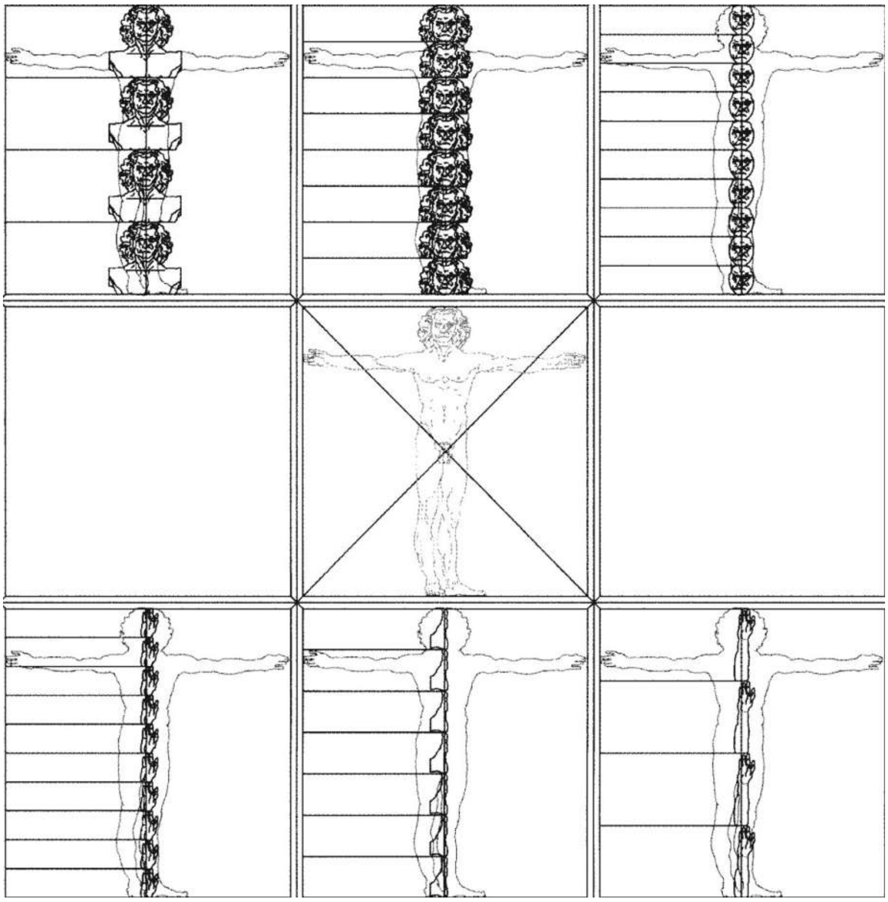
> ***"While Le Corbusier's Modulor Man created a normative standard for the human body, it was by itself already the result of modern architecture's project for human betterment". (...) The Modulor Man is a healthy white male enhanced by mathematical proportional gimmicks of nature[25]".***

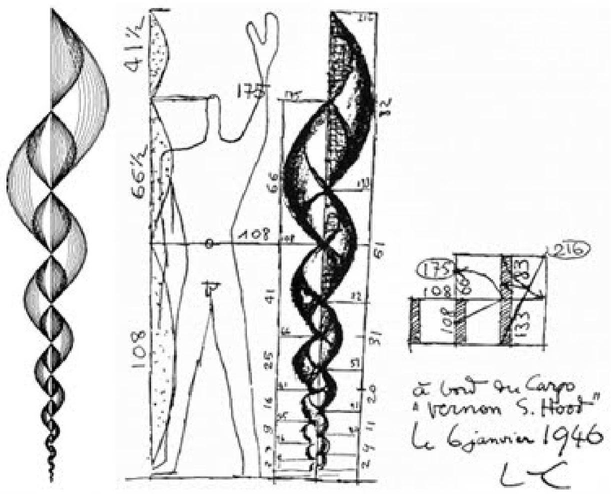
25 *Federica Buzzi, "'Human, All Too Human': A Critique on the Modulor - Failed Architecture," Failed Architecture, 2017, https://failedarchitecture.com/human-all-too-human-a-critique-on-the-modulor/.*

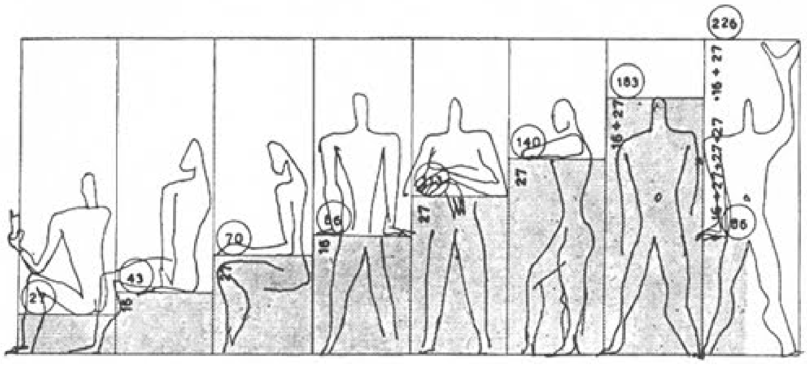
26 *ibid*

Fig. 11 Franco Sondrio, L´Uomo Vitruviano Secondo Leonardo Da Vinci, 2018.

Fig. 12 Charles Edouard Jeanneret Le Corbusier, Modulor Study of the Proportions of the Human Body in Various Positions, 1946.



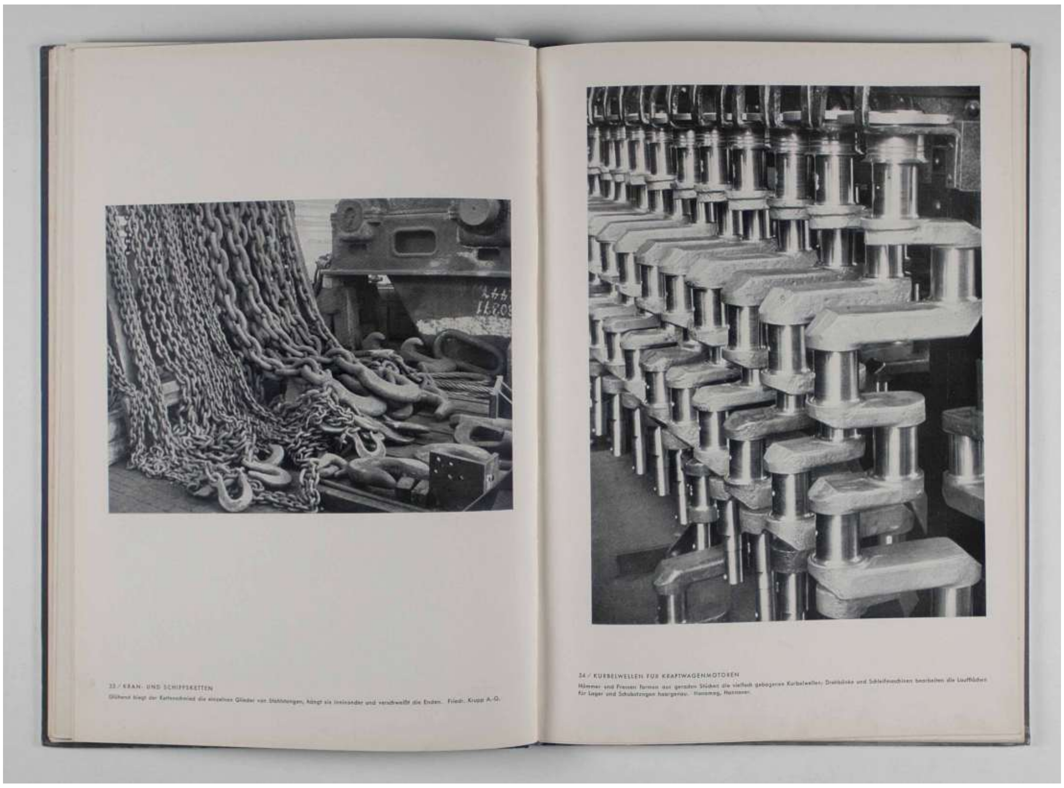




Taking Modernism, its beginnings and its evolution as a movement that still affects the language of contemporary architecture today as an example, it is incumbent to go over some essential aspects that characterized the movement that consolidated in Europe at the turn of the 1900s.

Although Modernism presented itself as a universal language, reflecting universal human rights, this current took on different characters according to different geographical locations, climates, cultures and material availability. It is incorrect, therefore, to speak of only one Modernism, when instead it is more correct to speak of several *modernisms*.
The common denominator to which this new language had to be able to respond, however, was only one: the new conditions of a world based on a machine **engined by combustion**.

Fig. 13 Eisen und Stahl. 97 Fotos von Albert Renger-Patzsch (Iron and Steel. 97 Photos by Albert Renger-Patzsch, 1931.



26 *Marianne Krogh, Connectedness: An Incomplete Encyclopedia of the Anthropocene. Views, Thoughts, Considerations, Insights, Images, Notes & Remarks. Contribution of Asmund Havsteen Mikkelsen (Vedbaek: Strandberg, 2020), 251.*

27 *ibid*

28 *Marianne Krogh, Connectedness: An Incomplete Encyclopedia of the Anthropocene. Views, Thoughts, Considerations, Insights, Images, Notes & Remarks. Contribution of Marianne E. Krasny (Vedbaek: Strandberg, 2020), 52.*

A quite radical view regarding of how architecture has been the central site of politics and resource exploitation, is found in Asmund Havsteen-Mikkelsen's contribution to Marianne Krogh's book "Connectedness: An Incomplete Encyclopedia of the Anthropocene". Here, the Danish artist states that "I will introduce an observation by the economist William Stanley Jevons, who in 1865 noted that efficiency in the use of coal did not lead to a decrease in use, but the reverse. The more efficient the steam engine became, the more demand for coal increased (since efficiency also lowered the price of energy). This phenomenon is called Jevons' paradox and describes how more efficient technology leads to increased energy use through new and unexpected possibilities[26]".
The paradigm of access and unlimited use of fossil fuels, the displacement of users from nature and the biosphere, and the promotion of a "novelty" imprinted with a "tabula rasa " of reality (moving away from concepts of care, conservation, reuse, and inheritance) always amplifies a side effect that has contributed, as mentioned by Mikkelsen "to the creation of an architectural condition for an immense luxury trap based on high-energy fossil fuel consumption patterns, a distant relationship with nature and an externalization of violence against non-human nature. Modernism made mass urban construction possible and created the mythology of modern life based on novelty and technological offerings. Modernism has been progress, but the rebound effect of this progress is the sixth mass extinction and climate crisis[27]".
Being critical of Modernism is nothing new. At least since the days of Robert Venturi and Charles Jencks, it has been common to deride Modernism. But today it is perhaps necessary to propose a different point of view, related to the unintended side effects (such as rebound effects) of the movement. Man above nature is fundamentally linked to the idea of modern architecture.
Underlying the modernist movement is a philosophy related to fossil fuels (coal for energy production and the automobile, airplane or train as means of transportation), whose language is that of an abstract spatial language (mathematical grid space) made for an individual (whether in private homes or in the isolation of apartments within skyscrapers) universal (because of the global presence of capitalism) and progressive (as in the implementation of new technologies[28]).
By analyzing the impact of modernism over an environmental, political or social gaze, it is not intendet to diminish the wonders and inspiring theories this movement had and whose principles are still relevant for the history of architecture today, however, with the benefit of hindsight, it is hard not to reconsider that today, given the global crisis we find ourselves in, these same principles need to be revised.
Seeing Modernism in all its facets helps to broaden not only the positive impacts it has exerted on architecture today, but extends its influence on times of valence purely related to anthropocentric values and ideals.
In all its facets, modernism reflects the driving forces of this new age, in which man has become a geological agent.

Fig. 14 *ibid*

Reviewing different historical periods under a critical lens brings us back to the current condition in which we find ourselves, the so-called Anthropocene[27]. This dimension sets humans as the dominant force impacting the Earth's geology. Although it has not been formalized officially, this event is so significant in nature that it may constitute a new geological era for the lithosphere: a period characterized by accelerated exploitation of the natural environment, accompanied by different patterns of behavior associated with consumerism, travel, and economic expansion. Many environmental historians help emphasize the physical manifestations of this event, while architectural historians have tended to highlight its cultural and social dimensions in architectural practice.

Central to this evolution, which is rooted in the modus operandi of the industrial age, are technological developments, which have elevated human action to the level of a "geological force." Anthropos, using the Greek word, thus defines our present condition. But it would be wrong to think that human action has become the only game in play.

At the attempt to build a society marked by sustainability, democracy and resilience are challenged as they are incorporated to forces determined in the Anthropocene, thus becoming "business as usual".

The Earth's ability to manage overconsumption and waste has a limit, and today modern society is pushing the limits of overdraft and soon the Earth will not be able to lend any more, but will react with heavy penalties in the form of global warming and resource depletion[29].

An example of relevant visual impact can be found in an article by Jon Moallem in the New York Times Magazine accompanied by the mesmerizing photos of open-pit mining captured by photographer Edward Burtynsky. Moallem reflects that humans have always extracted resources from the earth, but that the scale at which this happens now becomes intangible and that we may feel threatened by the strength of our own society. Burtynsky said that "if you feel revulsion for this landscape, you should feel revulsion for your whole life," since we are all complicit in development through our lifestyles and choices[31].

An interesting critical theory of contemporary capitalism can be explained with the words of Marzen Labban borrowed from Arboleda for his "Planetary Mine: Territories of Extraction Under Late Capitalism", where Labban conceptualizes this new Geography as follows:

> ***"The geography of extraction that emerges as the most genuine product of two distinct but overlapping world historical transformations: first, a new geography of late industrialization that is no longer confined to the traditional heartland of capitalism (i.e., the West), and second, a quantum leap in the robotization and computerization of the work process brought about by what I will call the fourth machine age[32]".***

Can a new definition of architecture emerge from its ethical obligation and political task? This must be done so that architecture can play a role in restoring *futurity* that means having a future in the future.

29 An early concept for the Anthropocene was the Noosphere by Vladimir Vernadsky, who in 1938 wrote of "scientific thought as a geological force". Scientists in the Soviet Union appear to have used the term "anthropocene" as early as the 1960s to refer to the Quaternary, the most recent geological period. Ecologist Eugene F. Stoermer subsequently used "anthropocene" with a different sense in the 1980s and the term was widely popularised in 2000 by atmospheric chemist Paul J. Crutzen, who regards the influence of human behavior on Earth's atmosphere in recent centuries as so significant as to constitute a new geological epoch.
Wikipedia Contributors, "Anthropocene," Wikipedia (Wikimedia Foundation, January 10, 2019), https://en.wikipedia.org/wiki/Anthropocene.

30 *Johan Rockstrom, "Let the Environment Guide Our Development," TED, August 31, 2010, https://www.ted.com/talks/johan_rockstrom_let_the_environment_guide_our_development.*

31 *Edward Burtynsky and Text by Jon Mooallem, "Edward Burtynsky's Mesmerizing Images of Copper Mines," The New York Times, October 22, 2015, sec. Magazine, https://www.nytimes.com/interactive/2015/10/25/magazine/25mag-copper.html.*

32 *Martín Arboleda, Planetary Mine : Territories of Extraction under Late Capitalism (Brooklyn: Verso Books, 2020).*

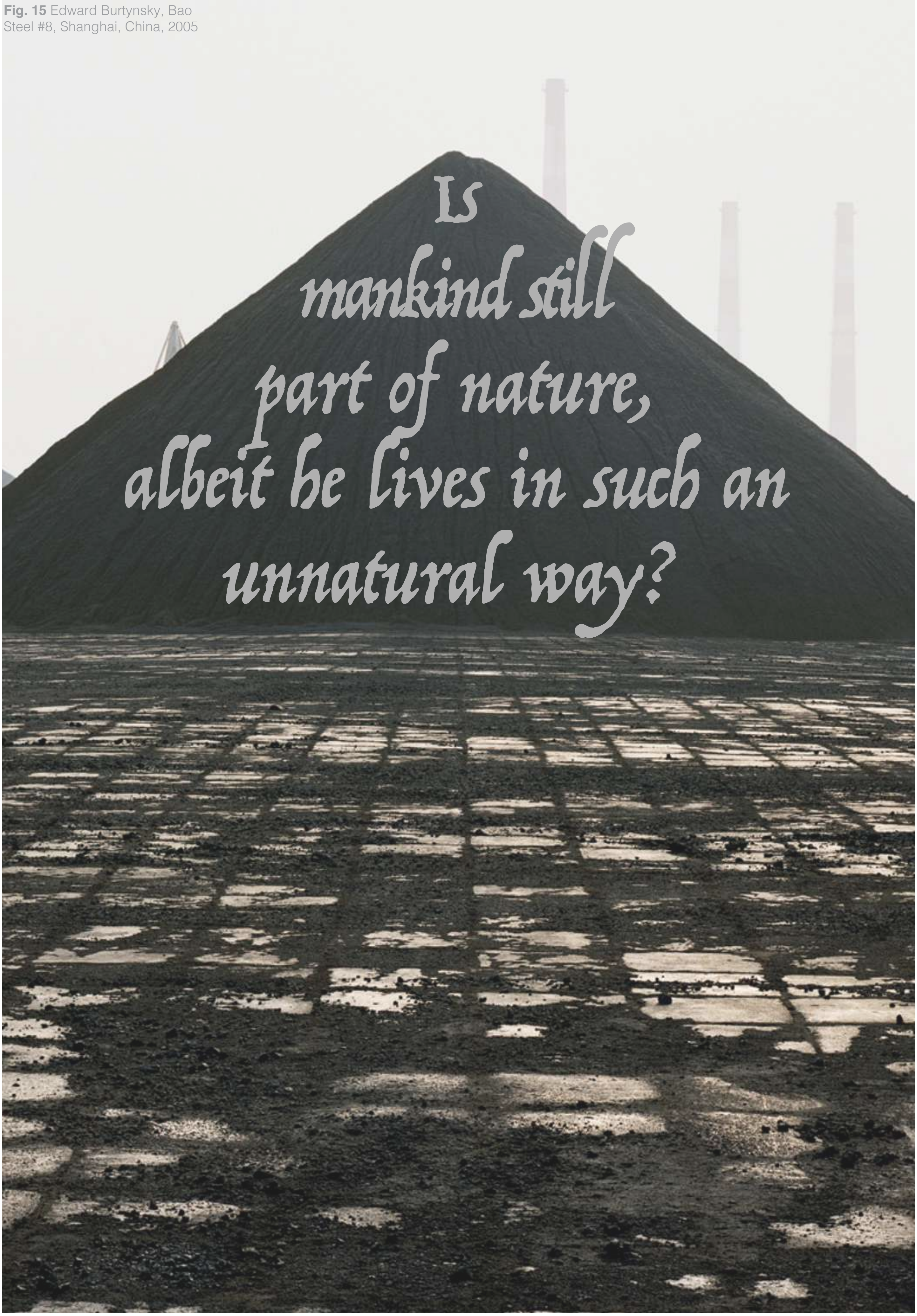


Fig. 15 Edward Burtynsky, Bao Steel #8, Shanghai, China, 2005

Fig. 16&17 Armin Linke, Anode Carbon Blocks, Bahrain, 2016 and Ertan Dam, Downstream Side, Panzhihua (Sichuan), China, 1998 (right).

fundamentals of matter

"Materials are the basis of craftsmanship, architecture, design, agriculture, industry and commerce"
Le Amon

Fig. 18 Fabio Viale, 18 Tons of Stone Chippings & Marble Sculptures, Galleria Poggiali, Florence, 2020.

By understanding the physical properties and origins of materials and exploring the narrative behind human-nature dualism in architectural discourses, a greater understanding of the implications of the continuing trajectories of materials-related production can emerge.
It is therefore incumbent to understand how the search for them has shaped and still shapes the history of the human species, which directly defines the history of culture itself.
Our approach on how to source materials, use them, and even create them is a critical aspect that addresses contemporary global challenges. Seeing architecture outside the frame of the drawing, enables a better understanding on how material extraction directly affects economics, climatic and ecological issues of the construction industry today.
Construction has been a fundamental aspect since the earliest traces of human presence on earth, and the built environment itself has been shaped by the availability of primary resources.
Briefly reviewing the different epochs, one can see that the first is characterized by a primarily material age during which civilizations relied on primary engines, biomass and primordial renewable energy; in a second, one can see how the exploitation of fossil fuels reached unprecedented levels.
The one that characterizes the period in which we find ourselves today follows the line of the previous one with the addition of the simultaneous expansion, variation and optimization of resources. This new system is driven by an increased awareness of the limits of many of the resources that have been seen as predominant to date, the inefficiencies of current production and distribution systems, and the negative impact of human activity. This third phase incorporates approaches from both the former and the latter within a model that is no longer linear but rather cyclical, a model in which greater respect is given to aspects such as zero-waste material flows, showing unprecedented diversification of energy and material resources.
Due to the simplified access and cheap labor-related character of material extraction, in his book “Small is beautiful” (1974) the economist E. F. Schumacher shows how the illusion of “endless” resources contributed to a further loss of value of materials[33]. In his book “ The Perception of the Environment” (2000), anthropologist Tim Ingold refers to the detachment from matter and the growth of mechanics.
Because materials are so accessible, they also lose economic value and are disposed of fairly soon relative to their potential lifespan.
According to Ingold, while machines provide a level of precision that the craftsman may lack, they also eliminate the creative part of the physical engagement in the manufacturing process, the relationship between man and matter. The anthropologist goes on to reflect on the relationship between architecture and matter by stating that the architect has become a creator of structures “...and significantly, the process by which the architect or theoretical scientist arrives at new ideas, as distinct from their subsequent implementation or experimentation, is often described more like art...[34]”. It is evident how the interaction with the material has fallen under the category of technology and is gradually becoming a markedly

33 *E. F. Schumacher, Small Is Beautiful (Harper Perennial Modern Thought, 1975).*

34 *Tim Ingold, The Perception of the Environment : Essays on Livelihood, Dwelling and Skill (London ; New York: Routledge, Taylor & Francis Group, 2000) p. 295.*

mechanical performance. In this way, the material becomes detached from the design process and is imposed as a tool for making form.

The question of matter is important because it includes issues that are not merely physical or chemical in nature. To shed light on the importance of the material world is to open brackets that in fact concern our relationship with the environment and other species, legislative frameworks, industrial practices and production chains.
To talk about the origin and sourcing of materials today equates to opening up social, political and economic policies.
In the field of architecture, the paradigm between the natural and built environment has only recently begun to receive substantial attention.
In the book "Connectedness: An Incomplete Encyclopedia of the Anthropocene another relevant contribution of Mikkelsen states that "Human presence has such a strong impact on the Earth's ecosystem that it causes irreversible changes in climate, structure and soils. The problem stems from the dominant human influence on all climatic, biophysical, and evolutionary processes occurring on a planetary scale. At the root of the problem is not only climate change, but the entire system of capitalist-style development that undermines the very foundations of life on Earth´s soil.
Historically, traditional architecture has facilitated and stimulated economic growth while contributing to an ever-increasing human footprint, exponential carbon emissions, resource extraction and biodiversity loss (...)[35]".

35 *Marianne Krogh, Connectedness: An Incomplete Encyclopedia of the Anthropocene. Views, Thoughts, Considerations, Insights, Images, Notes & Remarks. Contribution of Asmund Havsteen Mikkelsen (Vedbaek: Strandberg, 2020), p. 250-253.*

Fig. 19&20 Xandra van der Eijk, Future Remnants, Revolutionary development of minerals, Milan Design Week, 2018

architectures of extraction

> ***"For the past eight years I have spent every day of my professional life working for an industry that is responsible for nearly 40 percent of global climate emissions. I don't work for an oil or gas company. I don't work for an airline. I'm an architect."***
> ***Stephanie Carlisle***

In the current climate of geopolitical uncertainty, occurring against the backdrop of unprecedented environmental change, it is up to architects and designers to recognize the vulnerability of their field.
About 40 % of global materials and energy consumption is used in the construction industry and about 10 percent of that becomes waste.There are many solutions that seek to promote more sustainable lifestyles such as energy-efficient homes that rely on a cyclic service system[36].
However, the ***embodied energy***[37] that goes into the construction of a building or the impact of materials extraction and production are still of low priority. This could be due to an architectural tradition in which materials are secondary to form[38].
The construction industry relies on 4 material strongholds: cement, steel, aluminum and glass, whose carbon intensity is very high. In the supply chain, steel, cement and aluminum are responsible for 23% of total global emissions; in the construction world alone, they cross ownership boundaries, economic sectors and markets[39].
The United Nations predicts that the global number of square meters built will double until 2060[40]. This corresponds to building the city of Paris every week for the next 40 years. Since the construction sector is estimated to consume the most energy and resources, another largely impactful aspect to consider regarding future targets is the control of waste itself from the construction world. Construction and demolition waste is estimated to make up 33% of the total waste generated annually in the European Union[41].
Buildings today are not considered a temporary repository of valuable resources; dismantling and subsequent recycling of materials are rarely an integral part of planning[42]".
According to the Paris Agreement (2016) we have only a few decades to create a fossil-free global society, and the rest of this century must be spent restoring the balance by sucking carbon out of the atmosphere.

36 *Jon Goodbun and Karin Jaschke, "Architecture and Relational Resources: Towards a New Materialist Practice," Architectural Design vol. 82, no. no. 4 (2012): pp. 28–33.*

37 Embodied energy is the energy associated with the manufacturing of a product or services. This includes energy used for extracting and processing of raw materials, manufacturing of construction materials, transportation and distribution, and assembly and construction.
Rabin Tuladhar and Shi Yin, "Embodied Energy - an Overview | ScienceDirect Topics," www.sciencedirect.com, 2019, https://www.sciencedirect.com/topics/engineering/embodied-energy#::text=Embodied%20energy%20is%20the%20energy.

38 *Katherine Lloyd Thomas, Material Matters : Architecture and Material Practice (London: Routledge, 2007).*

39 *UNEP, "CO2 Emissions from Buildings and Construction Hit New High, Leaving Sector off Track to Decarbonize by 2050: UN," UN Environment, November 9, 2022, https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector*

40 *Søren Brøndum and Lars Ostenfeld Riemann, "A Low-Carbon Home Is Built on Data," Ramboll Group, 2022, https://ramboll.com/ingenuity/a-low-carbon-home-is-built-on-data#::text=The%20total%20number%20of%20buildings.*

41 *United Nations, "Construction and Demolition Waste: Challenges and Opportunities in a Circular Economy — European Environment Agency," www.eea.europa.eu, 2020, https://www.eea.europa.eu/publications/construction-and-demolition-waste-challenges.*

42 *Dirk E. Hebel, "Resource City," arch.ethz.ch, 2016, https://arch.ethz.ch/en/news-und-veranstaltungen/lehre-forschung/ressource-stadt.html.*

43 *Rob Hopkins, The Transition Handbook from Oil Dependency to Local Resilience (Cambridge Uit Cambridge Ltd, 2014).*

More efficient use of local resources could be a key to combating these threats. A land-focused approach could also support the development of more environmentally, socially, and economically resilient societies[43], the transformation from a linear to a circular system could thus be the promoter of a new post-carbon era.

The crisis of climate change and natural resource scarcity requires a new modus operandi. Architects, planners and engineers need to be drivers of innovations in the field. As partially responsible for the overexploited implications, it is the responsibility of this sector to perpetuate it from further damage by transforming guilt into collective change.

Fig. 21 Demolition of the Pruitt-Igoe estates in St. Louis Missouri, 1976.

post-carbon

*"Architecture can exist only when there is transformation of an environment. It is the way in which this happens – that is, how the environment is transformed.
Even architecture, a mere instance of form, in this field of action has a power and a responsibility – that of expressing the identity, desires and deepest intentions of humankind. And while it expresses all this, it can also inspire an idea – it can give life to a dream. In our era, the Anthropocene, architecture can – it must – design and represent a different approach, one of coexistence and symbiosis with the biosphere. It must point out a new path. It will be for the world (and politics) to ignore it or take it"*
Mario Coppola

Looking back in history, one of Humboldt's achievements (1769-1859) was the development of an alternative system that encompassed existing species. In contrast to the independent method of Swedish botanist and zoologist Carl Linnaeus (1707-1778) underlying Humboldt's thinking resided a notion of interaction or interconnection between organisms and the landscape around them.
This new order of observing and cataloging the biological and natural worlds can be seen today as a turning point for the science of ecology. While the industrial revolution was the milestone that symbolized the complete dissociation of humans from nature, facilitating the exponential growth of globalization and leading to unprecedented exploitation of the earth´s surface, on the other hand the growing awareness that human activity has on the planet, however, has generated some profound changes in thinking. A tendency in sublimating and bringing to the center of economic and political discourses climate issues, the impact these same industries have on nature, the importance of preserving the wild world, and the rapid decline of natural resources has a major spotlight now, specially when in 1972 that The United Nations Conference on the Environment in Stockholm[44] marked the very first world conference to make the environment a major issue.

44 *United Nations, "United Nations Conference on the Environment, Stockholm 1972," United Nations, 1972, https://www.un.org/en/conferences/environment/stockholm1972.*

45 *Space Caviar, NON-EXTRACTIVE ARCHITECTURE : On Designing without Depletion. (S.L.: Sternberg Pr, 2021).*

46 *Timothy W. Luke, "Ephemeralization as Environmentalism: Rereading R. Buckminster Fuller's Operating Manual for Spaceship Earth," Organization & Environment 23, no. 3 (September 2010): 354–62, https://doi.*

This awareness is evident in the subsequent growth of fields such as sustainability, ecology and biomimicry, whose purpose is to remedy the damage caused by excessive and polluting human activities.
Less obvious, but no less important, is the realization that the intensification of natural and human processes are more similar than we think.
The creations that have most influenced the history of human innovations (cities, the financial market, or the Internet) have as their common denominator that they must adhere to complex and intrinsic natural principles in order to endure. For the first time, this movement of thought posits man, and thus his activities, as part of the world, rather than divided from it.
The construction sector is both critically important in meeting basic human needs and, on the other hand, responsible for the consumption of resources and the emission of pollutants.
It is therefore necessary to find alternative solutions to redefine what it means to build.
An essential reading regarding a post-carbon future concerns that of "Non-Extractive Architecture." Here, Space Caviar performs an analysis of non-extractive architecture applied to practical examples.
The architecture proposed by Joseph Grima and his team, challenges the assumption that construction must inevitably cause some kind of irreversible damage or depletion somewhere-preferably somewhere else-and the best we can do as architects is to limit the damage caused. Engineering for efficiency is key, reuse is key, reversibility is key.
The reading goes on to mention that the goal of architects is not to limit carbon emissions, but to propose an idea of architecture that is not inherently dependent on some form of exploitation (of resources, of people, of the future)[45].
By the term *extractivity*, Space Caviar refers to a wide range of fundamental aspects, not only material but also sociological, economic and geopolitical.
The book seeks to highlight that the intent for a new sustainable paradigm in the field of architecture is not to return to the vernacular, or the practices of the past, but rather to harness and integrate technological development in a more ethical and responsible manner.
Although contextually distant, both Illich and Fuller were concerned with the issue of sustainability.
On the one hand, Fuller was aware of the limits of the earth's resources, advocating a principle he decided to call "ephemeralization" or "doing more with less[46]".

> ***"Nature is a totally efficient, self-regenerating system. If we discover the laws that govern this system and live synergistically within them, sustainability will follow and humankind will be a success"***
> ***R. Buckminster Fuller***

Fig. 22 Lara Almarcegui Construction Rubble of Secession's Main Hall, Vienna, 2010

Is it possible then, to reconstruct a system based on what is the current model?
To conclude the chapter of the post-carbon architecture, it is worth quoting the inspiring words given by Material Reforms “Building for a post-carbon future”.
A major contribute is the one the book gives to the regenerative *resources model*. These are resources that are extracted from cyclical growth processes without minimizing its ability to regenerate. These materials are harvested from ecosystems under active restoration or from restored ecosystems where the very risk of depletion is minimal. Underlying this reform lies the idea of bringing the construction industry back to the regional level, consolidated by a study of the quantities and nature of materials that can be harvested and managed regeneratively[47]. Thus, a new interrogation of the palette of materials we use is needed so that today´s infrastructure, economies, and technical training can produce results that are not only necessary for the environment, but also possible.

47 *Material Cultures, Material Reform, Mack Books, pp. 20-21*

towards a new material ontology

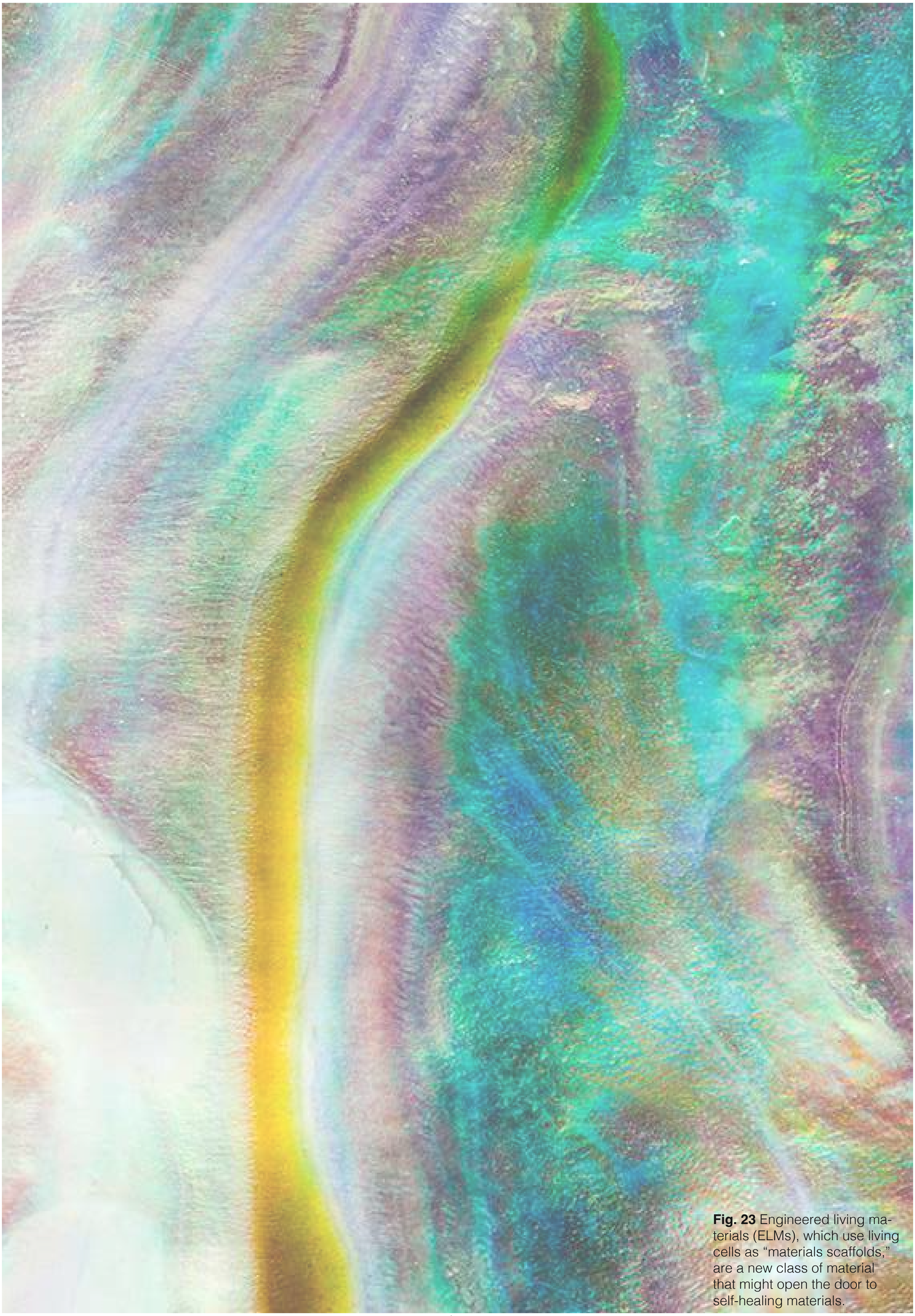


Fig. 23 Engineered living materials (ELMs), which use living cells as "materials scaffolds," are a new class of material that might open the door to self-healing materials.

48 *Katherine Lloyd Thomas, Material Matters : Architecture and Material Practice (London: Routledge, 2007).*

49 *Marianne Krogh, Connectedness: An Incomplete Encyclopedia of the Anthropocene. Views, Thoughts, Considerations, Insights, Images, Notes & Remarks., Contribution of Diane Coole, (Vedbaek: Strandberg, 2020), P. 270.*

It seems that the interest in materials resides from different practices in architectural theory. After many years of research on sustainable architecture, more attention is being paid to the use and recognition of origins, fabrications, transportation, and socio-cultural and economic conditions regarding the material sphere.
If we look back even to the ´60s in England, the advent of performance specifications allowed a contractor to use any material as long as it met certain standards (e.g., in terms of fire resistance or acoustic separation). Whereas today, thanks to nanotechnology, designing new materials means being able to define their behavior and adaptability.
Contemporary interest in material remains within architecture, ignoring the cultural and political issues that an engagement with material might produce[48].

> ***"Often pluralized, the new materialisms cover a range of approaches that have become influential over the past decade. What links them is a commitment to give matter its due, to explain how and why matter matters, to explore novel forms of contemporary materiality and to pose questions about the nature of the material world in ways that challenge existing ideas about society and the human[49]".***
> ***Diana Coole***

form follows matter

The last decade has seen the emergence of a new modus operandi in various professional fields that marks the growing interest of innovative materials applied to the sphere of technological potential, bio materials. Within them, a wide range of subordinates go on to define a new concept of ***material ecology***[50].
The combination of material science and digital fabrication push the boundaries and increasingly support the emergence of new frontiers applied to the world of various industries, including design and construction. This new paradigm promotes an interaction of multiple disciplines - intersection of biology, materials science and engineering and computer science, with a focus on environmentally informed design and digital fabrication - where material ecology comes into direct communication with products, buildings, systems and the environment[51].
Thanks to this revolution, new architectural to infrastructural forms have the opportunity to proliferate as material artifacts symbiotically linked to ecological processes themselves, a new architecture informed by nature[52].
The idea that the keys to the advancement of technology and design lie in cooperating with, rather than against, natural processes is critical to being able to counter the increasing fragility and degradation of the natural environment.

"The research also aspires to establish a new discourse on architecture´s relationship with the natural world, exemplified by the innovative approaches architects and designers are using today to integrate nature and human technology in profound ways[53]".

50 Material Ecology is an emerging field in design denoting informed relations between products, buildings, systems, and their environment
Neri Oxman, "Towards a Material Ecology – MIT Media Lab," MIT Media Lab, 2013, https://www.media.mit.edu/publications/towards-a-material-ecology/.

51 *ibid*

52 *Michael Weinstock, "ACADIA 08 Silicon + Skin › Biological Processes and Computation Proceedings 20 Nature and the Cultural Evolution of Architectural Forms," 2008, http://papers.cumincad.org/data/works/att/acadia08_020.content.pdf.*

53 *Blaine Brownell et al., Hyper-Natural : Architecture's New Relation with Nature (New York: Princeton Architectural Press, Cop, 2015).*

Fig. 24 Kayam Studio, Future Materials Bank SEAmpathy - Algae and Algae Byproducts.

designing with nature

By looking to nature as a teacher rather than simply as a source for raw materials, pioneers in the emerging bio-material movements are developing design and materials methods to create intelligent buildings that make our built environment more efficient, sustainable, and, most of all, livable.

Biobased raw materials are derived from living organisms such as different types of crops, wood, and algae. Renewable is a term used for both raw materials and energy. Biobased raw materials are derived from living organisms such as different types of crops, wood, and algae. Renewable is a term used for both raw materials and energy. All bio based raw materials are renewable, but renewable sources can be as diverse as the sun, wind, and water[54].
Biobased materials refer to products that consist primarily of a substance (or substances) derived from living matter (biomass) and that occur naturally or are synthesized, or they may refer to products made by processes that use biomass. Following a strict definition, many common materials, such as paper, wood, and leather, can be called biobased materials, but generally the term refers to modern materials that have undergone more extensive processing. Materials from biomass sources include bulk chemicals, platform chemicals, solvents, polymers, and biocomposites (some materials may fall into more than one category). The many processes for converting biomass components into value-added products and fuels can be broadly classified as biochemical or thermochemical. In addition, biotechnological processes that rely mainly on plant breeding, fermentation, and isolation of conventional enzymes are also used. Biobased materials are perceived as potentially more environmentally friendly alternatives to their petroleum-based counterparts; however, this claim comes under close scrutiny[55]. New biobased materials that can compete with conventional materials are continually emerging, and opportunities for their use in existing and new products are just beginning to be explored. These plant-based materials are abundantly and sustainably available both locally and globally, especially in the form of by-products and recycled waste.
Like all materials, plant-based materials are subject to a range of environments that can affect material performance, such as the effects of weathering and moisture. In addition, because bio-based materials are organic in nature, they are likely to be subject to attack by natural organisms, from bacteria and fungi to insects and higher animals. When developing new materials and testing existing ones for suitability for specific uses, the material must be tested against the specific environment or organisms involved[56].

54 *Anna Berggren and Malin Johansson, "Bio-Based and Renewable," www.perstorp.com, 2019, https://www.perstorp.com/en/news_center/news/2017/20171109_bio_based_and_renewable.*

55 *Michael A. Curran, "Bio Based Materials," cfpub.epa.gov, 2010, https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=231873.*

56 *Dennis Jones and Christian Brischke, Performance of Bio-Based Building Materials (Duxford, United Kingdom Woodhead Publishing, 2017).*

Although the field of research is still experimental in nature, requiring a strong interdisciplinary approach to research that includes designers, health professionals, ergonomists, materials scientists, and input from users and manufacturers, the future prospects regarding such interdisciplinarity has the potential to solve looming problems in today´s ecology. There is evidence that bio-based materials have the peculiarity of contributing positively not only to the health of the environment but have been found to have a positive impact on human health itself; in fact, they can be functionalized in specific ways to improve the quality of the indoor environment through a variety of processes.

In the book *Embodied Energy design* (2017) to refer to the idea of how nature can be a source of inspiration and consequent action, author David Benjamin refers the cheetah to define the philosophy on which his company Evocative is based: “A Cheetah is self-assembled, molecule by molecule, by the cells in its body. With a power-to-weight ratio about double that of a Ford Focus. At Evocative[57] biomaterial grow whole organisms into finished materials and products ... By using a living organism to grow polymers, we take advantage of biology to create better products and better processes. As heat engine technology continues to improve, it will probably approach cheetah-level technology. But as a system, a cheetah will always be superior in terms of its elegant use of embodied energy and material flows: it supports itself by eating smaller animals, and at the end of its life cycle it’s completely recyclable. It becomes the nutrition for the environment that supports it[58]”.

This is a great example of how several companies define the design process not as “imitation” of biology, but rather as direct application to products in order to derive better results from them.

Benjamin goes on saying that “Looking to nature for inspiration and then using existing technology to replicate its functionality is ineffective and backward. Why copy a natural process by using inaccurate and sometimes toxic man-made materials such as iron, plastic or silicon, when you can resort directly to the beautiful complexity of a living cell? This is what happens when you build a house using lumber (a surprisingly effective biofabricated material) and it is what should happen to create the next generation of technologies that will enable humans to live happily and sustainably on a prosperous Earth[59].

57 Ecovative Design LLC is a materials company headquartered in Green Island, New York, that provides sustainable alternatives to plastics and polystyrene foams for packaging, building materials and other applications by using mushroom technology.
Wikipedia Contributors, “Ecovative Design,” Wikipedia, December 4, 2019, https://en.wikipedia.org/wiki/Ecovative_Design.

58 *David N Benjamin, Embodied Energy and Design : Making Architecture between Metrics and Narratives (New York, Ny: Columbia University Gsapp ; Zürich, Switzerland, 2017).*

59 *ibid*

living materials: a short atlas

A widely accepted definition of living from biology suggests living organisms as open systems, like machines, that survive by transforming energy and decreasing their local entropy to maintain a stable and vital condition defined as homeostasis.
Accordingly, all living things take in nutrients from their surroundings, for the purpose of growth or to provide energy. They break down food within their cells to release energy for carrying out processes such as movement.
They excrete. They grow. They all sense and respond to stimuli around them such as light, temperature, water, gravity and chemical substances. They all reproduce and adapt to their environment[60].
Biodesign integrates biological processes and living organisms (e.g. plants and organisms such as bacteria, algae and fungi) into design processes so that non-renewable resources can be reduced[61]. Living organisms are often used to achieve sustainable material alternatives and new material expressions in 'non-living' artefacts. However, Elvin Karana suggests that "liveness" can be extended to living artefacts so that design outcomes go beyond mere sustainable alternatives. Mobilising "liveness" over the useful life of a product and imagining "liveness" as a 'persistent material quality' in everyday products can enable new interactions, responsive behaviour and "new ways of acting and living".
To understand the experience of biobased materials, most scientific attention to date has been focused on user studies exploring the relationships between specific material properties (e.g. tactile roughness, sheen, etc.) and meanings and emotions (e.g. comfort, surprise). The unique qualities of living materials, such as their temporal properties, which are influenced by the well-being of organisms (i.e. their growth and reproduction), have not been part of design research and practice[62].
An interesting view over the emerging field of bio-based materials was tackled at the Triennale di Milano´s exhibition back in 2019 "Broken Nature", curated by Paola Antonelli.
By means of cross-over projects at the threshold between design and science, the exhibition aimed "correcting humanity's self-destructive course but also at replenishing our relationship with the environment and with all species – including other human beings[63]".
One of the most interesting selection was the one embodying notions of restorative design solutions.
But this whole restorative design, opened up a global network of experimental approaches questioning the idea of integrating living systems into the design process itself.
What if livingness was a quality of everyday artefacts and become active agent with autonomous subjectivity and self-maintaining chemistry?

Some other interesting examples can be found f.i. in:

60 *Elvin Karana, Still Alive: Livingness as a Material Quality (Delft University of Technology, 2020).*

61 *Vera Meyer, "Connecting Materials Sciences with Fungal Biology: A Sea of Possibilities," Fungal Biology and Biotechnology 9, no. 1 (March 1, 2022), https://doi.org/10.1186/s40694-022-00137-8.*

62 *Hazal Ertürkan, "Caradt," https://caradt.nl/project/living-material-experiences-facilitating-experiential-understanding-of-living-materials-in-material-driven-design/, 2019, https://caradt.nl/project/living-material-experiences-facilitating-experiential-understanding-of-living-materials-in-material-driven-design/.*

63 *Paola Antonelli, "Broken Nature Special Commissions | Triennale Milano," www.triennale.orgen, 2019, https://triennale.org/en/events/special-commissions.*

Fig. 25 Daniel Parnitzke, Mycelium Material Workshops, 2017.

Fig. 26 Atelier Luma, Algae Geograpies, Triennale di Milano Atelier Luma-Broken Nature 2019

Fig. 27 Daniel Parnitzke, Mycelium Material Workshops, 2017.

Fungal Mycelium Bricks - Ecovative

“Mushroom materials are durable and naturally fire resistant, and they can be easily moulded to any shape. Moreover, they are environmentally friendly. They are carbon neutral and if exposed to living organisms, they can be decomposed. Mycelium as a construction material offers excellent opportunities for upcycling agricultural waste into a low-cost, sustainable and biodegradable material alternative. The team constructed the bricks from mycelium grown on agricultural waste. The mycelium brick is by far not as strong as a conventional brick – but then it is much lighter. Whereas bricks have a compressive strength of at least 28 MPa, the mushroom bricks can only withstand 0.2 MPa. But they are 60 times as light as the conventional brick: 43 kg/m3 as opposed to 2,400 kg/m3[64].”

Algae Geographies by Atelier Luma

“A bio-laboratory set up by Atelier Luma in collaboration with Studio Klarenbeek & Dros in order to explore the potential of growing micro- and macro-algae locally. The algae are mixed with biopolymers to produce a fully bio-sourced material that can replace non-biodegradable fossil oil-based plastics. The project proposes a new model for circular production through biofabrication and decentralized fabrication such as 3D printing. Raw materials and waste materials (from 3d printer) were available. Once appropriately processed, these can be turned into bioplastics, biodegradable plastics made from natural raw materials[65].“

Alive, David Benjamin

“This probiotic pavilion is a kind of walk-in living sponge constructed from luffa, chipboard and microbes, which will uniquely interact with human visitors. (Luffa is a gourd from the cucumber family; it has been cultivated for centuries for its fibrous innards, used as sponges.) The pavilion will be home to specific colonies of microbes, which will combine with microbes brought in by human visitors to create a healthy, balanced microclimate[66].”

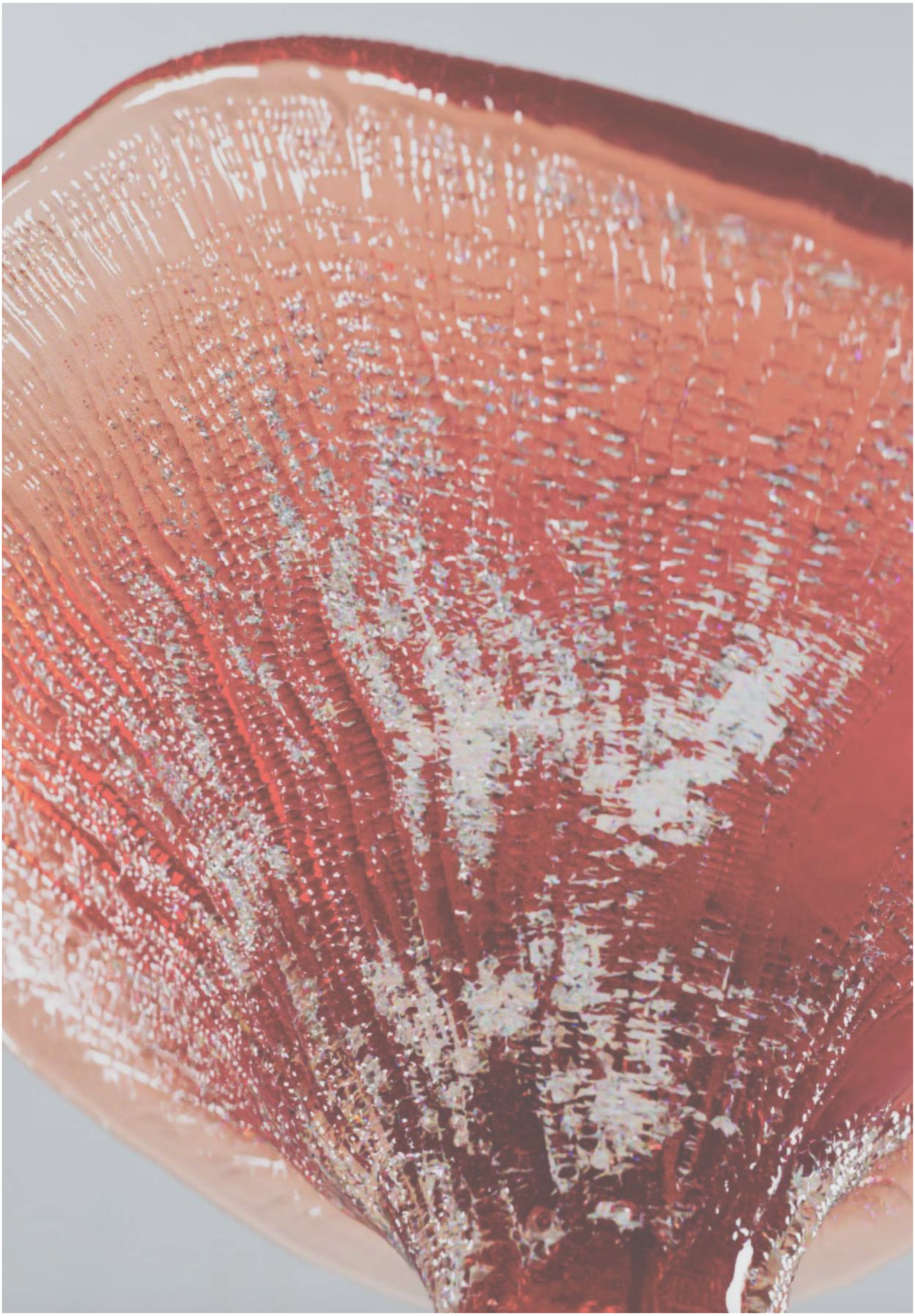
64 *Daniel Parnitzke, “Workshop: Introduction to Fungi,” Daniel Parnitzke, 2017, https://danielparnitzke.de/project/workshop-introduction-to-fungi.*

65 *Atelier Luma, “Claudia Catalani - Algae Geographies,” catalaniclaudia.myportfolio.com, 2021, https://catalaniclaudia.myportfolio.com/copia-di-fish-left-lovers.*

66 *Silke Bender, “Nomad / David Benjamin,” The Nomad Magazine, accessed December 30, 2022, https://www.the-nomad-magazine.com/david-benjamin-architecture-comes-alive/.*

II

fungal mycelium



***"We are stuck with the problem of living despite economic and ecological ruination. Neither tales of progress nor of ruin tell us how to think about collaborative survival. It is time to pay attention to mushroom picking. Not that this will save us - but it might open our imaginations."^
Anne Tsing***

Fig. 28&29 Jason Wu, Mushroom Digital, New York, 2022.

fungi kingdom

Like an iceberg, the visible portion of a fungus is only a small fraction. Below the surface, it develops white thread- like roots called mycelium. These are extremely thin and develop in all directions, creating a reticulated net that grows very fast. When planted in the right substrate, mycelium behaves like glue, binding that substrate and transforming it into a solid block. When creating products for construction, this substrate usually is agricultural waste such as sawdust, residual wood, hemp, or straw. Fungal biotechnology can advance the transition from our petroleum-based economy into a bio-based circular economy and can sustainably produce resilient sources of food, feed, chemicals, fuels, textiles, and materials for construction, automotive, and transportation industries, for furniture, and beyond. Fungal biotechnology offers solutions for securing, stabilizing, and enhancing the food supply for a growing human population, while simultaneously lowering greenhouse gas emissions. Up until now, it has been used as a packaging material by Dell and Ikea, as faux leather by Hermès and the possibilities for building are slowly being explored and tested. Mycelium serves as a load transfer medium between a fibrous substrate, in a similar way to the matrix phase of a polymer composite. Fungal biotechnology has, thus, the potential to make a significant contribution to climate change mitigation and meeting the United Nation's sustainable development goals through the rational improvement of new and established fungal cell factories[67]. Fungi are organisms having a place with the kingdom Fungi that incorporates 144,000 types of organisms, for example, yeasts, rusts, molds, mushrooms, etc. Fungi are the most broadly disseminated organism on the globe as it has medicinal properties. A portion of these organisms makes parasitic or symbiotic associations with plants and animals[68]. Their existence is critical to individuals, as it produces food and things like bread, cheese and wine. Once considered plant-like organisms, this species is more closely related to animals than plants. A major distinctions between fungi and plants is that fungi manufacture their cell walls from chitin, while plants from cellulose.
As for the lifecycle itself, most fungi undergo mitosis, which is extremely different from plants. It's worth noting that early in the last century, they were grouped in the plant kingdom. Later systems of classification recognized these fundamental differences - and the fact that they indi- cated a fundamental disconnect between plants and fungi - and started including them in their kingdom[69]. Neither plants nor animals, fungi are the most underappreciated kingdom of the natural world. During a billion years of evolution, they've become masters of survival. And yet, fungi have also been integral to the development of life on Earth. Neither land plants nor terrestrial animals would exist without them. "Fungi are remarkable chemi-

67 *Vera Meyer, "Connecting Materials Sciences with Fungal Biology: A Sea of Possibilities," Fungal Biology and Biotechnology 9, no. 1 (March 1, 2022), https://doi.org/10.1186/s40694-022-00137-8.*

68 *David Moore, Geoffrey D. Robson, and Anthony P. J. Trinci, "4.1 Mycelium: The Hyphal Mode of Growth," www.davidmoore.org.uk, 2019, http://www.davidmoore.org.uk/21st_century_guidebook_to_fungi_platinum/Ch04_01.html.*

69 *CK 12, "CK12-Foundation," flexbooks.ck12.org, 2022, https://flexbooks.ck12.org/cbook/ck-12-middle-school-life-science-2.0/section/6.10/primary/lesson/fungi-classification-ms-ls/.*

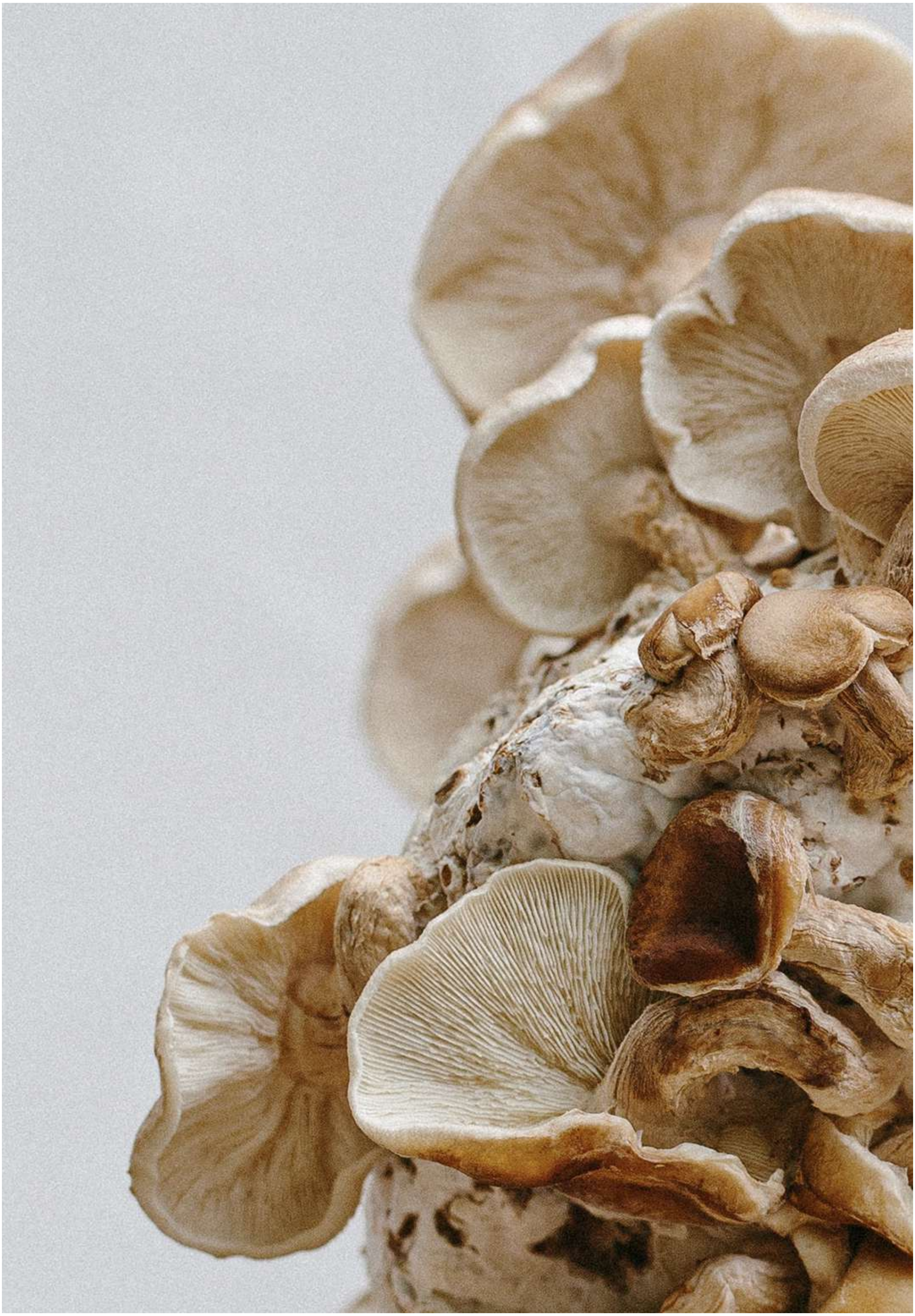
sts," says McMaster University biochemistry professor Gerry Wright. Fungi produce molecules that humans still can't reproduce in a lab, and we're only beginning to scrape the surface of what we can learn from them[70]. Their natural habitat is vast. They can be found in practically every environment on earth, from forests to des- erts even the ocean depths. They have some characteristics in common with both plants and animals. Like plants, these organisms live in one place and cannot move on their own. Some species reproduce through spores, like simple plants. Like animals, they are heterotrophic because they get their nourishment from other living things or decaying organisms. Within the kingdom, there is much diversity, both in physical characteristics and in the way they reproduce. For example, molds are tiny fungi that grow in moist environments. However, most fungi have some common characteristics. A dense network of long filaments called hyphae forms in the underground part of the fungus. Hyphae are part of the mycelium, which is the main body of the fungus and is usually found in the underground part. Fungi do not do chlorophyll photosynthesis like plants but grow directly on their food resources, such as soil, wood, and even dead animals when hyphae penetrate the food, they produce chemicals that turn organic matter into nutrients that can be absorbed. The hyphae expand as much as possible to absorb all available nutrients. So what we see of a fungus is only a very small part. This aerial part is called the fruiting body and is made up of the stalk and the cap. Underneath the cap of some fungi has special hyphae, called lamellae. Their job is to produce the spores, that is the reproductive cells. When the spores detach from the gills, they fall to the ground and sprout, giving life to fungi. Yeast, on the other hand, does not reproduce through spores, instead of using a process called budding. New organisms form on the body of the parent, and then break off. Fungi are much more a part of our lives than we may think, some are extremely poisonous other fungi can create skin diseases like ringworm and athlete's foot. Most importantly, mushrooms are the cause of 80% percent of plant diseases. However, they can also be very useful, as they are decomposers and feed on dead organisms, putting nutrients back into the food chain. Some fungi live in symbiosis with other organisms[71]. Lichens, which are a combination of fungi and green algae, promote the erosion of rocks and their transformation into the soil. Many antibiotics are derived from particular types of molds. Like bacteria, fungi play an essential role in ecosystems because they are decomposers and participate in the nutrient cycle by breaking down organic materials into simple molecules. Fungi often interact with other organisms, forming beneficial or mutualistic associations[72]. Within the previously mentioned properties, studies already showed numerous additional characteristics given by this impressive species. Fire resistance and thermal properties of mycelium are a few of the various peculiarities that can be found within such an extraordinary material.

70 *Chris Dart, "Fungi Are Responsible for Life on Land as We Know It," Cbc, n.d., https://www.cbc.ca/natureofthings/features/fungi-are-responsible-for-life-on-land-as-we-know-it.*

71 *Angela Hartsock, "Introduction to Fungi," Study.com, 2022, https://study.com/learn/lesson/kingdom-fungi-overview-characteristics-examples.html.*

72 *David Moore, Geoffrey D. Robson, and Anthony P. J. Trinci, "4.1 Mycelium: The Hyphal Mode of Growth," www.davidmoore.org.uk, 2019, http://www.davidmoore.org.uk/21st_century_guidebook_to_fungi_platinum/Ch04_01.html.*

Fig. 30 & 31 Marta Golova, Shiitake Mushroom Macro, 2022.



anatomy of fungi

This extremely resilient species, show us and address crucial questions about today, at the peak of the Anthropocene: what can we learn from such an extraordinary organism which can adapt insight of climate changes? Nature has organized life in innumerable forms and ways, all autonomous but independent, like the single instruments of a great orchestra. Every living species, whether plant, animal, or intermediate between the two, such as fungi, contributes to the decomposition of substances. Through successive decompositions, whatever "thing" has lived must return to be what it was originally: Nitrogen, Carbon, Hydrogen, and Oxygen. Therefore, they should be seen, together with other living beings, as instruments that, directed by nature, allow the continuation of life. Consequently, their collection or destruction, if done systematically and, besides impoverishing the mycological flora, could also lead to the extinction of entire species and alterations in the biological balance[73].
Fungi represent a group of living organisms, comparable to very atypical vegetables: as opposed to the latter, they do not have chlorophyll. Moreover, they differ from most plants because they need to live off substances already elaborated by other living beings, as they are not able to elaborate on them or manufacture them by themselves. They can resemble green plants because, with few exceptions, they have defined cell walls and, just like plants, are immobile. Finally, they reproduce using spores, which can be compared to the seeds of higher plants. However, fungi do not have stems, roots, or leaves and are devoid of the vascular system - which from the roots carries the vital lymph up the trunk to reach the branches and leaves - typical of plants. Like any living organism, they are formed by the whole of an indefinite number of cells, whereby cell we mean the basic system of structure and functioning of every living organism. The main part of the fungal organism is formed by a thin and intricate network of whitish filaments, most of the times invisible to the naked eye, which, starting from the base of the stem, branch out in the soil and the ground below, sometimes even for several tens of meters in length. What is collected as "mushroom" is the fructification, limited and temporary, of that intricate and invisible network of underground filaments called mycelium, which can be, therefore, compared to a tree, of which the mushroom is the fruit[74].
Mycelia form very long-lived complexes, sometimes almost perennial: in nature have been seen to grow fungal colonies continuously for over 400 years and some can likely reach the venerable age of 1000 years[75].

73 *Anna Tsing, The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins (Princeton: Princeton University Press, 2015).*

74 *Brian Lovett, "Three Reasons Fungi Are Not Plants," ASM.org, 2021, https://asm.org/Articles/2021/January/Three-Reasons-Fungi-Are-Not-Plants.*

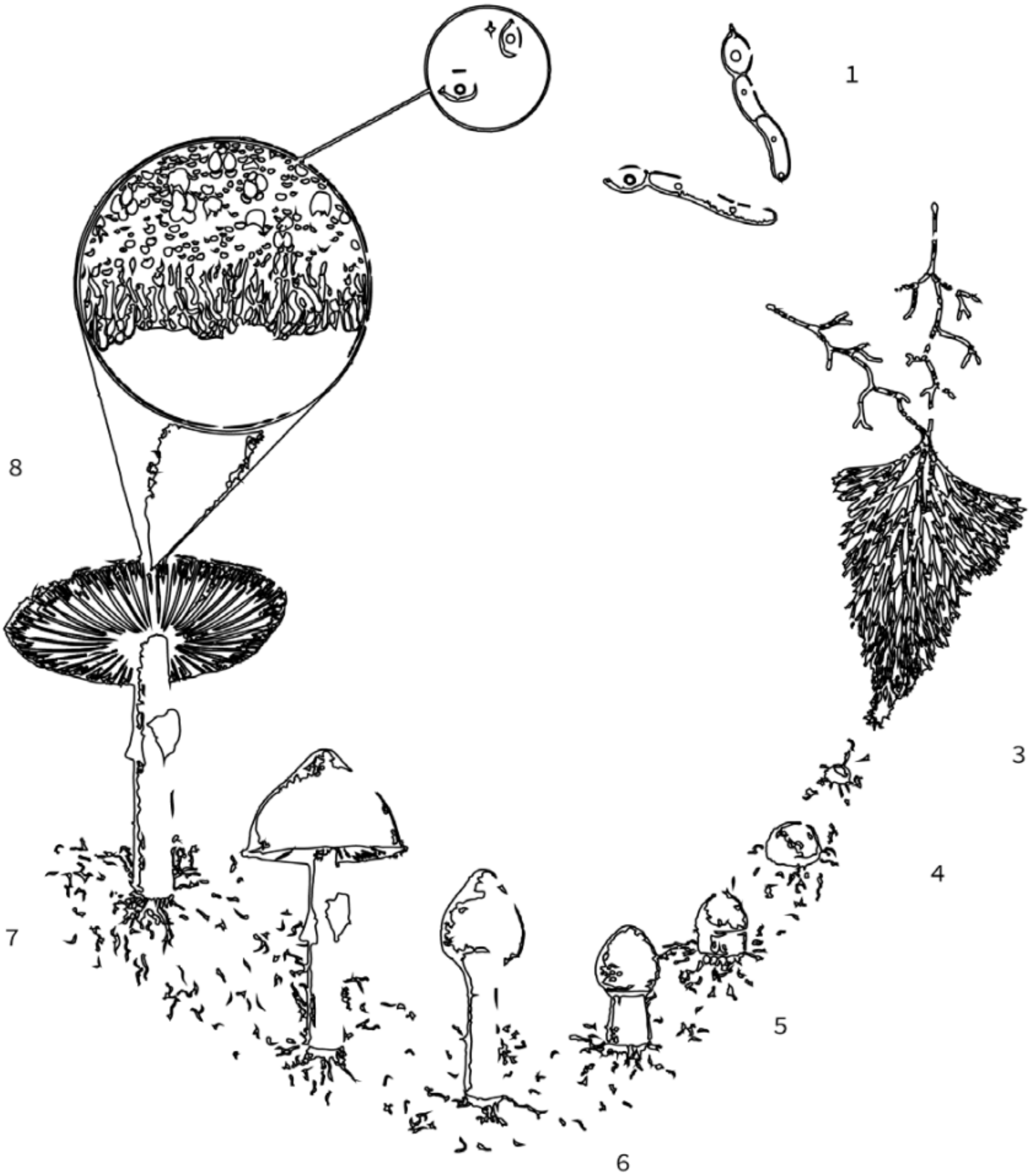
75 *Julien Haut-Rhin Mycological Society, "Mycelium - La Boutique Du Champignon in Eguisheim," La Boutique Du Champignon, May 18, 2021, https://www.laboutiqueduchampignon.com/en/the-mycelium/.*

76 *Mycorena, "Mycelium, Mycoprotein and Fungi, What Does It Mean?," Mycorena, 2021, https://mycorena.com/mycotalks/mycelium-mycoprotein-and-fungi-what-does-it-mean.*

77 *Roberta Lombardi, "Il Regno Dei Funghi," www.youtube.com, 2021, https://www.youtube.com/watch?app=desktop&v=8b-2ST3A2BjY&ab_channel=RobertaLombardi.*

Theoretically, it is possible - in ideal conditions - to have a certain production of mycelium fungi every year. It is therefore the whole of the fruiting bodies or "mushrooms" and the network of underground filaments or "mycelia" which make up the whole fungal body. The mycelium is formed by very thin single filaments that have a di- ameter between 0.0005 and 0.15 mm. Single filaments are called mycelial hyphae, whereas - as already under- lined in the previous paragraph - a whole of numerous hyphae is called mycelium. The hyphae, ultimately, are nothing more than simple successions or linear multiplications of cells that can, in theory, stretch to infinity, if they do not find obstacles or limits to their proliferation[76].
They can then divide, thanks to particular intermediate cells, giving rise to other branched filaments that diverge from the main hyphae: with this mechanism they multiply and branch in every direction. Only when you reach multiple bundles of hyphae you can start talking about real mycelium and finally when more mycelia merge and enlarge, we are faced with the so-called mycelial cords, already visible to the naked eye. This is the moment in which the mycelium passes from the vegetative phase to the reproductive one: on the mycelial cords are formed clusters similar to big lumps, to mushroom sketches, called thalli, which growing take the typical shapes with a stalk and a cap. When the carpophore or fungus is completely sketched out the last act takes place: the fungus from underground pierces the ground and comes to the light to finish its development and to mature to reach its real purpose, that of reproduction which happens with the release of millions and millions of spores, that is the seeds of fungal reproduction[77].

Fig. 32 Paul Stamets, Schematic Life Cycle of Fungi, 2017.



1. SPORE GERMINATION
2. FUSION OF COMPATIBLE HYPHAE
3. HYPHAL KNOT
4. MYCELIUM IS FORMED
5. PINHEAD
6. PRIMORDIUM
7. FRUITBODY
8. SPORULATION

mycelium composites

Mycelium is the vegetative part of fungi consisting of a system of filamentous hyphae. The cell wall of hyphae is made of chitin, a modified polysaccharide that is tough, inert, and not soluble in water, which has promising potential for biotechnology.

It grows on lignocellulosic substrates and can be made into lightweight composites. Although mycelium composites have great potential to replace some building components, it is still unclear whether they can be used and produced on a large scale, and manufacturing process issues can be improved. Mycelium offers a wide range of capabilities for real-world applications, particularly for design. As a relatively new material in the field of architecture, there is still ample room for research and implementation in this area. This leads to many new methods, information and ideas from those working with fungi. Mycelium has no definite shape and grows exponentially in three dimensions in search of food in interaction with bacteria, roots, rocks and soil. Mycelium plays an indispensable role in the natural ecosystem. The breakdown of organic matter prevents its accumulation and renews the soil by creating space for new life[79]. Mycelium connects trees and plants and facilitates the transfer of nutrients and information between them through mycorrhizal networks[80] and has the remarkable ability to thrive even in environments disturbed by humans. The mycelium is the network of intertwined, threadlike hyphae that make up the vegetative part of fungi. An "hypha" is the most basic unit of development of filamentous fungi, which grow by elongating and branching hyphae into a substance. The industrial potential of fungi has long been explored in human history, from food production (such as cheese, bread and beer) to medical biotechnology (such as antibiotics and antiviral drugs) and, more recently, to the manufacture of everyday artifacts (such as furniture, plastics replacement and clothing).

Fungal lignocellulosic materials inherit the properties of both wood and mycelium, resulting in lightweight and strong biocomposites. In general, they exhibit good insulating properties for both heat and sound, are hydrophobic, and have good tensile and compressive strength[81]. In addition, the raw materials for these composites are cheap, locally produced, renewable, and able to capture and store carbon dioxide. The main components of mycelial composites are lignocellulosic fibers from soil or forest material streams linked together by an interwoven network of mycelia, the root-like structures of fungi. When the fungus colonizes a substrate, it first grows on the surface and, depending on the properties of the material, gradually spreads its mycelium over the entire surface in a complex three-dimensional binding matrix. During growth, the fungus secretes extracellular polymeric substances (EPS) composed mainly of polysaccharides and proteins[82]. Their role is to facilitate growth and allow the cells to anchor themselves to the substrate, acting as an adhesive between the hyphae and the substrate. In addition, the EPS (extracellular polymeric substance) allows the particles to aggregate around the hy-

78 / *Mouyna et al., "Glycosylphosphatidylinositol-Anchored Glucanosyltransferases Play an Active Role in the Biosynthesis of the Fungal Cell Wall," The Journal of Biological Chemistry 275, no. 20 (2000): 14882–89, https://doi.org/10.1074/jbc.275.20.14882.*

79 *Suzanne Simard, "How Trees Talk to Each Other | Suzanne Simard," YouTube Video, YouTube, August 30, 2016, https://www.youtube.com/watch?v=Un2yBglAxYs&ab_channel=TED.*

80 *Elise Elsacker et al., "Mechanical, Physical and Chemical Characterisation of Mycelium-Based Composites with Different Types of Lignocellulosic Substrates," Mechanical, Physical and Chemical Characterisation of Mycelium-Based Composites with Different Types of Lignocellulosic Substrates, March 7, 2019, https://doi.org/10.1101/569749.*

81 *Kylie Boyce, K Boyce, and A Andrianopoulos, "Morphogenesis: Control of Cell Types and Shape Molecular Techniques for Use in Talaromyces (Penicillium) Marneffei View Project Morphogenesis: Control of Cell Types and Shape," Morphogenesis: Control of Cell Types and Shape, 2006, https://doi.org/10.1007/3-540-28135-5_1.*

82 *Salvatore A. Gazzè et al., "Nanoscale Observations of Extracellular Polymeric Substances Deposition on Phyllosilicates by an Ectomycorrhizal Fungus," Geomicrobiology Journal 30, no. 8 (September 14, 2013): 721–30, https://doi.org/10.1080/01490451.2013.766285.*

phae, leading to irreversible fusion of the material. Mushroom-based materials are part of a class of biotechnology that promises to largely offset the effects of the short lifespan of buildings in the modern era and can be composted at the end of their lives[83]. Micromaterials have become an international business and are being produced on an industrial scale. The cultivation of micromaterials involves the propagation of fungal hyphae in a fibrous substrate for several days, under the right environmental conditions, until a composite mass is formed. Mycelial biomass is formally agnostic and can be grown in almost any form by packing the inoculated fibers with a live fungus in a mold of a breathable, noncellulose-based material (usually plastic) to prevent the mycelium from permanently attaching to the mold. The limits to growth are biological and environmental. Important precautions are sufficient sterility to avoid contamination by unwanted organisms, access to food and nutrients, maximum darkness, and proper access to oxygen. Depending on the region, species of fungus grown, and scale of production, growth chambers may need active control to maintain optimal temperature and humidity, which is likely to require energy resources. A common problem for mycelium growers is the accumulation of contaminants, sometimes dangerous molds and other organisms that thrive in similar environmental conditions. Usually, the fiber substrates in which mycelia are grown must be sterilized or pasteurized, which can also be prohibitively expensive because of the equipment and energy required for this process. Another important precaution when building with composite materials is that at certain thicknesses the mycelium does not grow sufficiently due to lack of oxygen, which can lead to contamination. Once fully developed, the final product is usually actively dried to arrest growth, resulting in a material similar to expanded polyurethane or expanded polystyrene, with flame spread resistance comparable to gypsum and low thermal conductivity. The many complex factors associated with the growth of mycelium materials make it difficult to control the relative properties of the material (mechanical, thermal, acoustic or other) and are considered as a reported average. Different combinations of mycelial strains and fiber substrates give different properties in terms of structural integrity, density, thermal conductivity, moisture resistance and visual quality. Some studies have reported on mechanical properties, moisture impact, acoustic properties based on mycelial growth, fire resistance, biodegradability, and aesthetic properties. One of the main challenges of using mycelium in large-scale structural applications is that it is a naturally weak material (0.1-0.2 MPa compressive stress on average without mechanical compression) and is assumed to perform best in compression[84]. Despite this limitation, micromaterials are also very light and have an advantageous strength-to-weight ratio compared to concrete. This suggests that large structures and even long-span structures can be built with advantageous material placement. Over the past decade, several large-scale pavilions have demonstrated the potential of micromaterials in building structures. Although these most of them are examples of using mycelium composites at the building scale, they are not load-bearing applications - excluding rare research cases[85]. “Interestingly, there has been little variation in the approach to building with mycelial

83 *Ohana Y. A. Costa, Jos M. Raaijmakers, and Eiko E. Kuramae, “Microbial Extracellular Polymeric Substances: Ecological Function and Impact on Soil Aggregation,” Frontiers in Microbiology 9 (July 23, 2018), https://doi.org/10.3389/fmicb.2018.01636.*

84 *Diederik van der Hoeven, “Mycelium as a Construction Material,” Bio Based Press, April 7, 2020, https://www.biobased-press.eu/2020/04/mycelium-as-a-construction-material/.*

85 *Jonathan Dessi-Olive, “Fabrication Techniques Using Myco-Materials | Encyclopedia MDPI,” encyclopedia.pub, 2022, https://encyclopedia.pub/entry/history/show/67056.*

86 *ibid*

materials, and the fabrication techniques used to assemble myco-structures have remained canonically familiar in architecture and engineering. These include logical adaptations of brick or block assembly systems, monolithic castings, 3D printing-based techniques, and hybrid techniques[86]".

This doesn´t want to discourage the possibilities that this material can hold for future challanges, considering the fact that mycelium composites are still an emerging material when it comes to architecture and the building industry. A building´s corpus is partially made of structural elements, a high percentage of it is still entailing secondary elements (infills, insulation, partition walls, etc...) and imagine that such elements could be fully recyclable and with a low-carbon footprint.

Fig. 33 Mike Smith, Mycelium, 2016.

After all, in the coming years, people will increasingly understand that it's a duty to work with nature instead of emptying it. Policies stimulate and reward the scaling up and knowledge sharing of bio-based processes and products. Niches industries replace their animals with algae, mushrooms, and mosses and their maize and soy with cattail, hemp, and other wet crops. Hopefully, this message will be delivered on a global scale. The construction world is engaged in converting those crops into products that they can use in homes, office buildings, and eventually the design of our cities. Artists and creatives shape fairs, artworks, events, and temporary installations with the most beautiful creations that consist entirely of nature. Citizens demand that their packaging, products, and applications cause little or no damage. The future is in the hands of those who hold CO2 instead of emitting it, raise the earth instead of lowering it, let houses breathe instead of suffocating, and bring people and nature back together. The choice to work with naturally grown and locally sourced materials is a choice to minimize the impact on the environment and to explore the path to a fully bio-based future. In addition, mycelium composites not only strive to minimize CO2 emissions but also to collect the CO2 already present in the air. It is well known that the kingdom of fungi is based on a biological system capable of transforming organic matter into multiple rich products of wide utility and provides distinct opportunities to address urgent challenges even before humans. Mushroom biotechnology can implement the ecological transition in a circular form not only from the energy point of view but also related to different industries, such as construction, food, chemical, pharmaceutical, automotive, textile, transportation, and so on. Most importantly, the role of fungi could play a very important role in reducing CO2 emissions and thus mitigating climate change, through the rational improvement of new and established fungal cell factories[87]. Without fungi to aid in decomposition, all life in the forest would soon be buried under amountain of dead plant matter. In short, fungi eat death, and in doing so, create new life. Scientists estimate that there are over 5,000,000 species of fungi on Earth, but we've only discovered about one percent of them. Further discoveries could be used for anything from breaking down industrial waste to developing new sources of food to making new medicine. "Most of the coolest stuff nature can do we haven't discovered yet. And so we both systematically look, and we bumble around a little bit[88]".

87 *Vera Meyer et al., "Growing a Circular Economy with Fungal Biotechnology: A White Paper," Fungal Biology and Biotechnology 7, no. 1 (April 2, 2020), https://doi.org/10.1186/s40694-020-00095-z.*

88 *Chris Dart, "Fungi Are Responsible for Life on Land as We Know It," Cbc, n.d., https://www.cbc.ca/natureofthings/features/fungi-are-responsible-for-life-on-land-as-we-know-it.*

89 *John Hill, "Hy-Fi at MoMA PS1 -," World-Architects, 2014, https://www.world-architects.com/en/architecture-news/found/hy-fi-at-moma-ps1.*

90 *Avinash Rajagopal, "Behind 'Hy-Fi': The Organic, Compostable Tower That Won MoMA PS1'S Young Architects Program 2014," ArchDaily, February 17, 2014, https://www.archdaily.com/477912/behind-hy-fi-the-entirely-organic-compostable-tower-that-won-moma-ps1-young-architect-s-program-2014.*

91 *Carlo Ratti, "The Circular Garden," Carlo Ratti Associati, 2019, https://carloratti.com/project/the-circular-garden/.*

92 *Amy Frearson, "Tree-Shaped Structure Shows How Mushroom Roots Could Be Used to Create Buildings," Dezeen (Dezeen, September 4, 2017), https://www.dezeen.com/2017/09/04/mycotree-dirk-hebel-philippe-block-mushroom-mycelium-building-structure-seoul-biennale/.*

Hy-Fi Pavilion - MoMA PS1, David Benjamin, 2014

Designed by David Benjamin to explore innovative forms and technologies. "Corn and mycelium fuse together to create lightweight, organic bricks that are stacked in a tubular tower. Wood structural members splay the undulating form to give revelers access to the cooling interior that is designed like a chimney to withstand wind forces and draw warm air up and out the openings at the top[89]. The mushroom brick tower consisted of 10,000 bricks and reached 40 feet into the air. "Our organic bricks are exciting because they harness the incredible 'biological algorithm' of mushroom roots and tune it to manufacture a new building material that grows in five days, with no waste, no input of energy, and no carbon emissions[90]", says the founder David Benjamin.

The Circular Garden - Carlo Ratti Associates, 2019

The Circular Garden pushes the boundaries of using mycelium – the fibrous root of mushrooms – in design. The Circular Garden engages with mycelium at the architectural scale – with a series of 60 4-meter-high arches made of mycelium scattered around the Orto Botanico, for a total of 1 kilometer of mushroom. In order to create self-supporting mycelium structures on such a scale, the project takes inspiration from the great Catalan architect Antoni Gaudí using the inverted catenary system. According to this method, the best way to create pure compression structures is to find their form using suspended catenaries and then invert them. The same applies to the Circular Garden, where the catenaries compose a series of four architectural "open rooms" scattered throughout the garden[91].

Myco Tree - Dirk Hebel and Philippe Block, (ETH Zürich) 2017

Myco-Tree is a spatial branching structure made out of load-bearing mycelium components. Its geometry was designed using 3D graphic statics, keeping the weak material compression-only and its complex nodes were grown in digitally fabricated molds. "To show the potential of new alternative materials, particularly weak materials like mycelium, we need to get the geometry right. Then we can demonstrate something that can be very stable, through its form, rather than through the strength of the material" says Block. These components are at- tached with a system of bamboo endplates and metal dowels – but it is the mycelium that is taking all the load. Something naturally grown and messy was contrasted with high-end digital fabrication[92].

Fig. 34 Kris Graves, Hy-Fi Pavillion from David Benjamin and Ecovative, MoMa PS1, 2014

Fig. 35 N.a., The Circular Garden, Carlo Ratti Associates for INTERNI Human Spaces, Orto Botanico Brera, 2019

Fig. 36 Carlina Teteris, MycoTree, KIT Karlsruhe + ETH Zürich + Singapore-ETH Centre, 2017

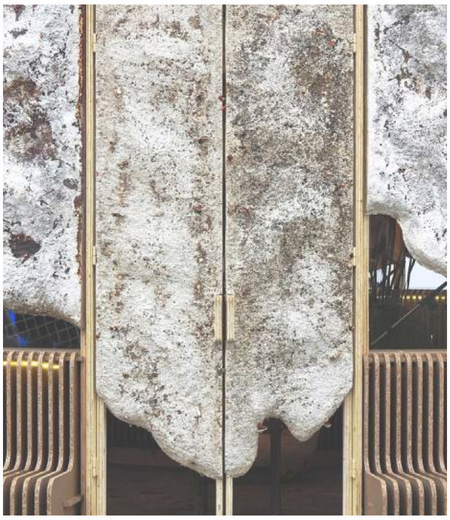
Insulation Panels - BIOHM, 2016

Among BIOHM´s achievements comes an insulation panel made out of mycelium, which will be the world's first accredited mycelium insulation product. To grow mycelium, they identify commercial and agricultural by-products that would otherwise go to landfills. "The manufacturing process is estimated to be carbon-negative, sequestering at least 16 tonnes of carbon per month". According to BIOHM, Mycelium has several benefits, outperforming the majority of market-leading synthetic insulation products. Initial thermal testing indicates that mycelium insulation can outperform the vast majority of market-leading synthetic and "organic" insulation products. BIOHM´s mycelium insulation panels can achieve a thermal conductivity of 0.024W/m.K. surpassing the values that can be achieved by market-leading but unsustainable materials such as glass fiber (0.032-0.044W/m.K.), mineral wool (0.032-0.044W/m.K), expanded polystyrene (0.036W/m.K) extruded polystyrene (0.029-0.036W/m.K) With the ever-evolving research this capacity can be an increase[93].

Acoustic Panels - Mogu, 2017

A collection of sound absorbing panels, characterized by remarkable technical properties and a unique aesthetics. Thanks to the standardization of biological processes, Mogu produces materials by activating the growth of fungal microrganisms on agroindustrial residues, such as cotton raw fibres. By feeding on the organic residues and transforming them in high-value matter, mycelium acts as a reinforcement and generates a coherent composite. The high porosity, together with its exceptional mechanical properties and fire resistance, makes Mogu products the perfect candidates to improve the acoustic comfort of every environment[94].

Cladding Panels for the Dutch Pavilion - GrownBio, 2020



The Growing Pavilion is an iconic ode to biobased materials. The award winning pavilion is unique in the large number of biobased materials used together to create a building and shows how it shows the possibilities and the new aesthetic of biobased materials.
The 10 ton CO2 negative and 95% circular structure is made up of five grown core raw materials: wood, mycelium, residual flows from the agricultural sector, bulrush (cattail) and cotton. Showcasing each material as raw as possible, the pavilion has a very distinctive visual identity, organic texture and color. It stands as a necessary and viable solution for reducing the use of fossil resources and its destructive impact on climate change. Sparking imagination to trigger a turnaround in thinking, acting and building biobased[95].

93 *Biohm, "BIOHM | Mycelium Insulation," BIOHM #FutureOfHome, 2021, https://www.biohm.co.uk/mycelium.*

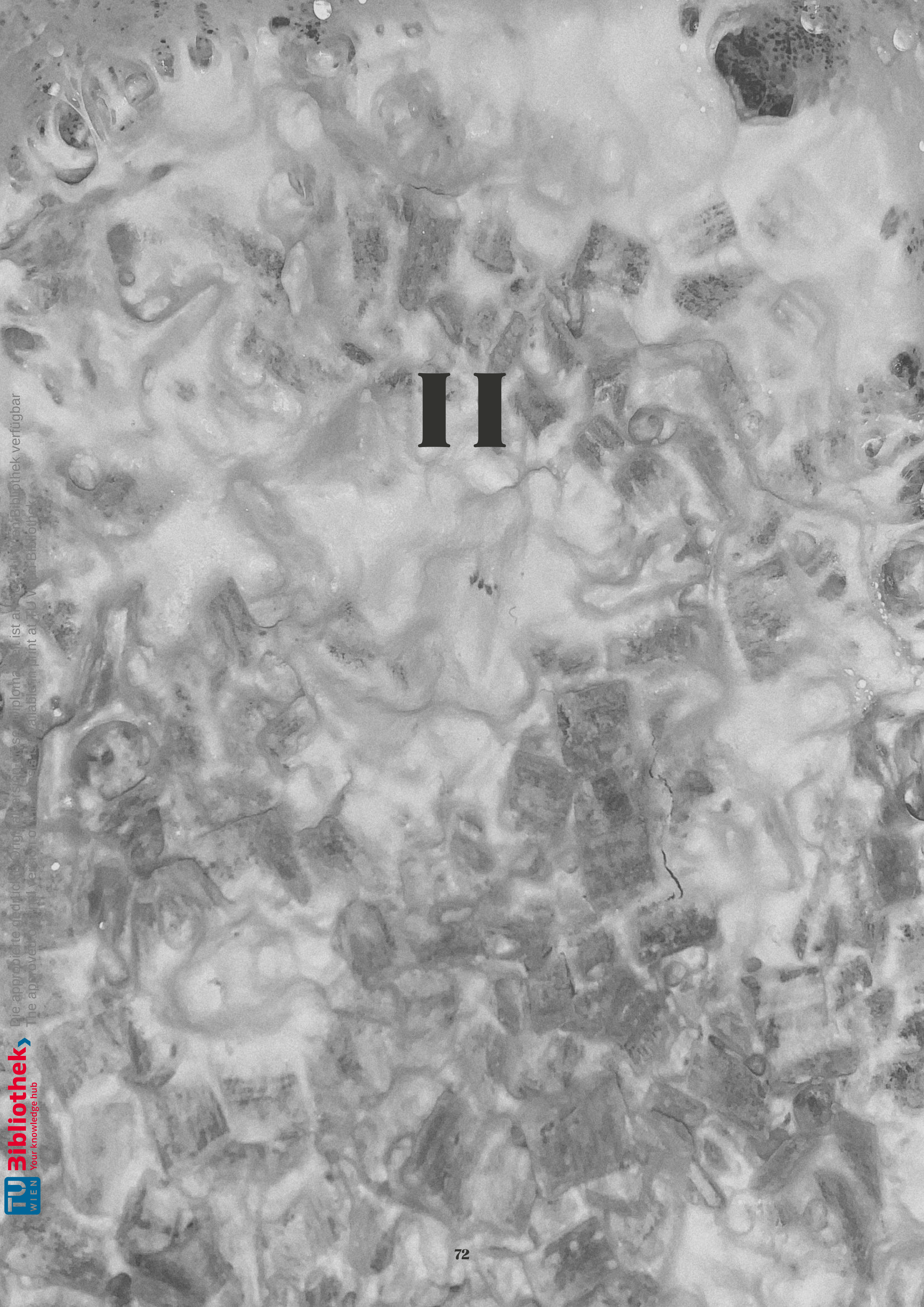
94 *Inarzo, "Mogu: Mycelium Decorative Acoustic Panels," Archiproducts, 2022, https://www.archiproducts.com/en/mogu.*

95 *The Growing Pavilion, "About the Growing Pavilion - the Growing Pavilion," The Growing Pavilion, 2019, https://thegrowingpavilion.com/about/.*

Fig. 36 Biohm, Insulation Panels, UK, 2016

Fig. 37 Mogu, Mogu Wave Acoustic Panels, Italy, 2022

Fig. 38 Erik Melander, The Growing Pavilion, 2019.



II

experiment

Bio-design as a conceptual solution is not only creating practically applicable concepts, its also contributes challenging previous concepts to capture future scenarios. In this part of the thesis, we aim to expand our research on a specific material experimentation as mycelium composites. Rather than one-sided strategies, the experiment focuses on mycelium´s material qualities. Mycelium is mainly composed of natural polymers of fungal hyphae. Its natural sources, such as chitin that forms dense polymer networks, will be used as a binding material for the composites. Polymer networks can be grown into desired shapes and with specific material composites can be adapted into desired shapes
The choice of implementing the materials into brick-casts is deliberate. After different attempts, we understood that the network of mycelium adapts quite easily in such a shape. Other considerations to this choice, concern time, logistics and feasibility.
The aim of the research is to combine an applied research to a design and build solution.
We have experimented only with Oyster mushrooms ,as far as they are known to be the most adaptable strain, able to colonize easily in every condition and can bind good to a variety of substrates.

ephemerality

Ephemerality comes from Greek word ephemeros, combination of, epi “on” and hemera “day”, meaning living or lasting for a day, temporary. It is a concept of thing being transitory and short lasting. The concept has been used in architecture as an art of designing structures that last only for a short time. The concept of impermanence, often used for theatrical spaces or festivals, pavillions or fairs. In USA, the Burning Man festival organizers and participants build and then remove all traces of a city that holds upwards of 50,000 participants each year, only lasting for one week.Each period in architecture had its techniques and methods for its time, today it is worth thinking of alternative solutions. Ephemerality continues to experiment new solutions for public spaces and temporary events, and it is worth continuing exploring such attitude towards designing in a time where change is the only constant.

In Japan, cities are in constant flux, like many other metropoles it is more common that cities are resilient to such conditions. The idea of permanence and monumental structures are today not suitable anymore.

Mycelium structures are light, resilient, with an almost negative carbon footprint and fully recyclable. they can adapt and dissolve easily within a life span. It is worth thinking about a closed-loop system. A structural concept that grows on its own and completely disappears when necessary, respecting nature, a material that can self-heal when necessary, that expand, and whose growth can be stopped when necessary, is our response to such circumstances.

Can the figure of the designer mediate between permanence and obsolescence? Can architecture teach or foster an attitude toward permanence that encourages both ecological and cultural sustainability?

Bringing the notion of ephemerality into architecture is one of the responses to the way we might design in the future, and the mycelium-composite pavilion is thus an experimental space and, in a sense, an educational laboratory where people can grasp the look, feel, and perhaps even taste of a living material which will eventually return to the Earth, serving as a fertiliser for the soil.

methods

Dealing with living materials means approaching the field through a variety of spectrums.
The transdisciplinary approach combines theoretical backgrounds ranging from architecture to biology.
The method chosen for the experimental part is to collect data from a series of empirical trials, tests and possible errors-all undertaken over a 6-month period.
Materials science research dedicated to mycelial composites is a fairly young field, and most of the information is gathered mainly from fungal cultures and mycology.
The design and construction solution, translated into a mycelium pavilion, aims to be used as an experimental field to understand what the biofabrication of a material actually means and to add value to an emerging science through which the topic of biobuilding can be discussed again.
The topic of sustainability and emerging materials needs further research and attention because of their unique and versatile properties that can actually enhance their application in one of the most crucial sectors such as construction and will play an extremely important role when it comes to low- or zero-emission construction and 100% recyclable nature.
A more radical approach towards biophilic design can help to better understand how to collaborate with living things and how to incorporate that knowledge for the creation of new artifacts at the border between the artificial and the organic.
Can architecture mediate between permanence and a closed cycle? Can architecture teach or promote an attitude toward permanence that promotes both ecological and cultural sustainability?
We do not want to create a new industry around this product, but to relocate the waste and emissions that the current system is producing.
Bringing the notion of ephemerality into architecture is one of the responses to the way we might design in the future, and the mycelium-composite pavilion is thus an experimental space and, in a sense, an educational laboratory where the public can grasp the look, feel, and perhaps even taste of a living material which will eventually return to the Earth, serving as a fertiliser for the soil.


Thursday 12
Friday 13
Saturday 14
Sunday 15
FABER-CASTELL
Oesterzwammenbroed
8719324307901
Pleurotus Ostreatus
8719324307901
Oesterzwammenbroed
WOOD CHIPS
COTTON
COFFEE
HEMP STRAW

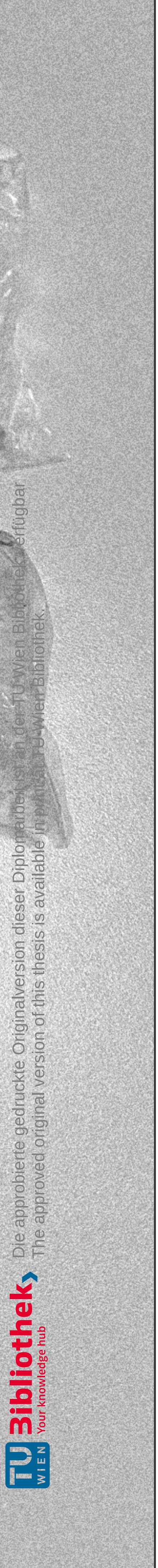


Figure 1 Materials

Dealing with living materials means approaching the field through a variety of spectrums.
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A more radical approach towards biophilic design can help to better understand how to collaborate with living things and how to incorporate that knowledge for the creation of new

experim

The experiment took place in two different places due to the lack of space. In order to provide the necessary environmental conditions, the spaces have been adapted into proper condition. In the places controlled by thermometer, additional thermal insulation is made, humidity machine and heaters are placed. According to the research we have done, sterilization has been the first priority in order to get the expected results. This step should be done very carefully. Composite studies were started after the necessary conditions were met.

Experiment I concentrates on with what kind of composite attempts we can achieve the production of bricks, by creating the necessary conditions with the fungus Pleurotus ostreatus? According to the research we have done, it is expected that the mixture made with hemp straw will yield more successful results.

In the first experiment we aim is to achieve a successful growth of mycelium composites, with the knowledge we have learned. At this stage, we wanted to test which composite is more suitable for the planned project. Due to the limited working area and environmental conditions, it is aimed to use the composite that

Figure 2 Mycelium Stocking in Fridge

ent I

Materials:
Oyster Mycelium
Cooking pots and a steam pot
Thermometer
Nutrition
Wood chips - 15 kg
Hemp straw - 15 kg
Cotton balls - 200 pcs.
Cardboard - ripped box
Knife
Scissor
Microfiber Towels - 8 Pieces
Disinfection
Plastic hand gloves
Scale
Metal teaspoons
Metal Bowls - 4
Plastic Boxes
Timer
Driller
Glass Jars
Pen
Sticker Papers
Notebook
Plastic Foil

Preparation

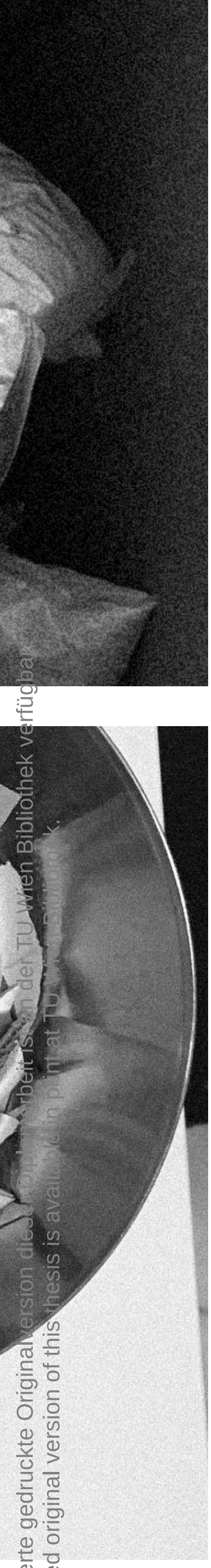


Figure 3 Preparations

Sterilization	
Material	**Sterilization Time**
Nutrition	Start: 17:00 End: 18:30
Hemp Straw	Start: 15:52 End: 17:29
Wood Chips	Start:15:52 End: 17:29
Cotton	Start: 15:52 End: 17:29
Cardboard*	Start: 16:53 End:17:29

The experiment continues with cooling down the substrates to room temperature.
After cooling down the substrates, we measured them and filed them in separate disinfected plastic boxes. Scaled mycelium and nutrition amounts are added to the substrates and mixed properly. We were gently touching the substrate-

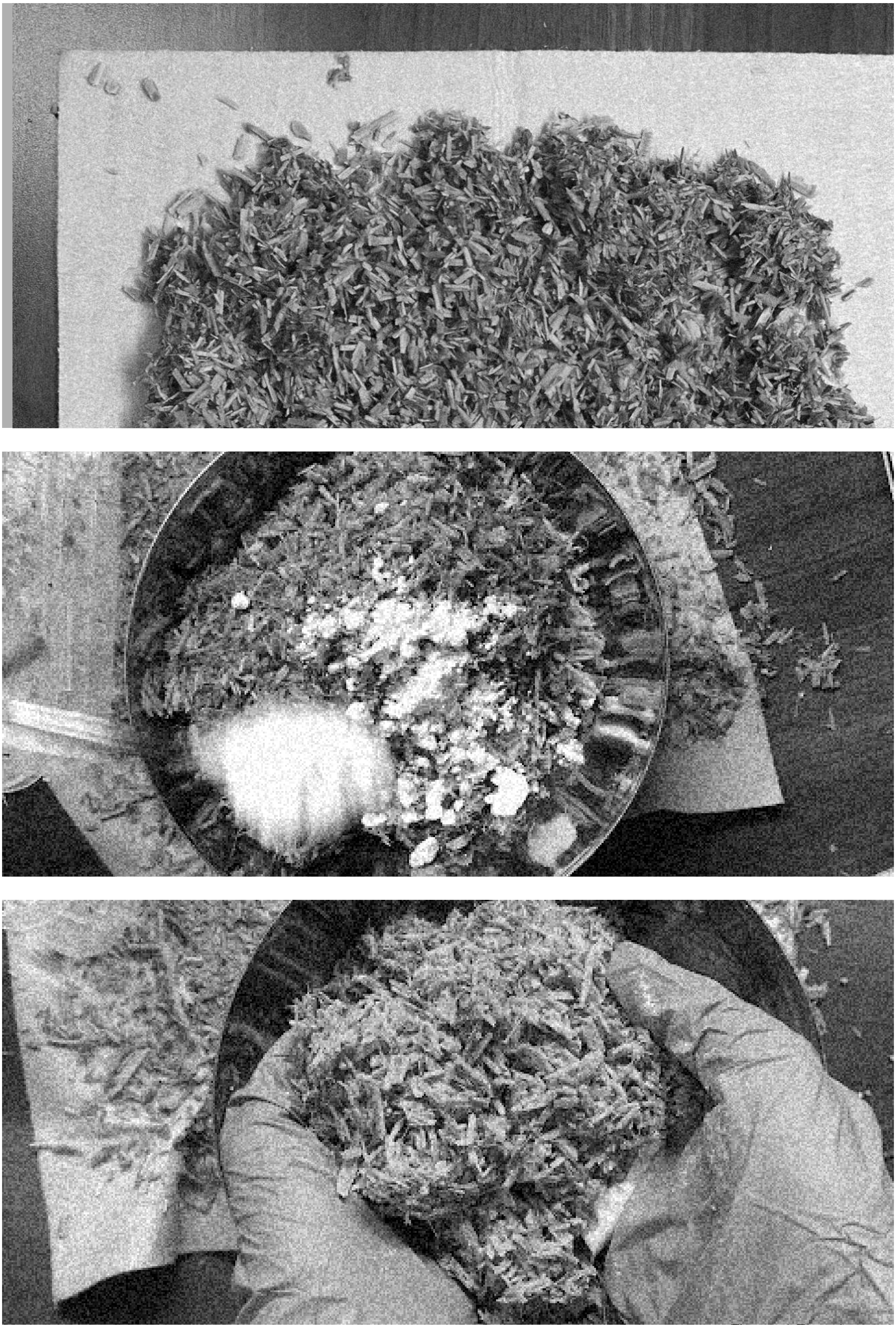


Figure 4 Experiment 1

DAY 1

DAY 5

DAY 10

DAY 20

Hemp


DAY15


DAY 30

Figure 5 Stages of growth 1 hemp

The mycelium composite with hemp substrate has successfully achieved the fully growth within 1 month.

DAY 1

DAY 5

DAY 10

DAY 20

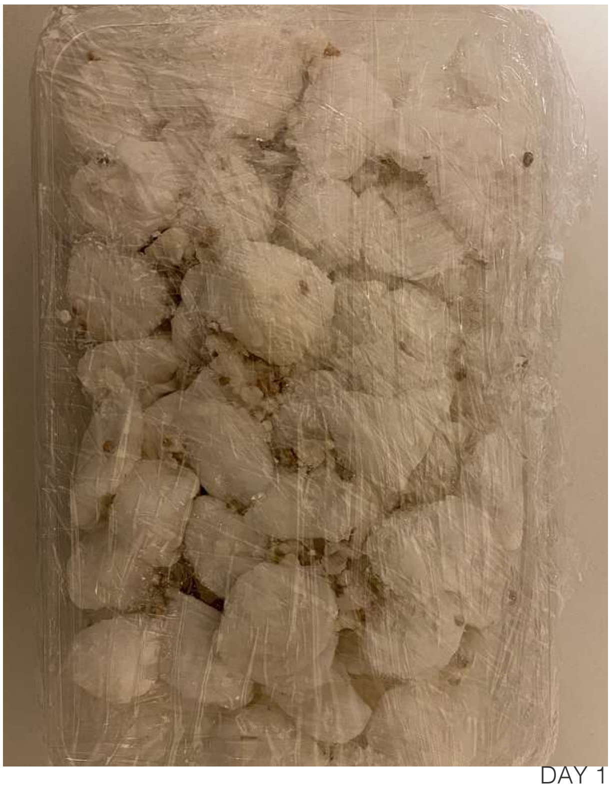
DAY15

DAY 30

Figure 6 Stages of growth 2 wood chips

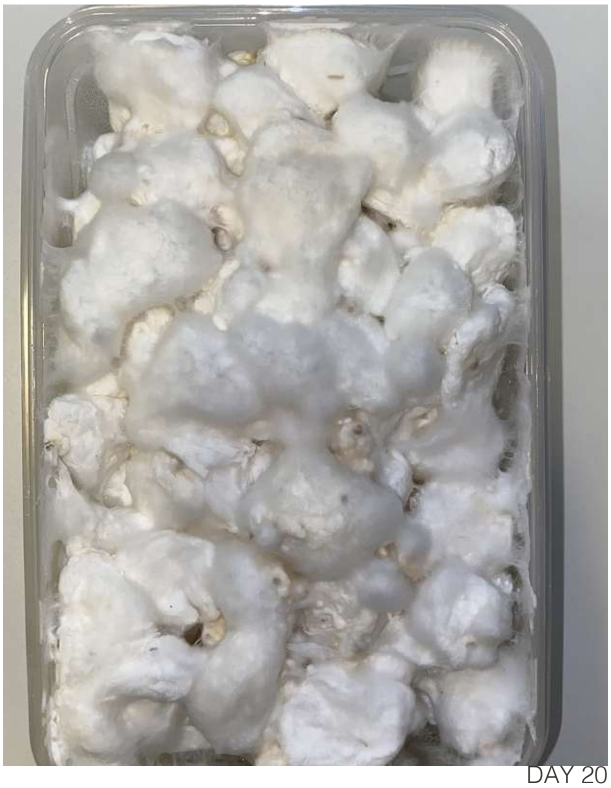
wood chips

The mycelium composite with wood chips as substrate has successfully achieved fully growth within 1 month.

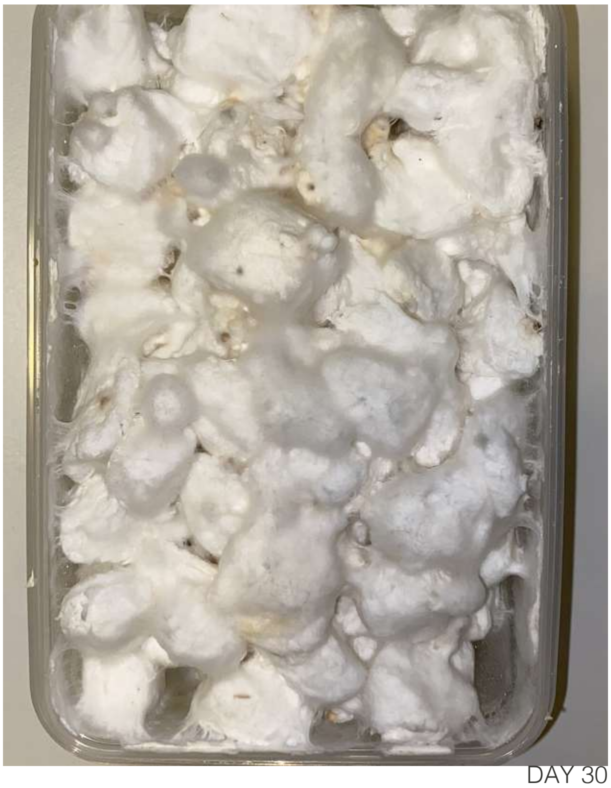

DAY 1


DAY 5


DAY 10


DAY 20

DAY15



DAY 30

Figure 7 Stages of growth 3 cotton

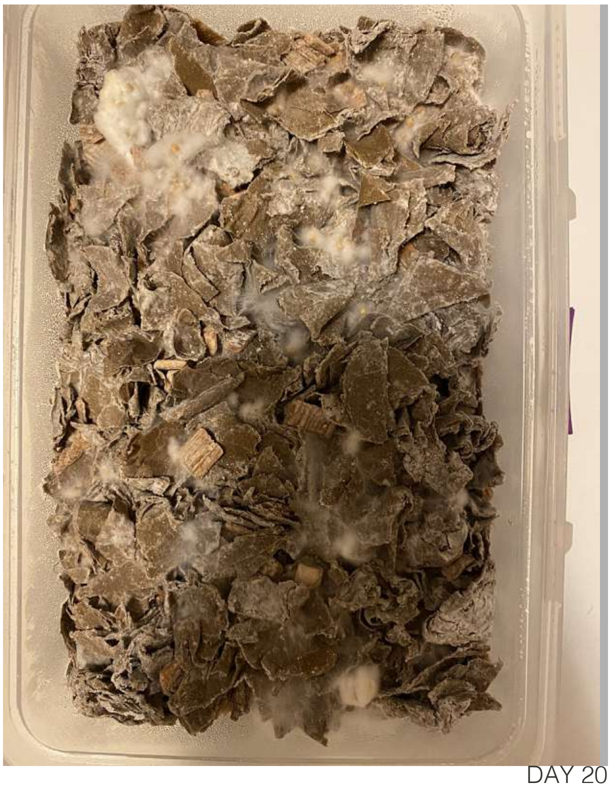
cotton

The mycelium composite with cotton balls as substrate has failed growth within 1 month.

DAY 1

DAY 5

DAY 10



DAY 20

cardboard

DAY15

DAY 30

Figure 8 Stages of growth 4 cardboard

The mycelium composite with cardboard as substrate has failed growth within 1 month.

DAY 1

DAY 30

Figure 8 Stages of growth 4 non sterile hemp

non-sterile

The mycelium composite with non sterilized hemp as substrate has failed growth within 1 month.

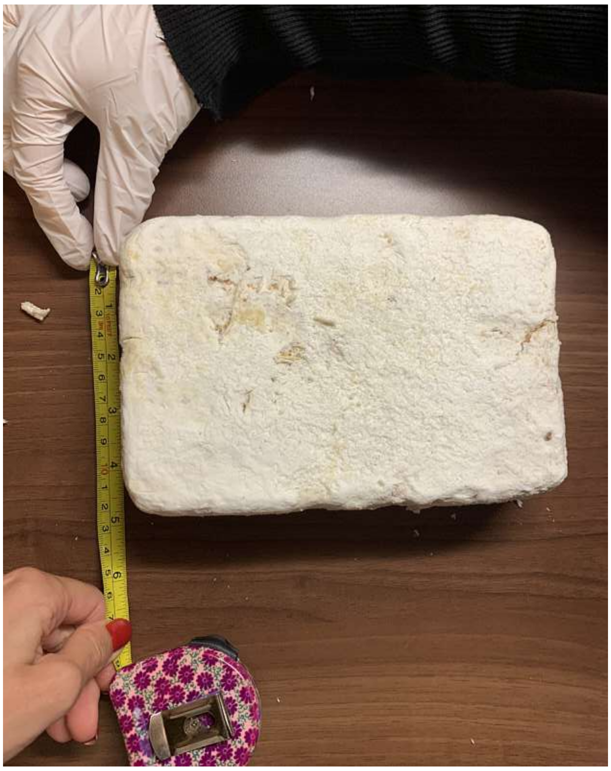


Figure 9 Results of experiment I

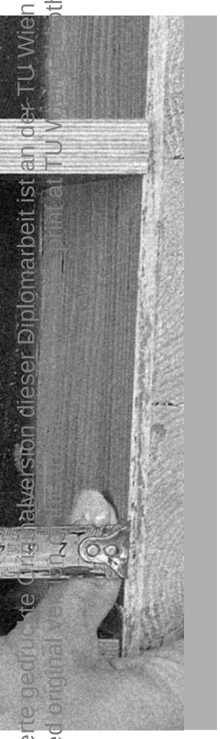
experim

Successfully completing the experiment I, further we would like to explore if the composite could be grown with and without sterilization process. Due to limited time and conditions, it is difficult to sterilize materials. This experiment also includes, different molds in order to understand the best growing method for our further steps. Expected results are, success without sterilization. We would also like to test, if different ratios of mycelium composite can speed up the growth process.

Figure 10 Fungi popping out

ent II

Preparation



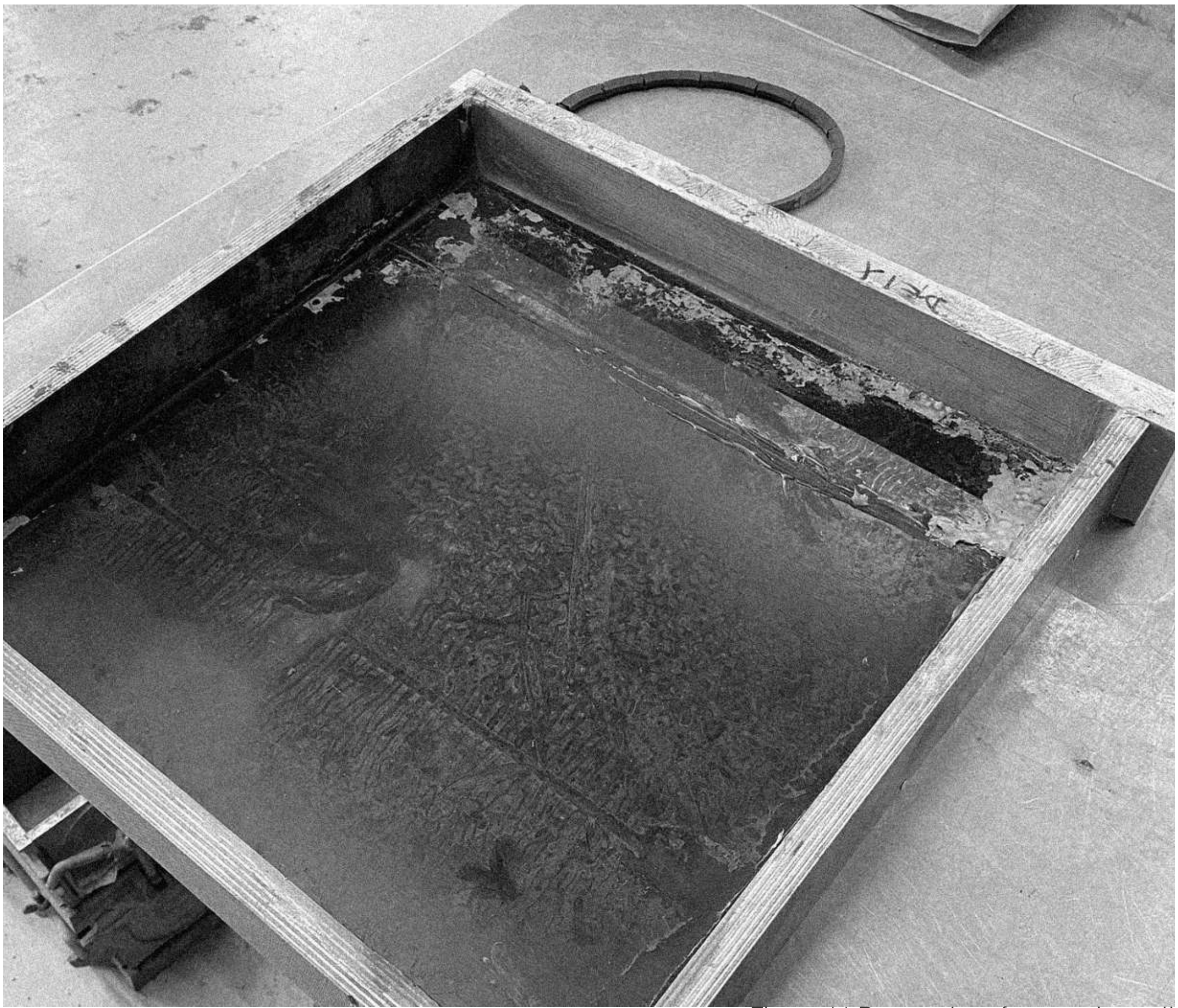


Figure 11 Preparations for experiment II

Materials and equipment have been carefully sterilized. The prepared and mixed mixtures were placed in the prepared brick molds. It was covered with a plastic foil and holes were opened to ensure oxygen intake.

Necessary conditions have been created for the growth to take place faster. A heater and a humidifier were placed next to the test samples placed on the shelves, and the conditions were followed with a thermometer in order to avoid sudden temperature difference.

Figure 12 Preparations for experiment II

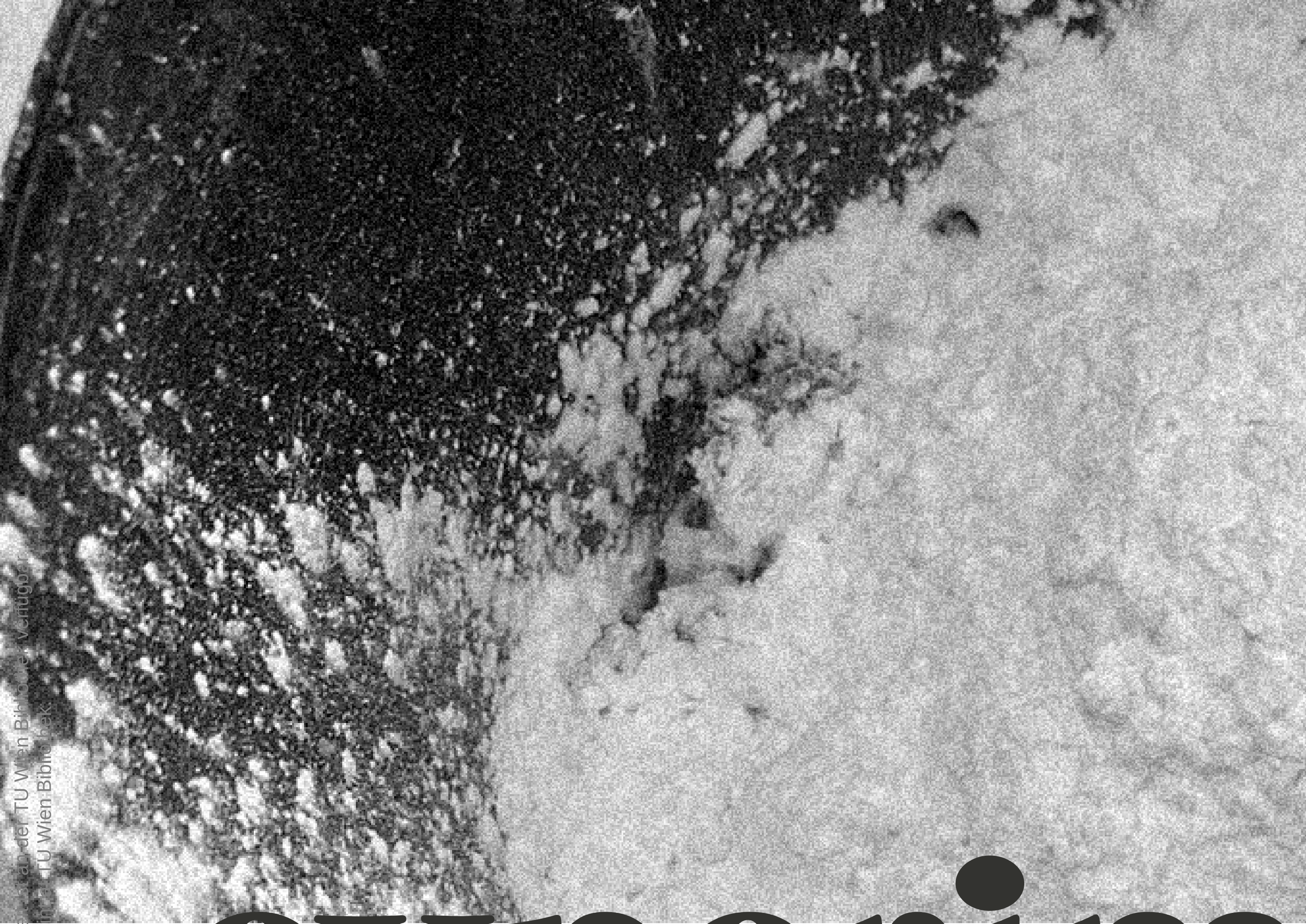
Figure 12 growth space for experiment II

Figure 13 Preparations for experiment II

Figure 14 Growth of experiment II

The experiment reached the expected results. The higher amount of mushrooms added accelerated the growth process and resulted in success. Growing specimens were removed from the molds, left to dry at room temperature and then baked in the oven.

Figure 15 Baking of samples



experim

In order to carry out the project, the last stage of the experiment, the bricks' assembly experiment, was carried out. It is aimed to try different methods as brick knitting mortar.

Figure 16 mixing of composite

ent III

Materials:
Oyster Mycelium
Keraquick
Eggs
Casting compound
Plastic Foil
Mold

Figure 17 preparations for experiment III

Figure 18 samples for experiment III


Figure 19 molded mortar

In the mortar tests we have done, the results were not as expected. Intense mold formation was observed. Therefore, it is planned to assemble the bricks using only mycelium without using any mixture.

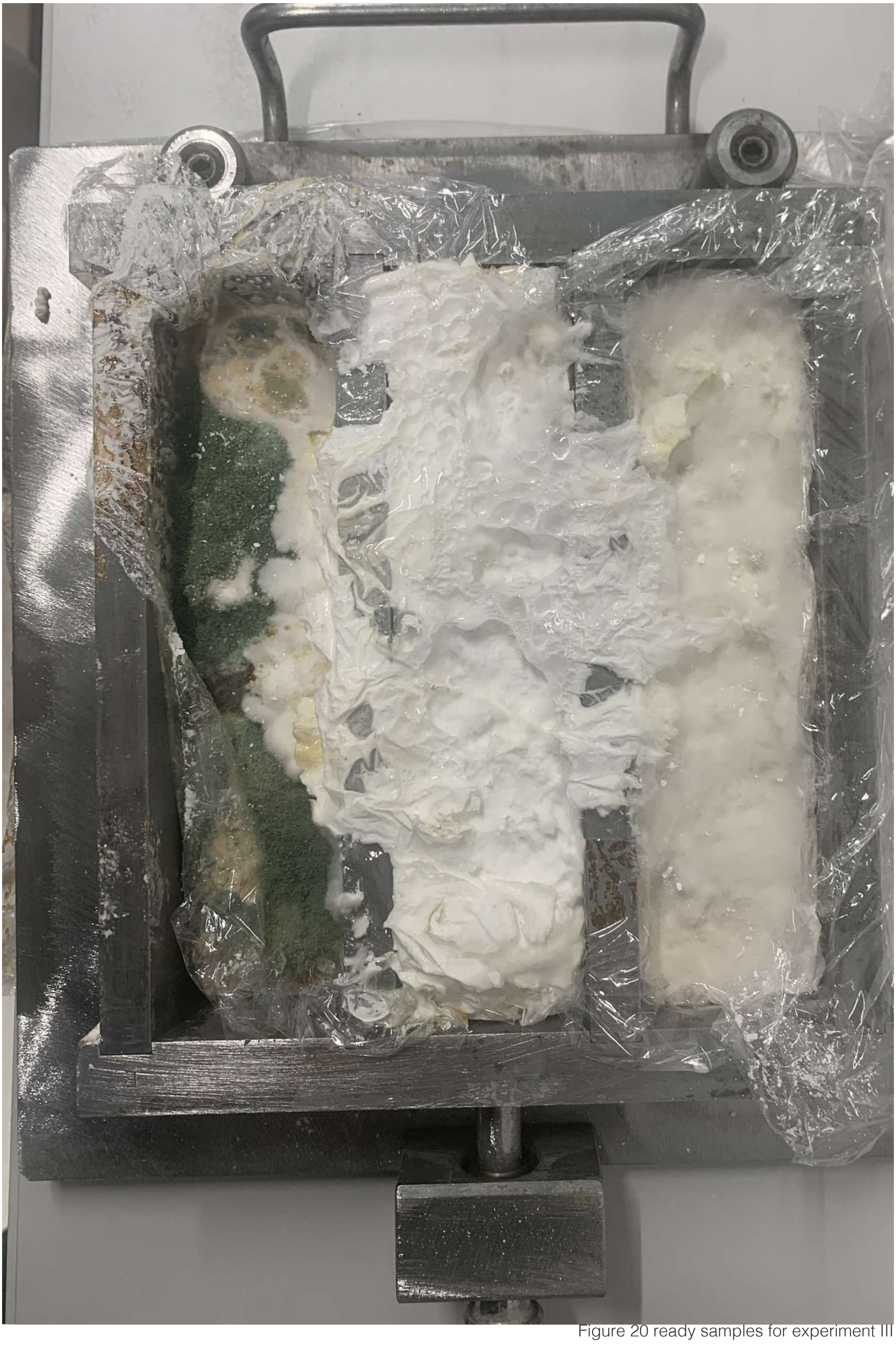
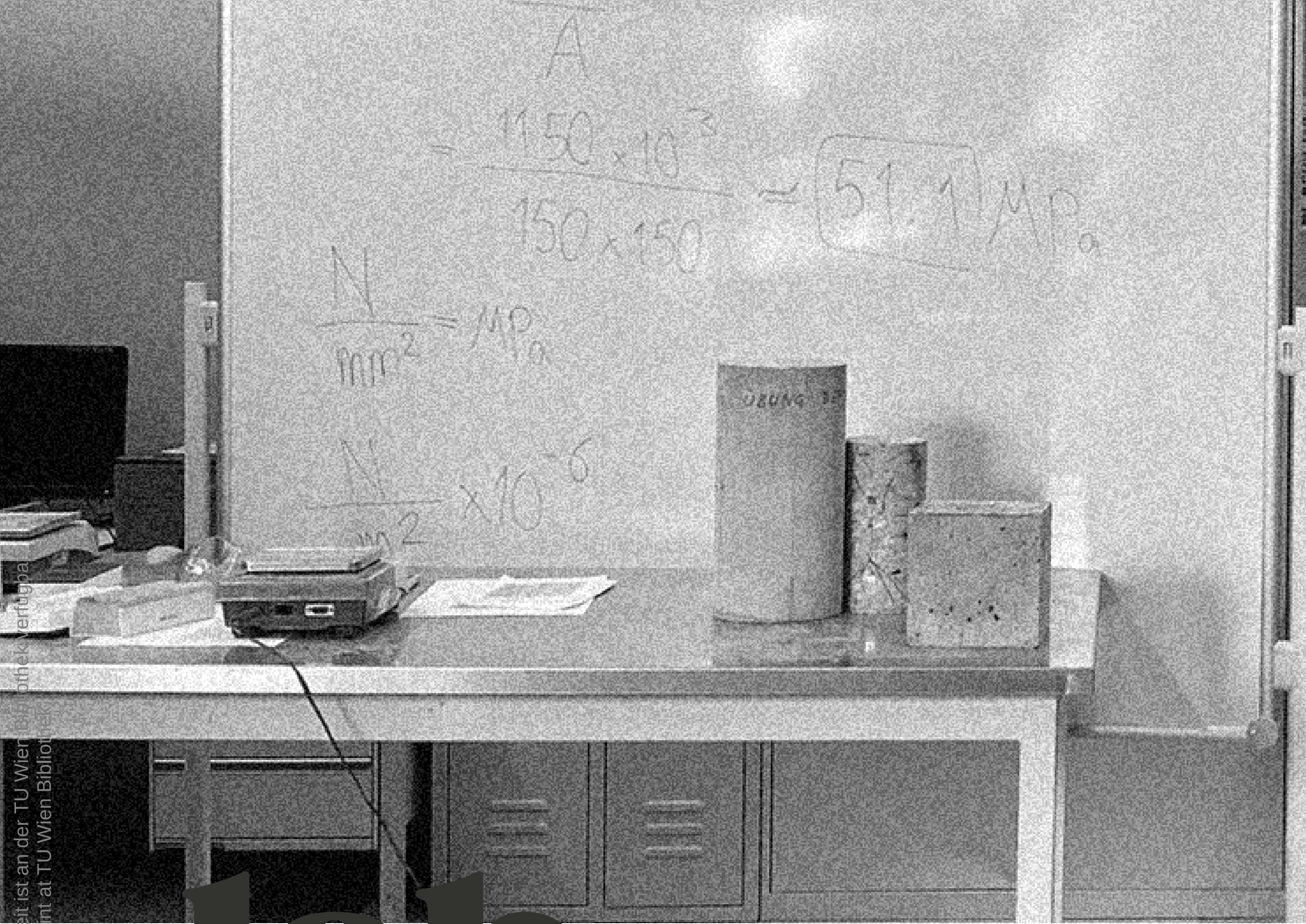


Figure 20 ready samples for experiment III



lab

Successfully completing the experiment I, further we would like to explore if the composite could be grown successfully with and without sterilization process. Due to limited time and conditions, it is difficult to sterilize materials. This experiment also includes, different molds in order to understand the best growing method for our further steps. Expected results are, success without sterilization. We would also like to test, if different ratios of mycelium composite can speed up the growth process.

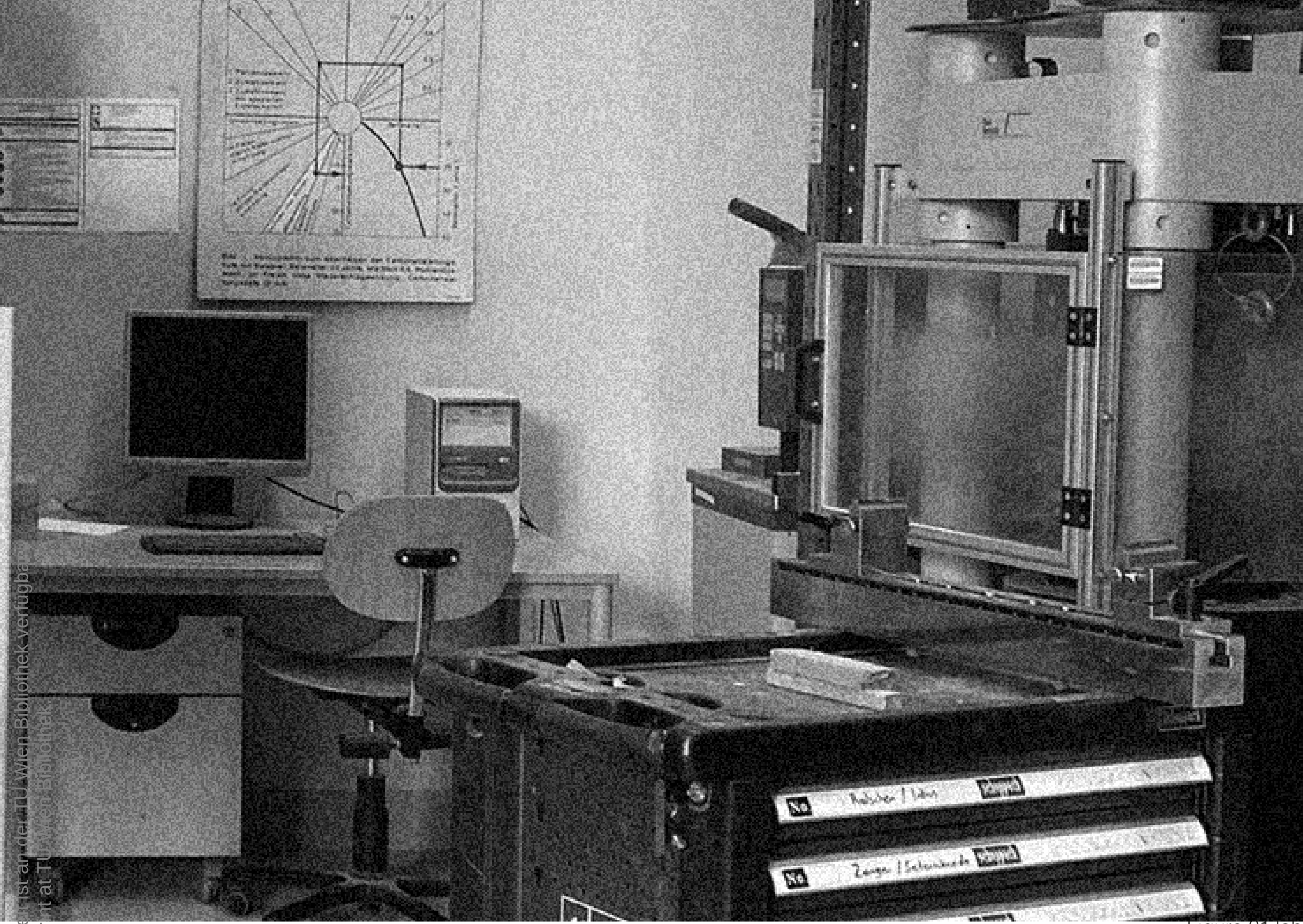


Figure 21 lab

Figure 22 lab tests

thermal conductivity test

Insulation in building industry is an important economic and environmental investment for buildings. To achieve less energy for heating and cooling, the most common thermal insulations are polystyrene and polymeric foam. Due to their synthetic structure, the decomposition of the materials are problematic in the sense of recycling and reusing. The manufacturing process of those materials are high energy consuming.
We have tested two different brick samples with Hot Disk Thermal Constants Analyser 7.3.5 programm. In our experiment , we have seen that both of the bricks have thermal conductivities ~ 0,094 W/mK. Polystyrene has thermal conductivity range from 0,0025 and 0,04 W/mK. The mycelium composite bricks have shown a great performance as a thermal insulation.

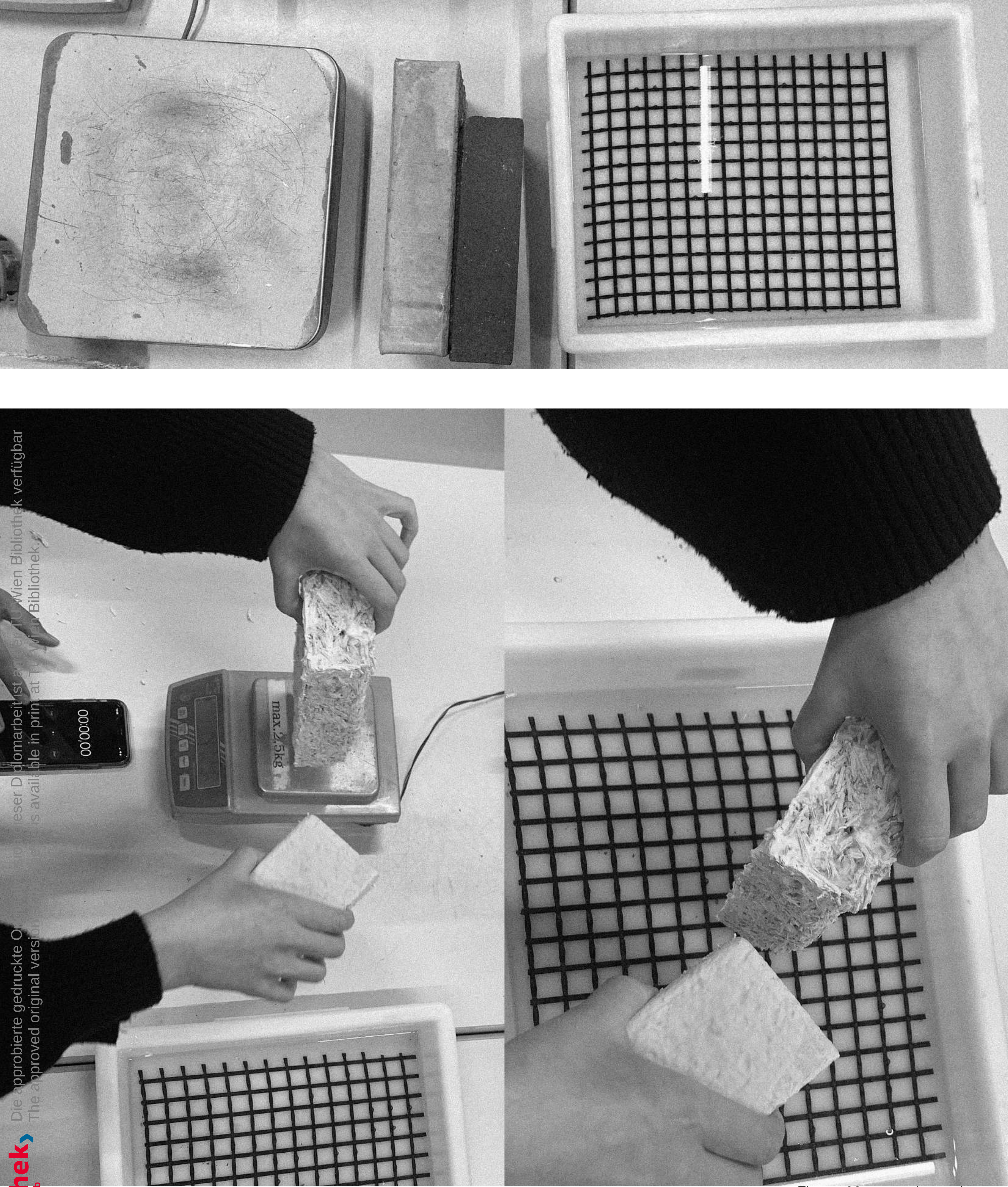


Figure 23 water absorption test

water absorption test

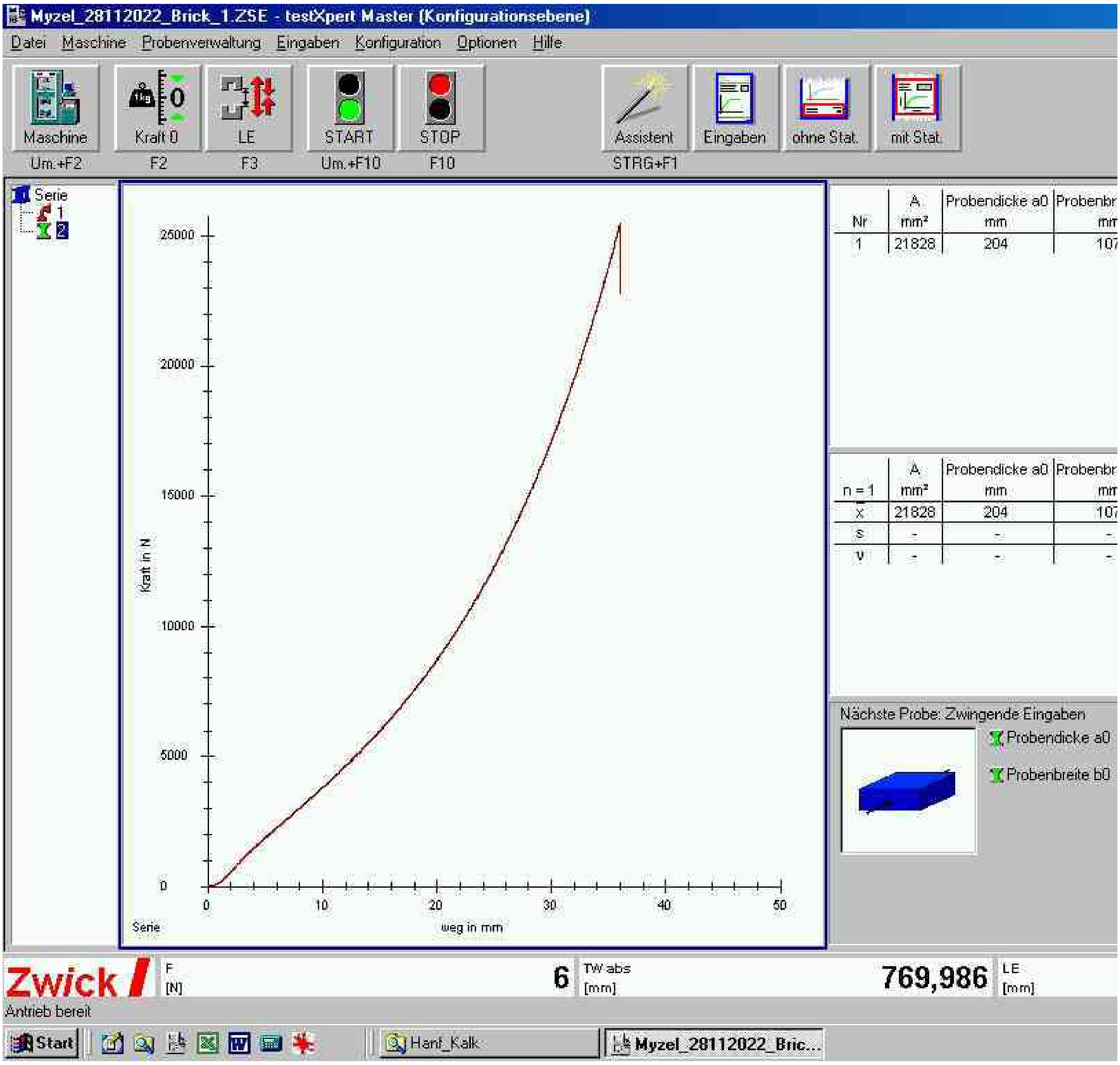
Before performing the water absorption test of the produced bricks, the bricks were weighed. The bricks, which were immersed in a container with water at a depth of 2 cm at certain time intervals, were kept and weighed. Observed data are listed below. The tests is essential to understand the material´s ability to absorb water depending on their surface properties and porosity which is also crucial for its frost resistance.

Time	Brick 1	Brick 2
0	176,80	236,67
1	178,36	237,38
2	179,91	237,52
4	181,22	237,82
6	181,90	237,82
10	183,04	237,91
15	184,66	238,18
20	185,83	238,33
25	187,35	238,67
30	187,61	238,63

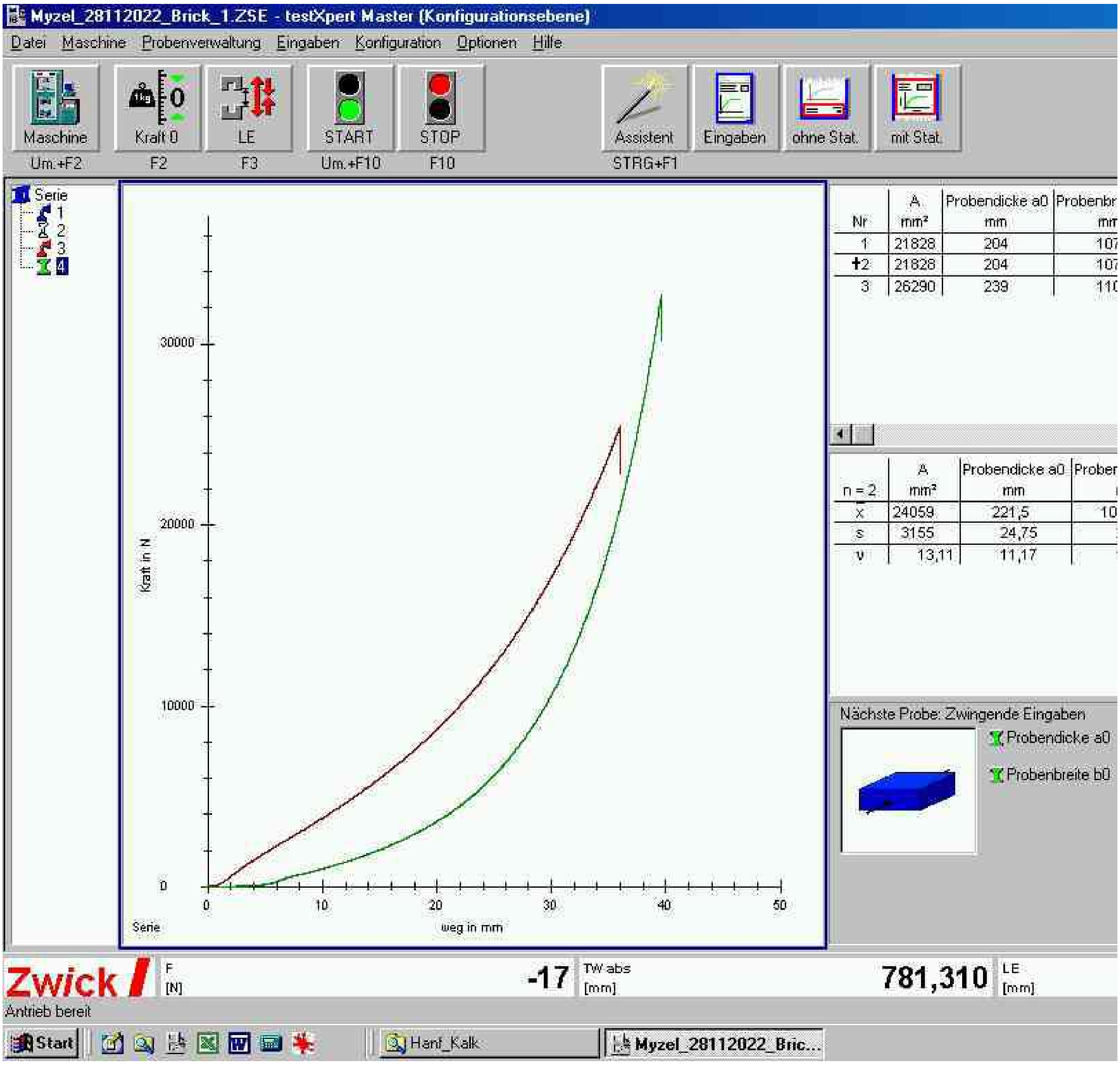
Figure 24 compression test

Compression test

The compressive strengths of mycelium composites vary greatly depending on the substrate material. Mycelium composite materials have been shown to exhibit properties similar to expanded polystyrene or other foams. Compression test have been tested with Zwick Z250.

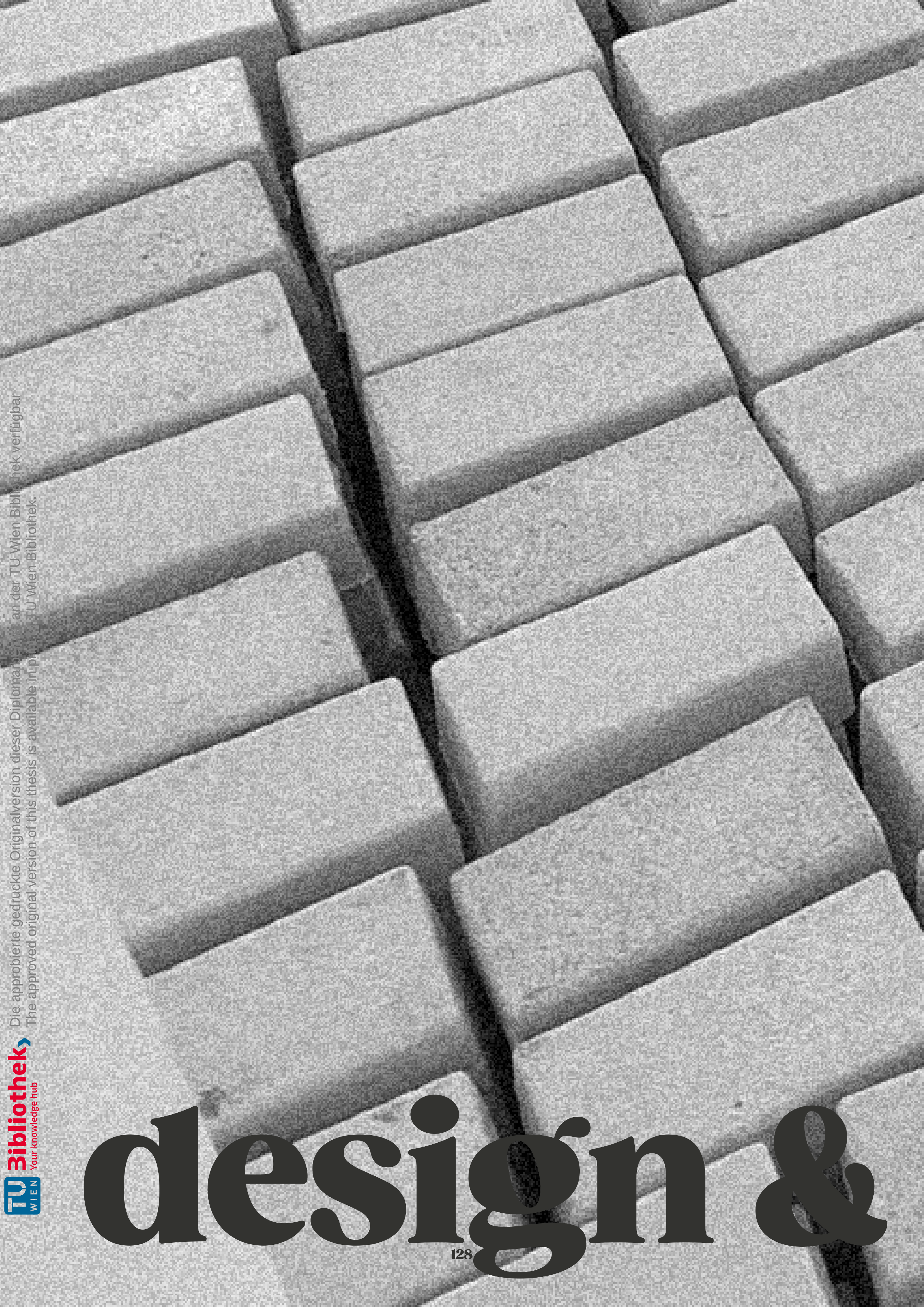


Brick 1Compression test result



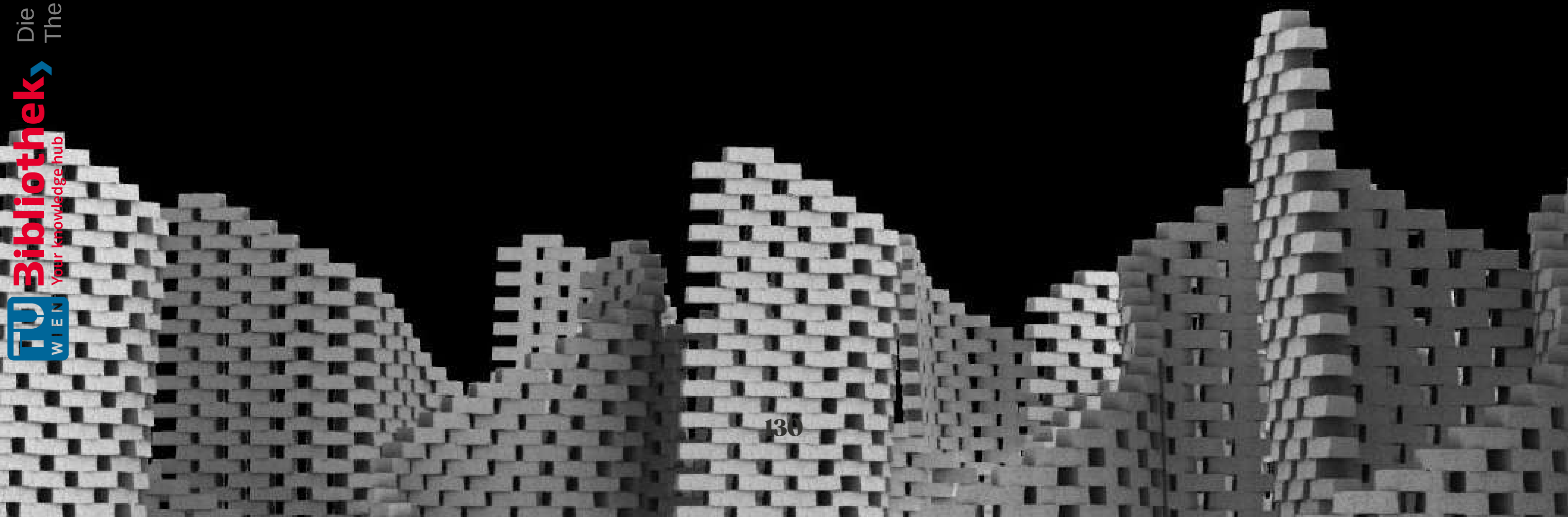
Brick 2 Compression test result

Figure 25 bricks after compression test



design &


build



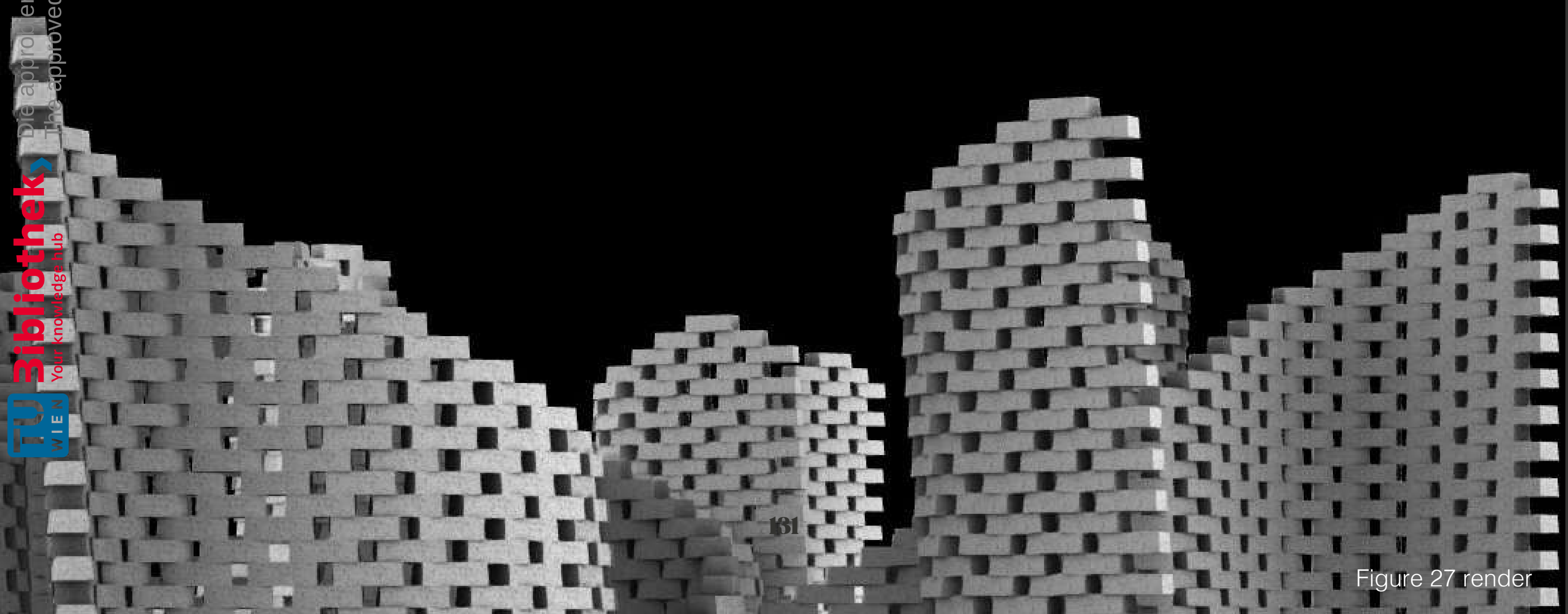
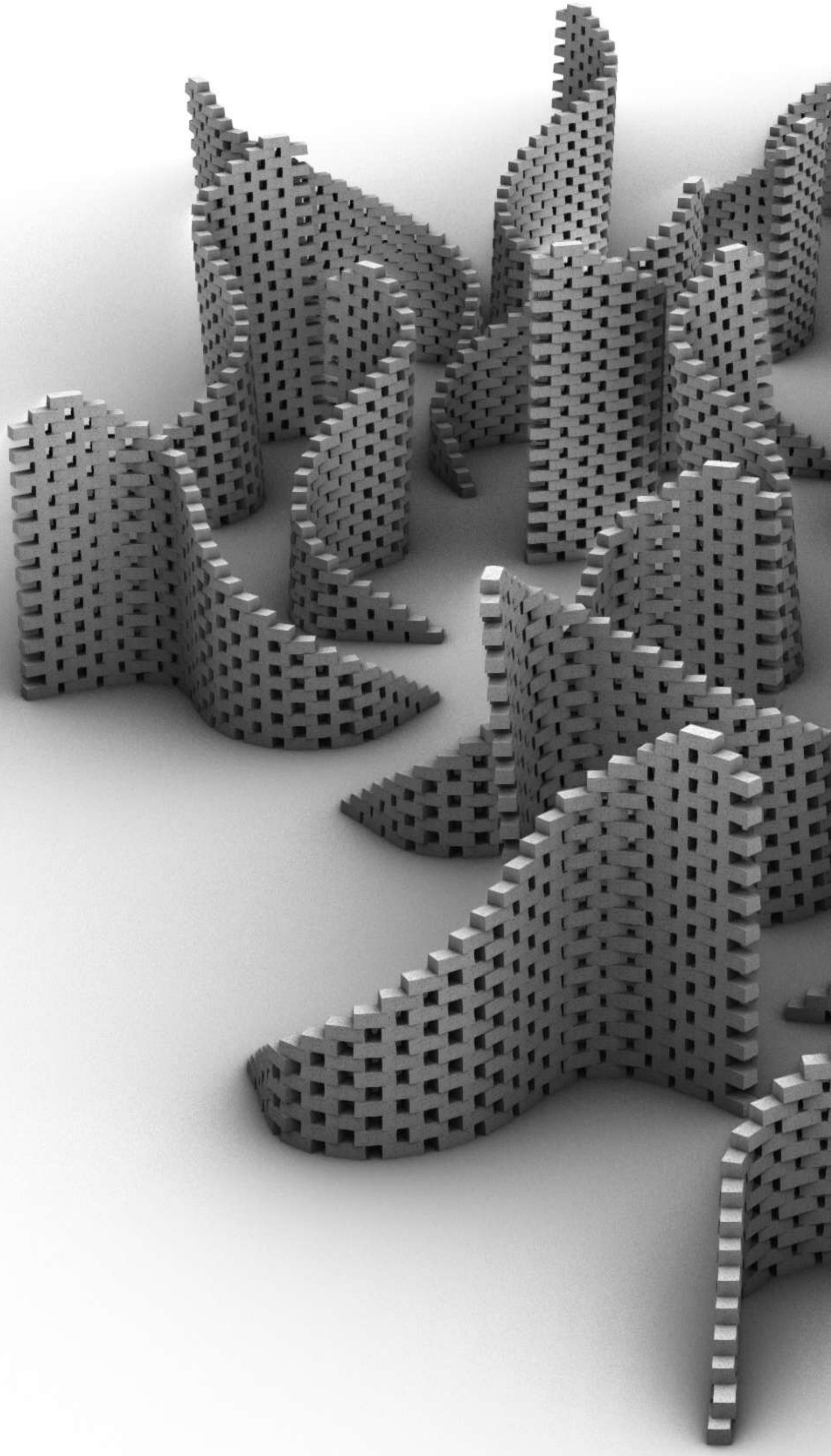


Figure 27 render



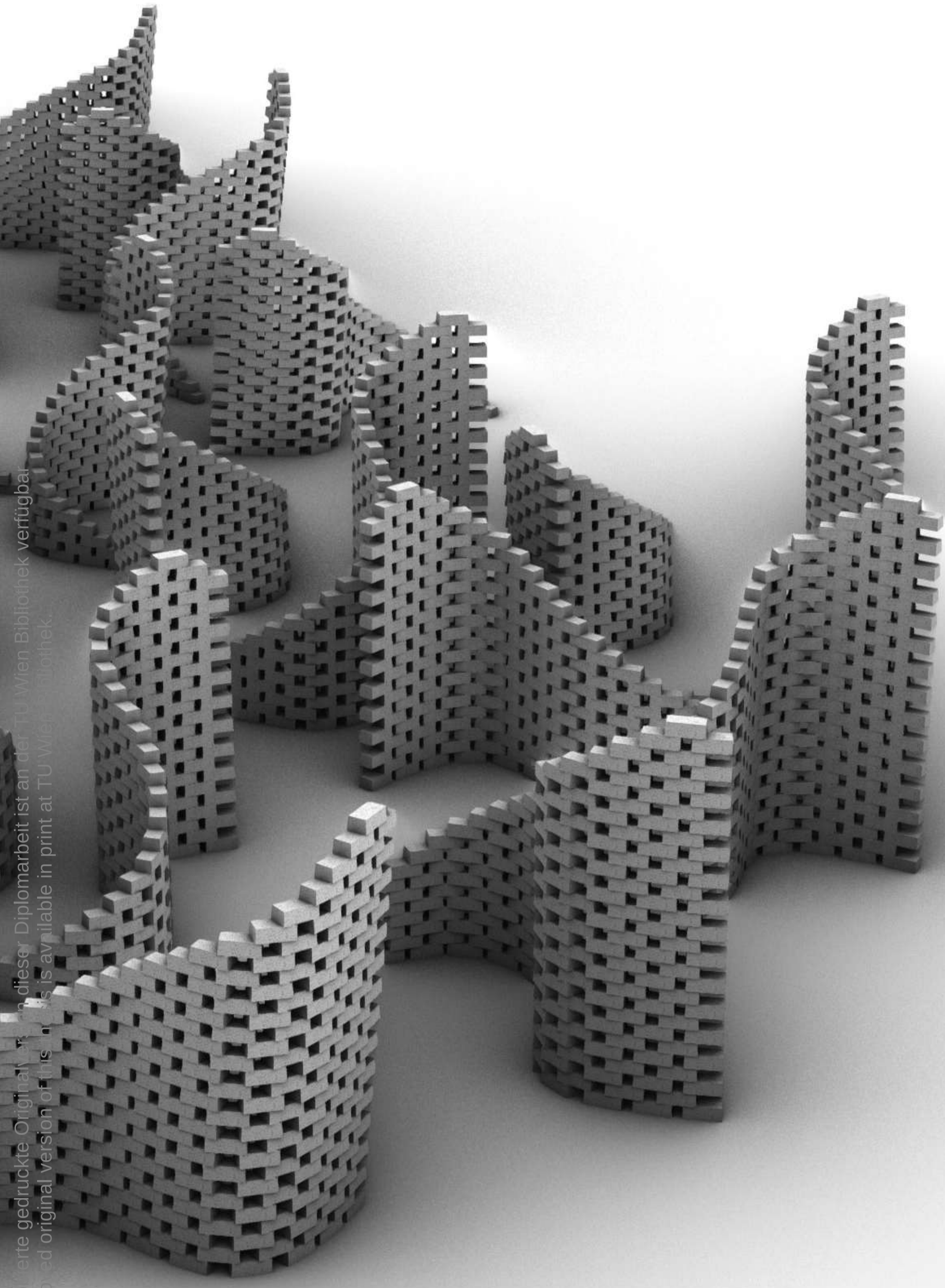
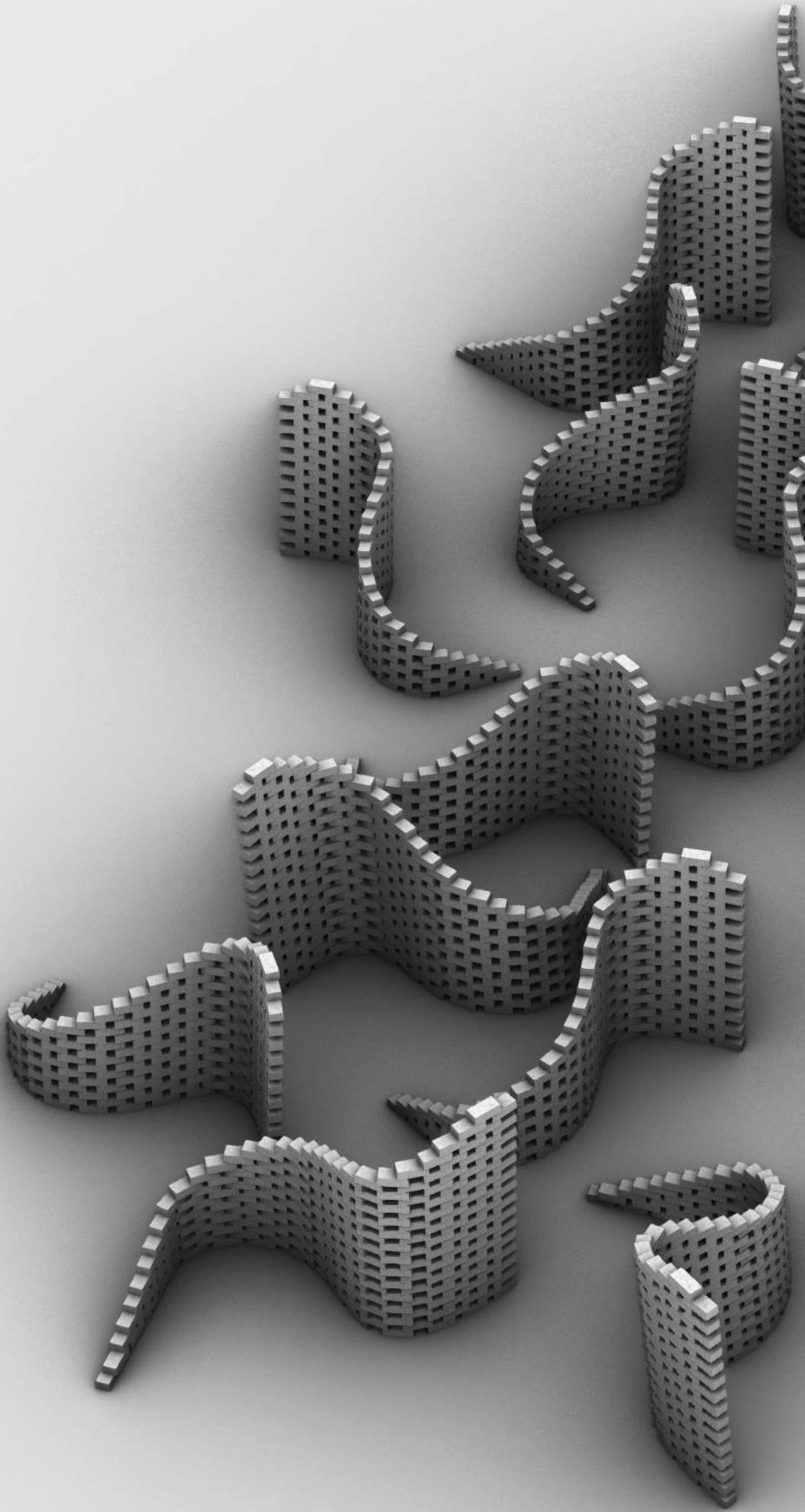
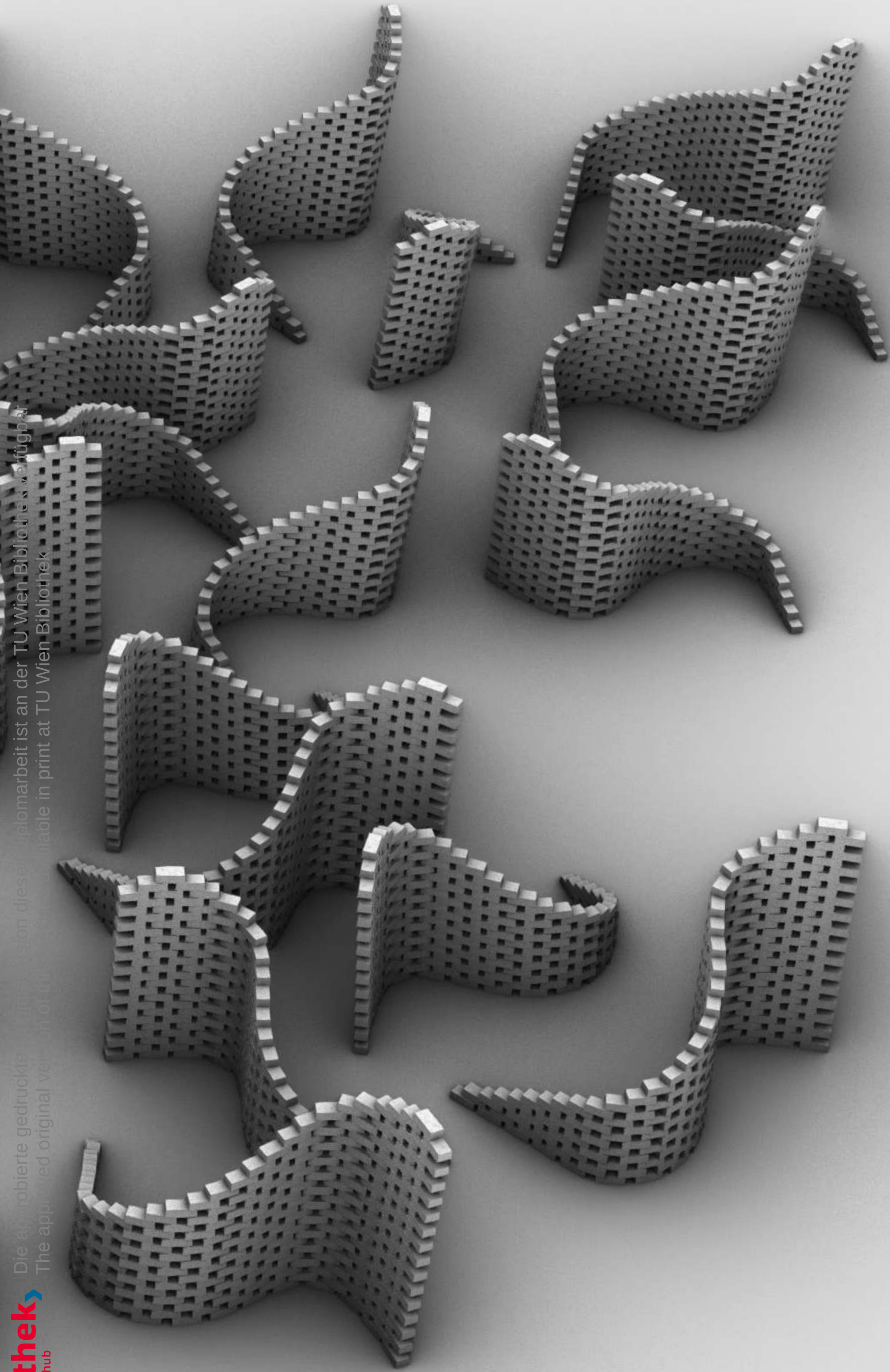


Figure 27 render

Figure 28 render





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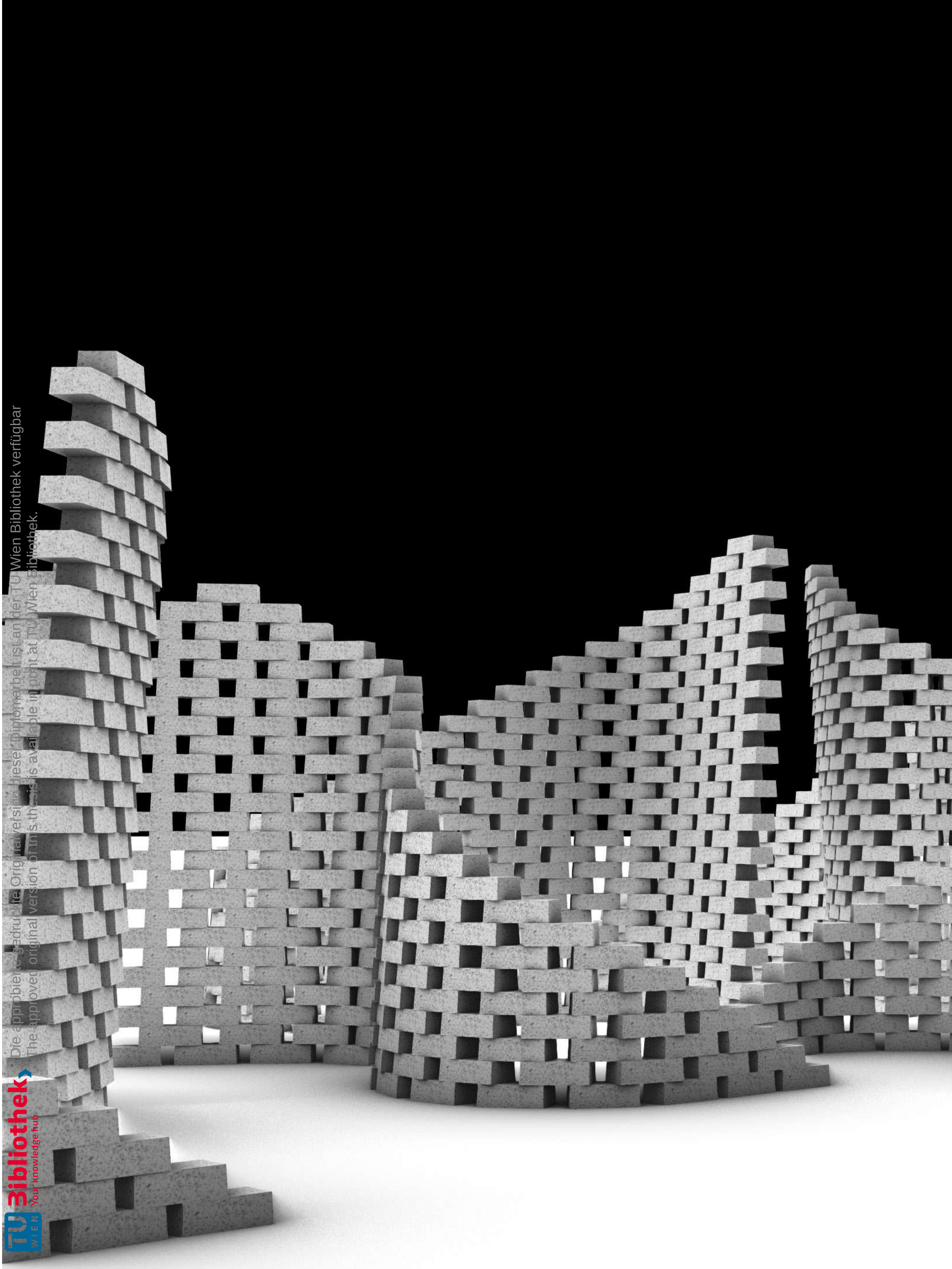

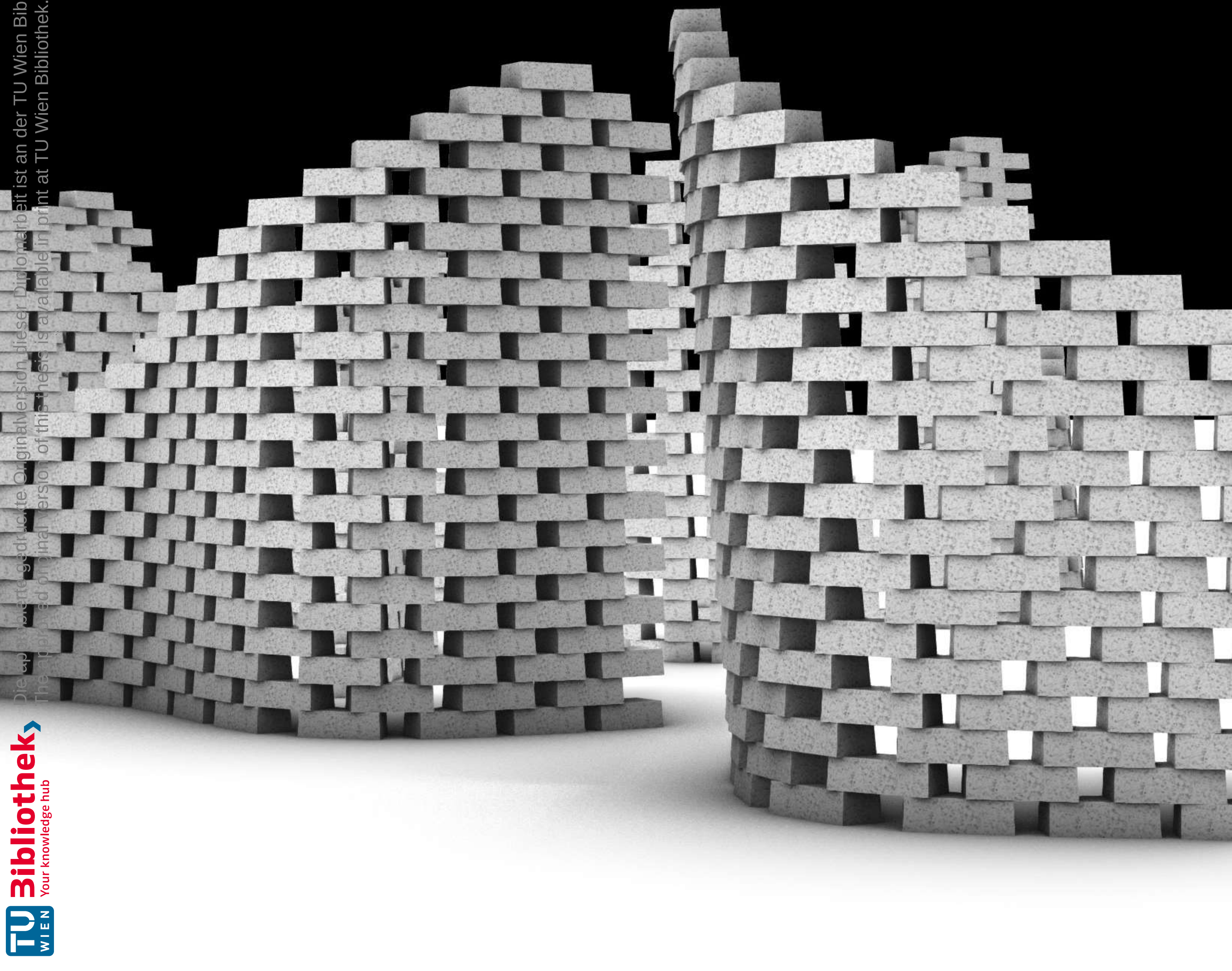

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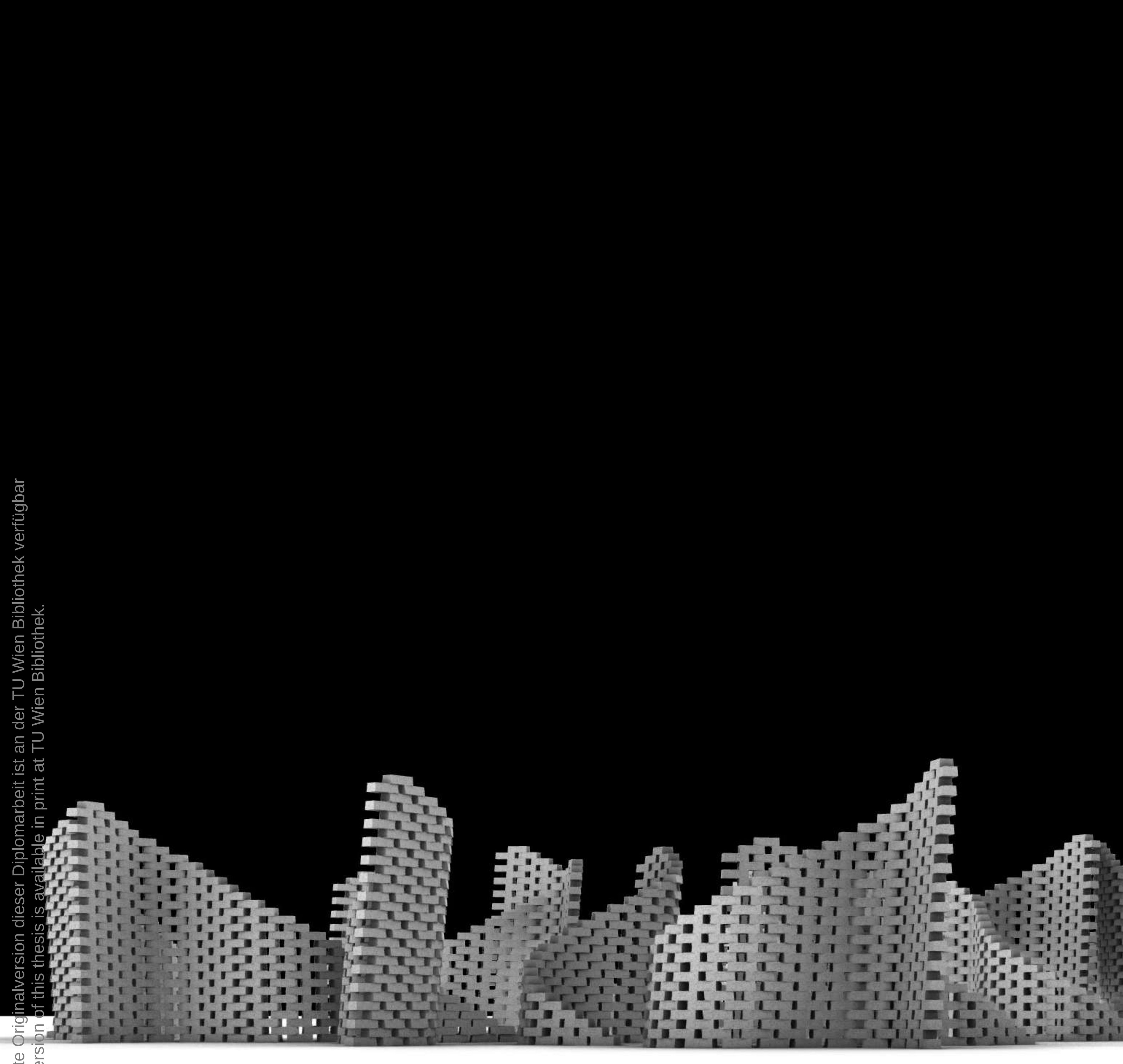


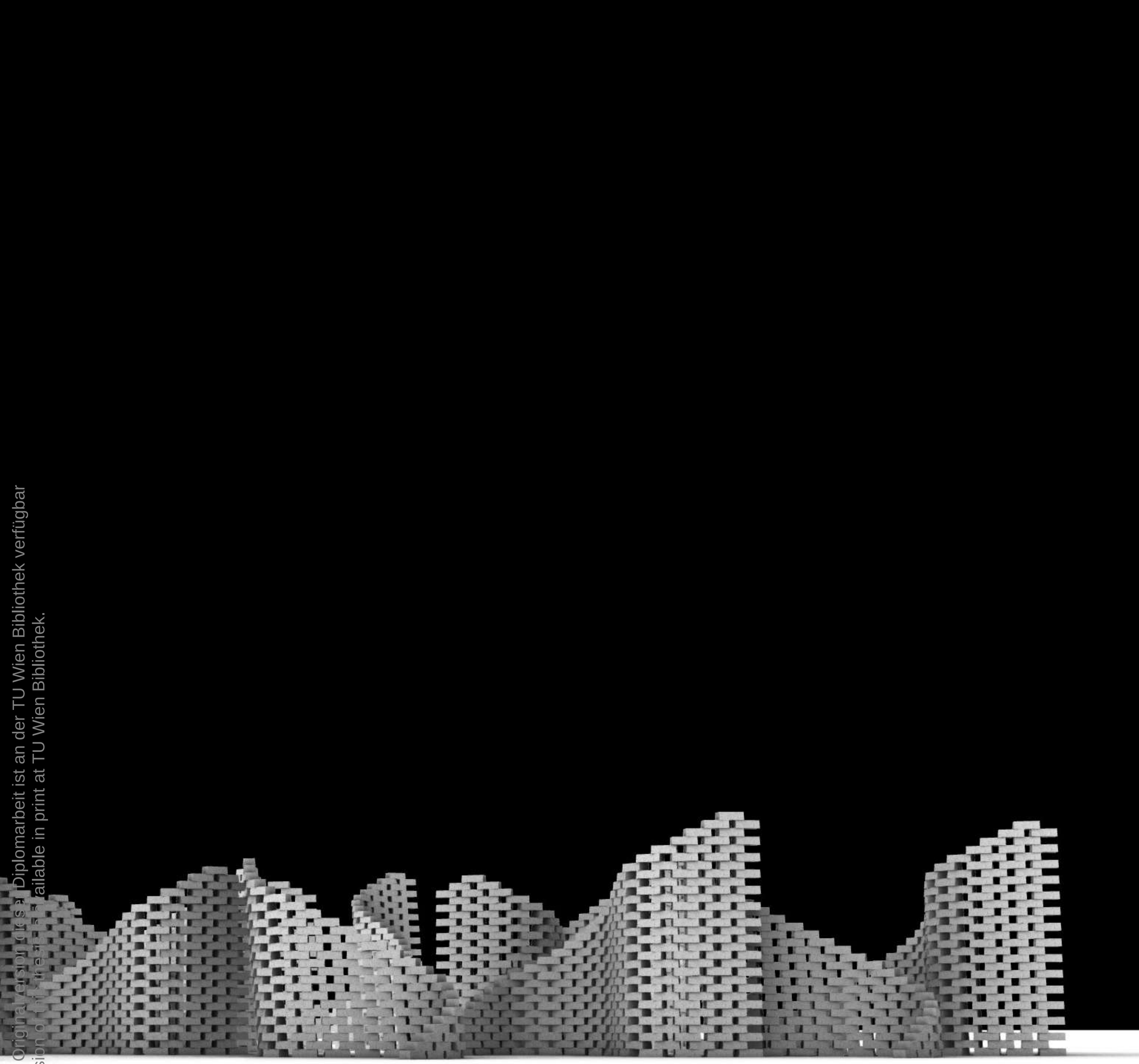
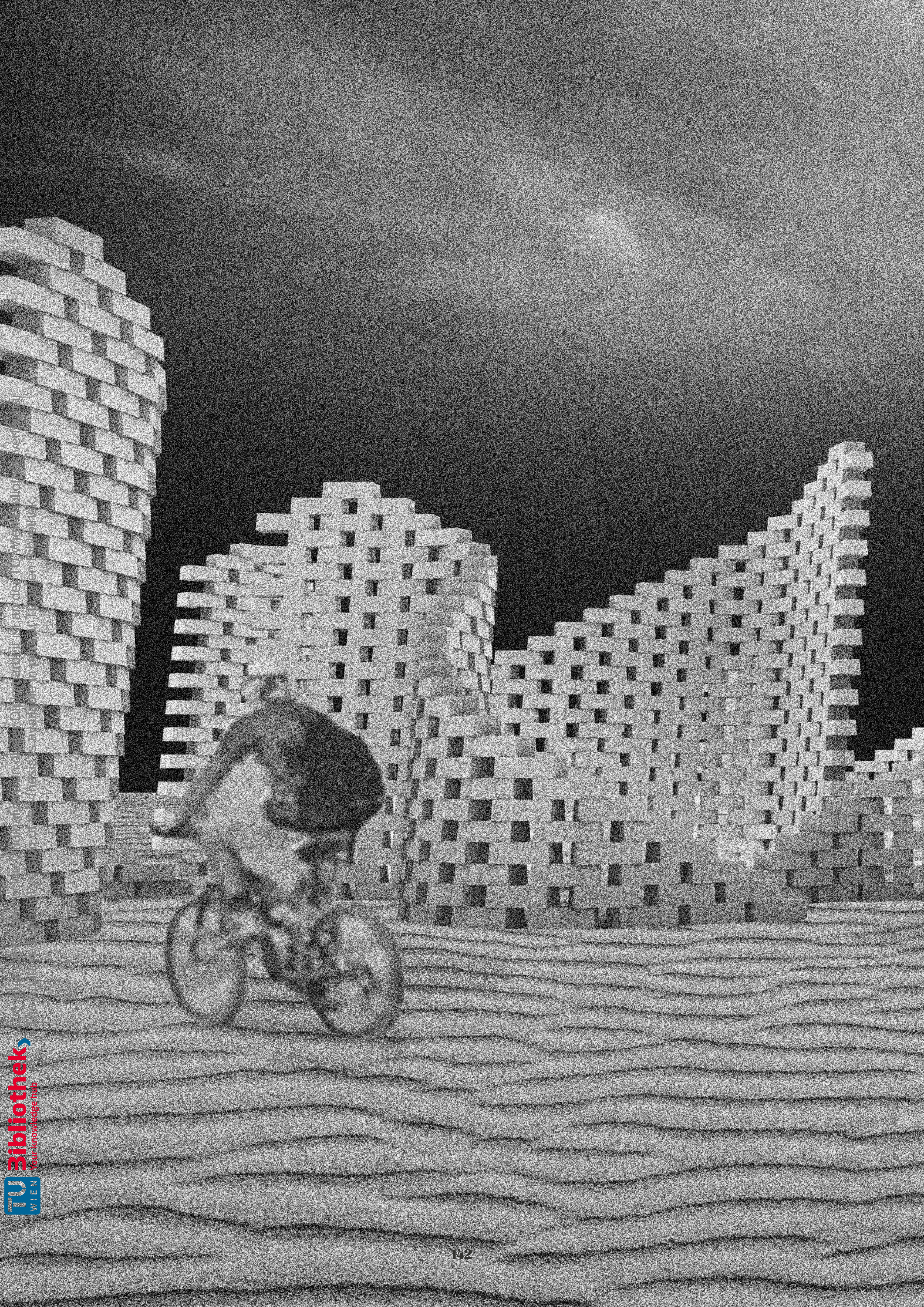


Figure 31 render



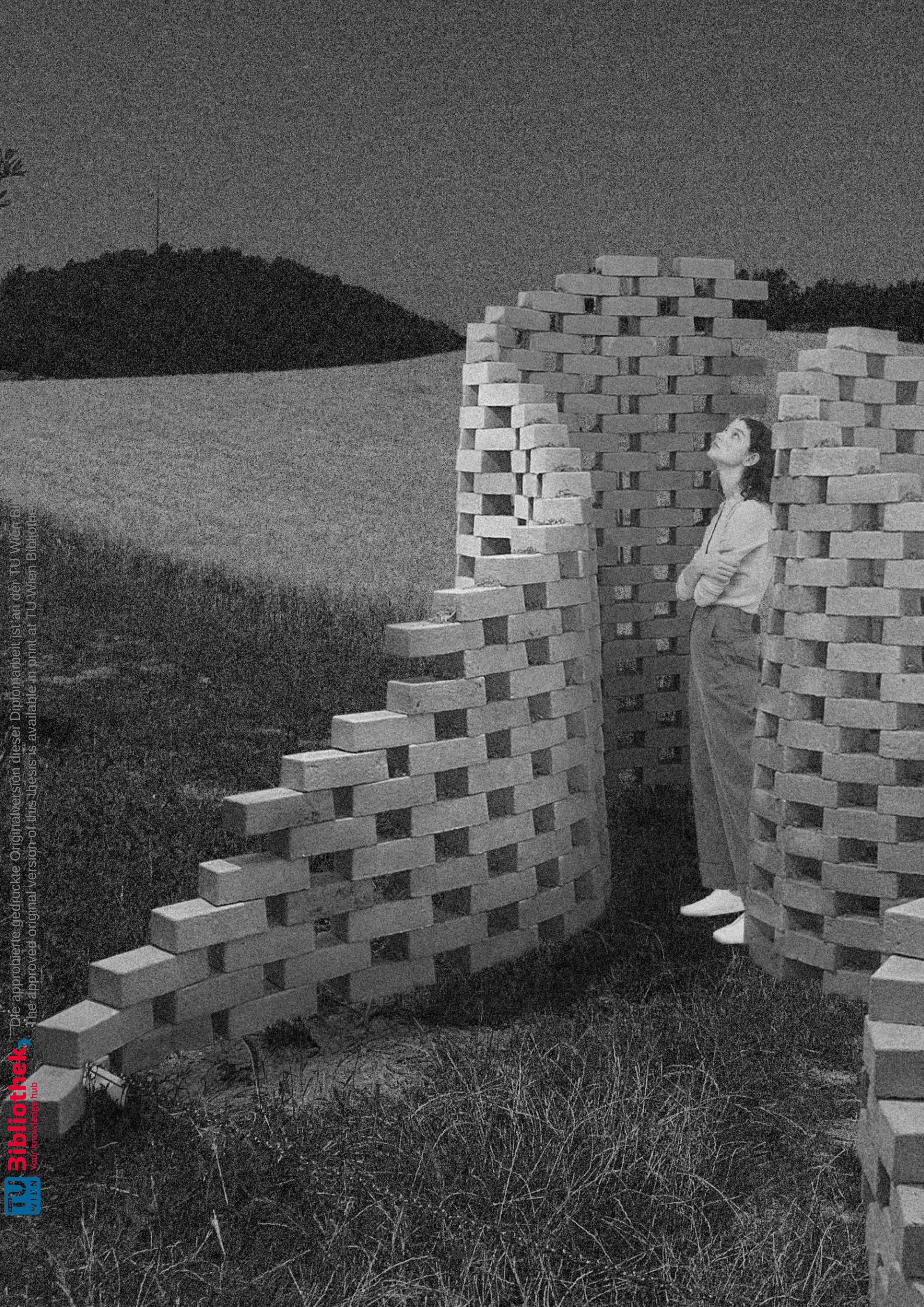


Figure 33 collage

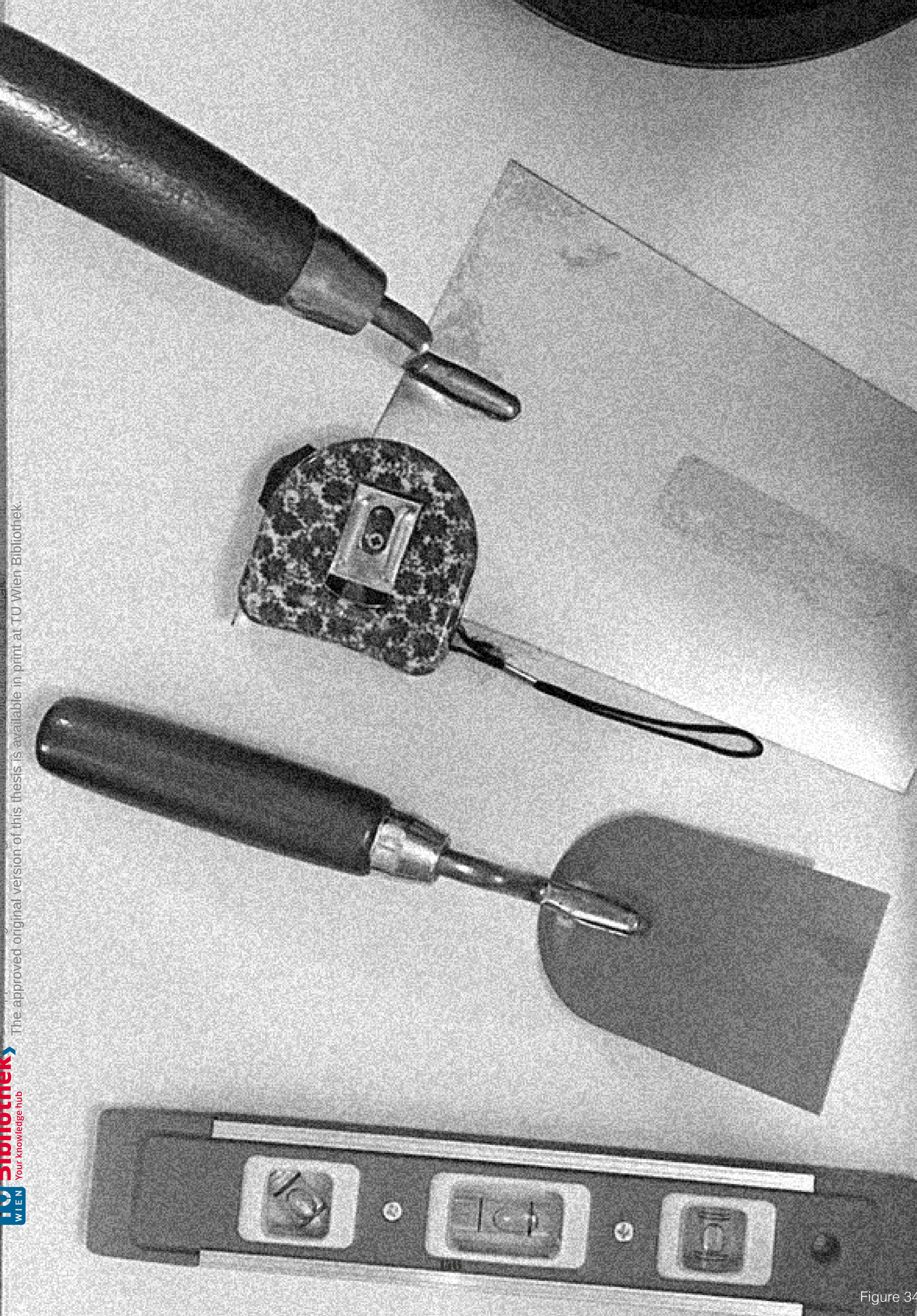
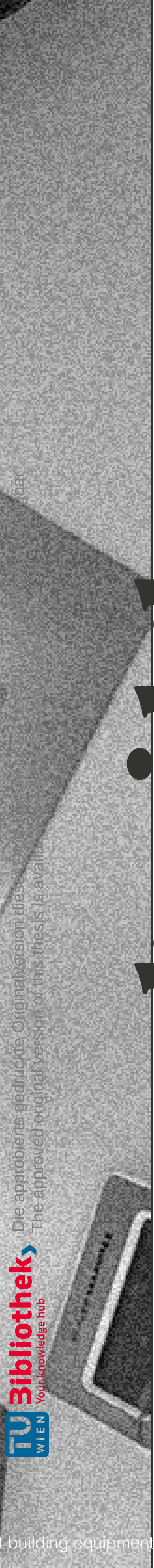


Figure 34



build

The implementation stages of the design, which was realized as a result of testing the completed experiments in the laboratory, are documented in this section.

Preparation

Preparations were made days in advance to prepare the construction environment. The doors are additionally insulated and the area carefully sterilized. The ordered materials have been stored under the necessary conditions.

Figure 33 door and ground insulation

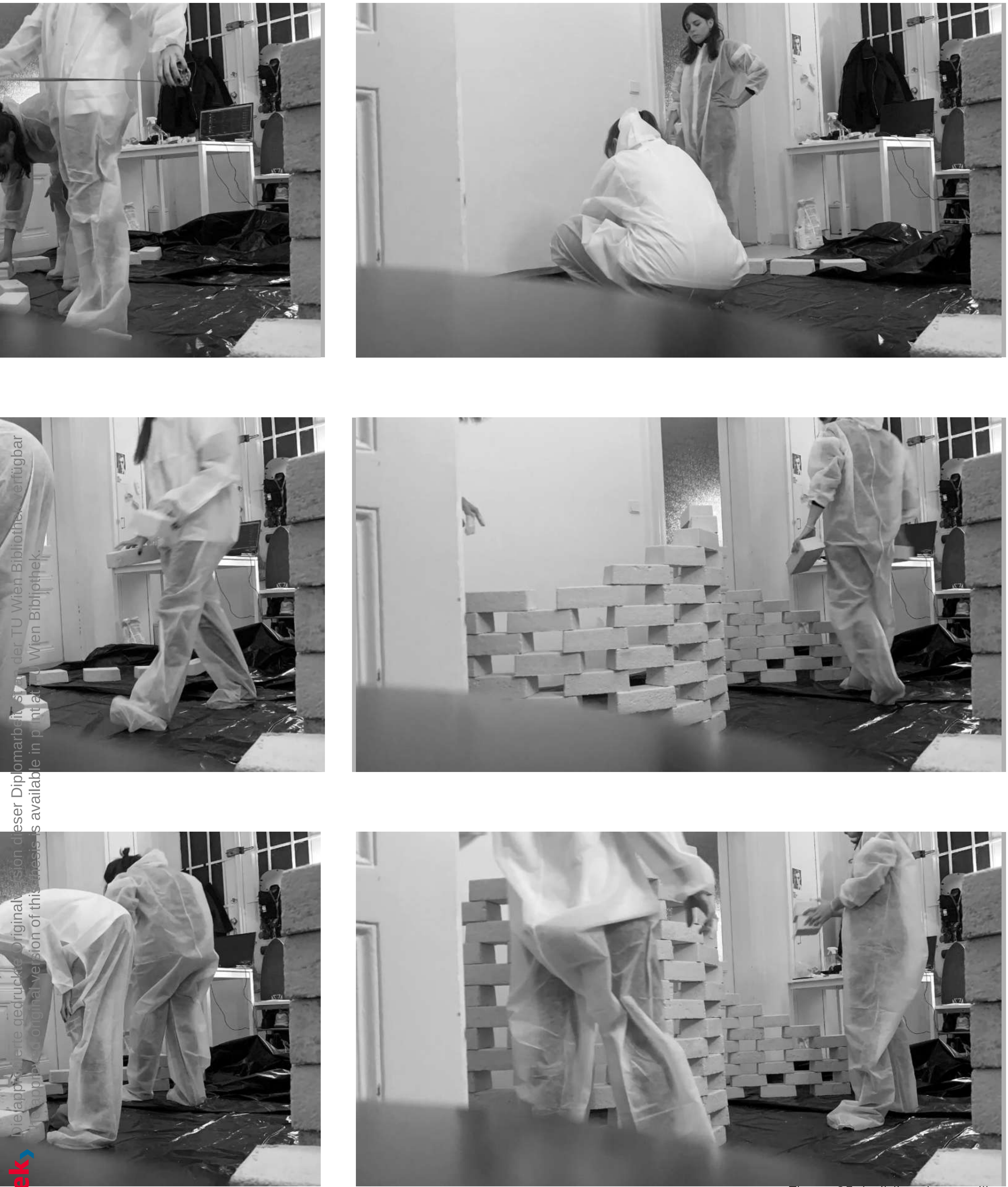


Figure 35 building the pavilion



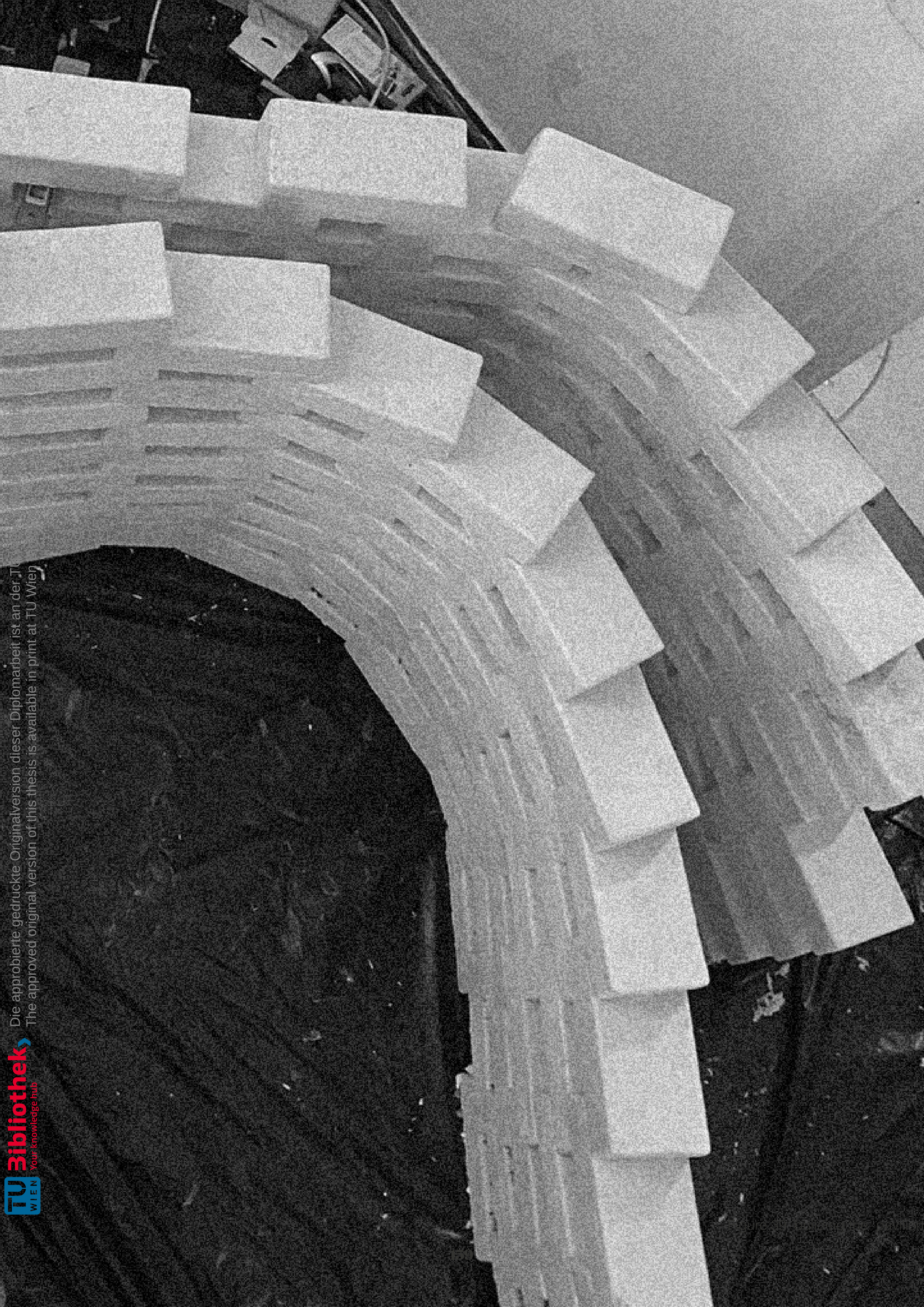



Figure 36 building the pavilion

Figure 37 building the pavilion

Figure 38 building the pavilion

mycelion



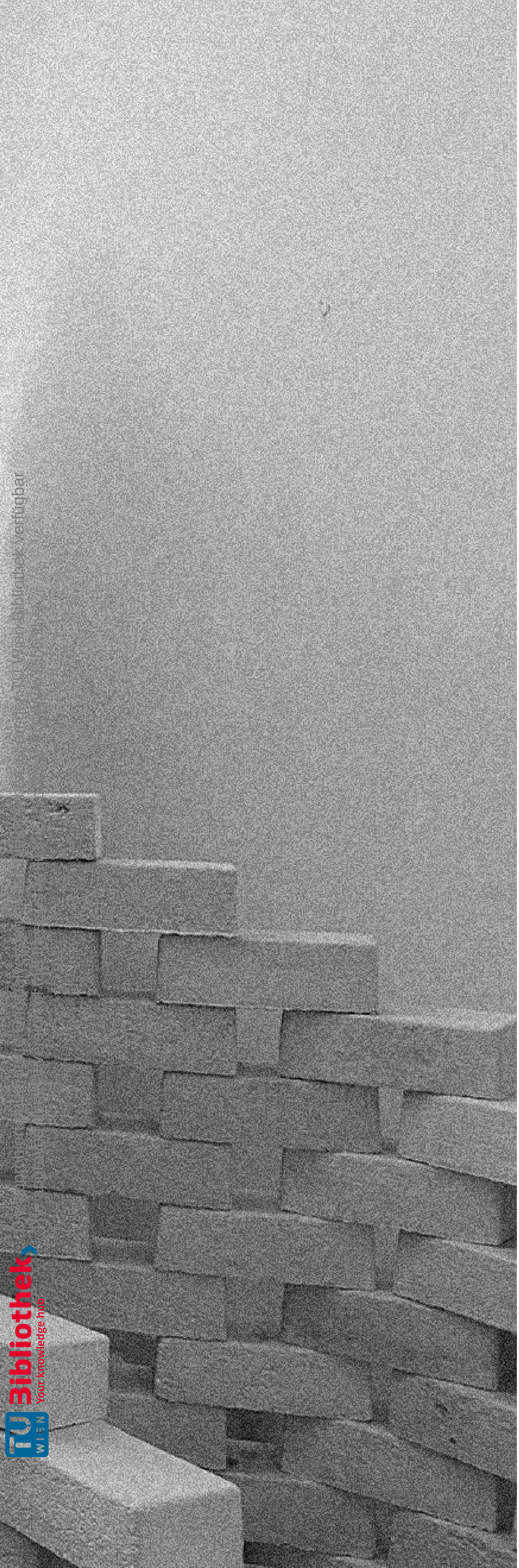


Figure 40 mycelion the pavilion

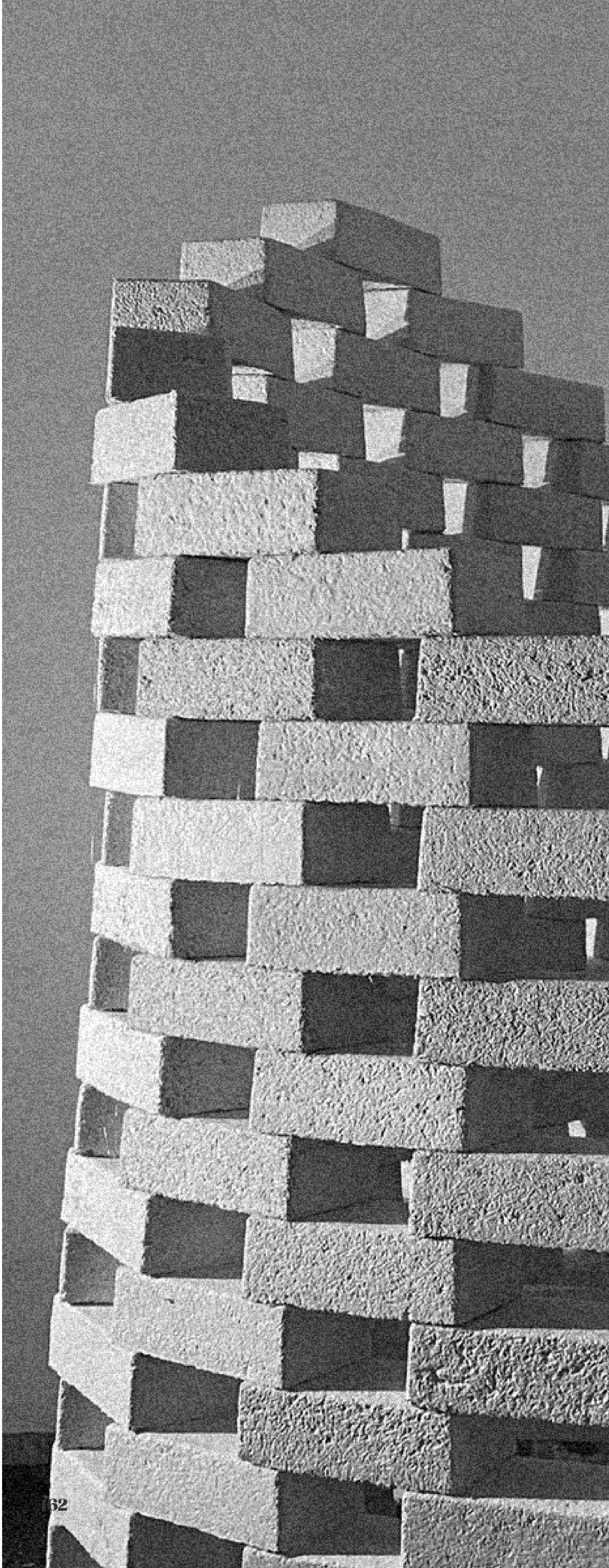


Figure 41 mycelion the pavilion

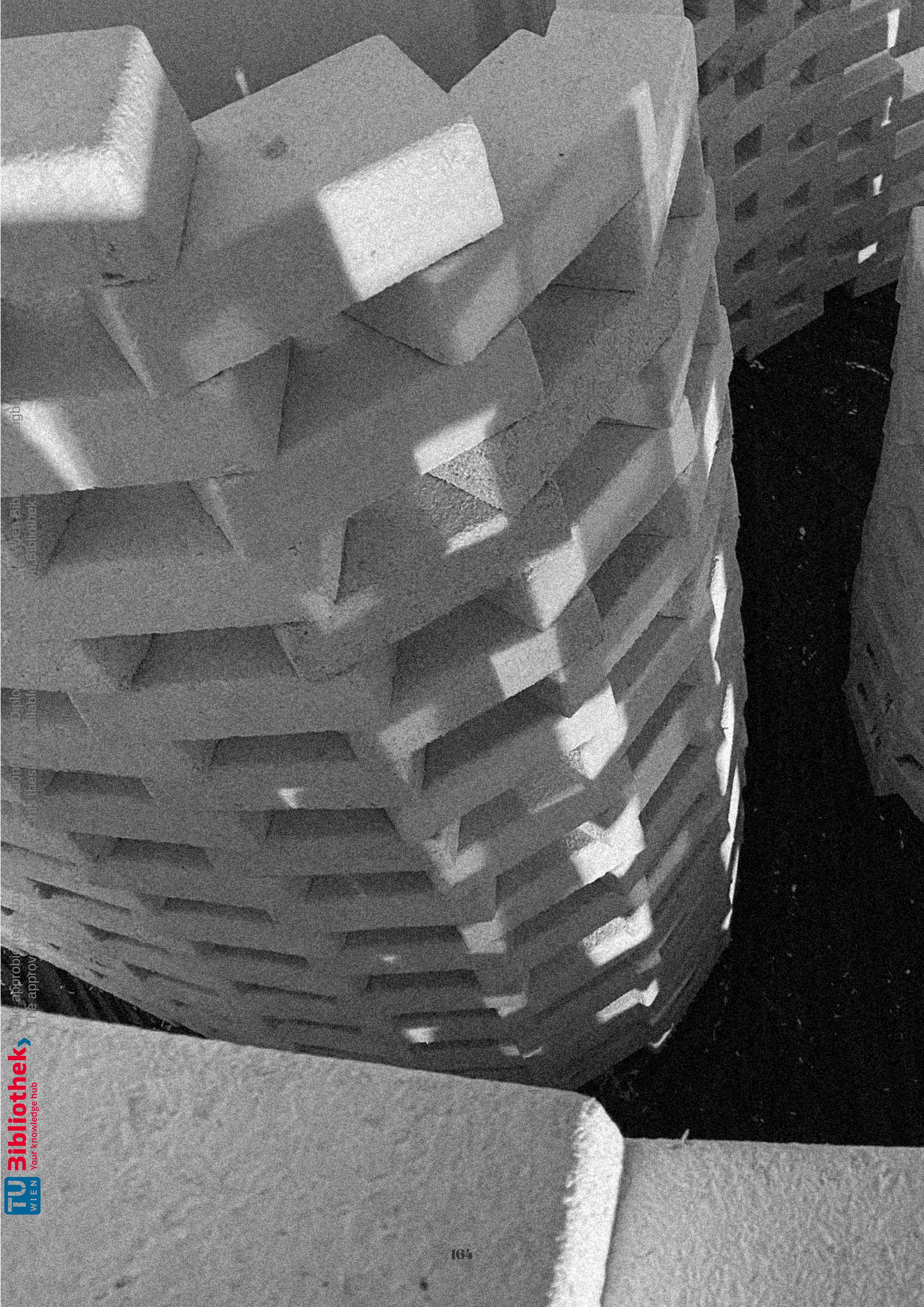


Figure 42 mycelion the pavilion

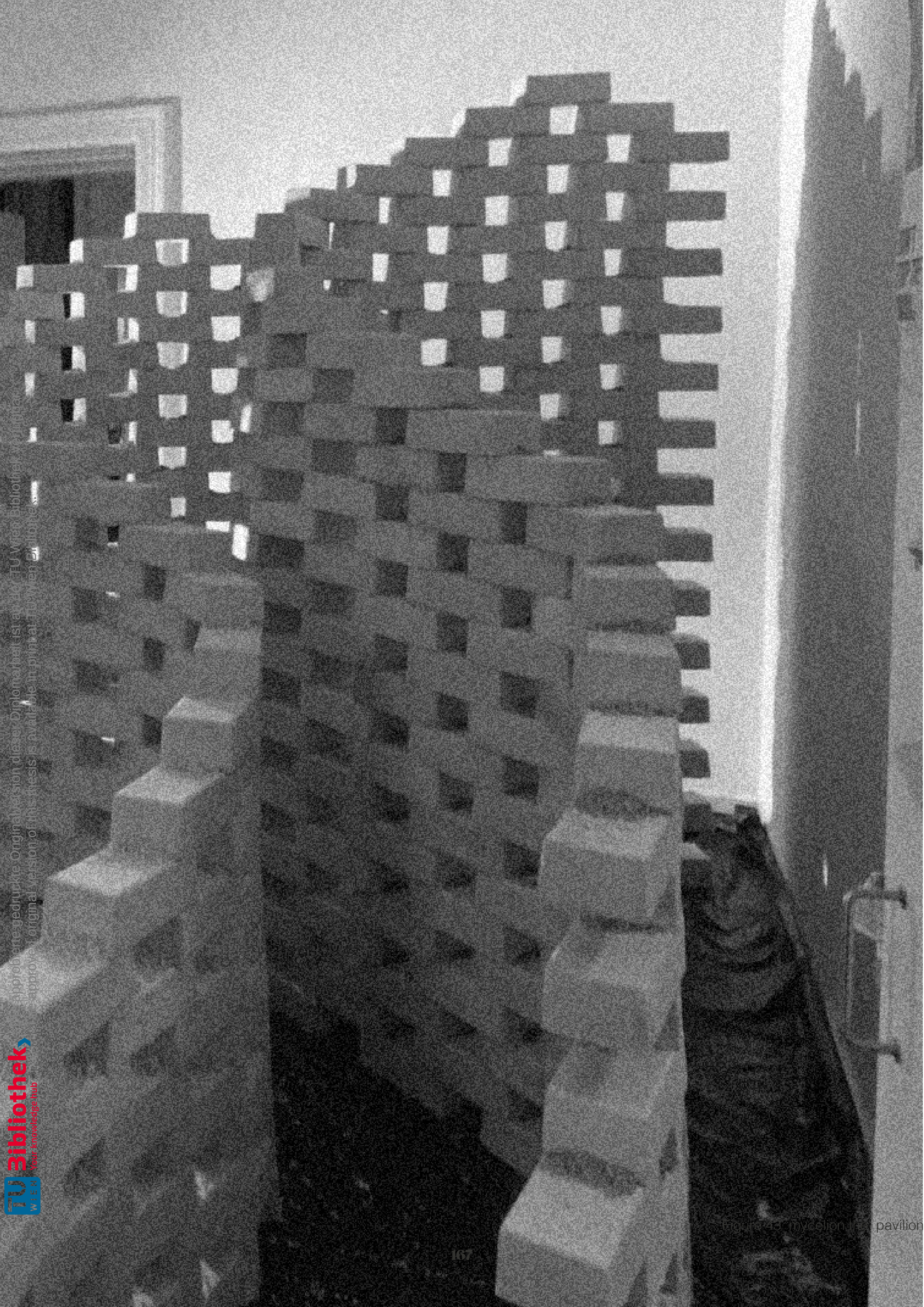


figure 43: mycelion the pavilion

Figure 44 mycelion the pavilion

Necessary conditions must be met for the expected growth to take place. The pavilion is still growing, using an additional dehumidifier and heater for this.

Figure 46 mycelion growing

conclusions

By encouraging recovered materials to circulate as many times as possible through reuse, recycling or upcycling, fewer resources become waste, minimising the need to extract raw materials from nature.
Designing with living, active and adaptable materials or considering materials as living entities in design practice is a complex issue and requires an experiential understanding of these materials. Today's designers can no longer limit themselves to the systematic approach of product design practice, where problem formulation and conceptualisation of ideas come first and are followed by translation of concepts into forms, functions and materials that are embodied in a final design product.

It is well known that the mushroom kingdom is based on a biological system capable of transforming organic matter into multiple rich products of wide utility and offers distinct opportunities to address urgent challenges even before humans. Mushroom biotechnology can implement the ecological transition in a circular form not only from an energy perspective, but also in relation to various industries, such as construction, food, chemical, pharmaceutical, automotive, textile, transportation and so on. Above all, the role of fungi could play a very important role in reducing CO2 emissions and thus mitigating climate change through the rational improvement of new and established fungal cell factories. Without fungi helping with decomposition, all life in the forest would no longer be able to function.
In short, fungi eat death and, in doing so, create new life. Scientists estimate that there are over 5,000,000 species of fungi on Earth, but we have only discovered 1 percent of them. By delving deeper into the world of fungi, we open new doors of knowledge. The discoveries could be used for anything from decomposing industrial waste to developing new food sources and producing new medicines to a possible replacement for plastic. Most of the interesting things nature can do we have not yet discovered.

During our experimental journey, we found out that the most successful test was the one engaging oyster mushroom together with a hemp substrate. Oyster mushrooms have proven to be the most resistant to contamination and faster in the growth process. During the experiment II we have found out that the more mycelium we add the faster the growth is processing. During winter time, it was difficult to accomplish a faster growth due to conditions in our house. We have tried our best to add extra insulation to keep the room temperature stabile but still it was not the most optimal condition for a better growth. From thermal testing we have seen that, mycelium composite bricks do have a great potential for insulation but less strength for compression. Based on our lab testings, we can say that the mycelium brick is not the very optimal way when it comes to load bearing structures but has proven to be a challenging competitor when it comes to acoustic panels or even insulation element. This doesn´t want to discourage the possibilities that this material can hold for future, considering the fact that mycelium composites are still an emerging material when it comes to architecture and the building industry. A building´s corpus is only partially made of structural elements, a high percentage of it is still entailing secondary elements (infills, insulation, partition walls, plastic based materials) and imagine that such fully recyclable elements could drastically reduce emissions associated with the built environment and act as a step toward de-carbonization. In a hypothetical scenario, mycelium made structures may be able to be grown on-site if there the growing conditions can be adapted properly and given the right sources in agricultural waste, it could act as a local economical hub model for communities. Historically, traditional architecture has facilitated and stimulated economic growth while contributing to an ever-increasing human footprint, exponential carbon emissions, resource extraction, and biodiversity loss. It is time for the power of design to contribute to an environmentally and socially conscious future and develop alternative visions. Although the ubiquity of new materials and technologies offers

designers a wide range of potential for creating design concepts and products that would not have been imaginable previously, today's designers must seek appropriate approaches, strategies, and tools for working with new materials that are variously changeable, growing, or responsive to the environment and/or other materials.
It is time for the power of design to contribute to an environmentally and socially conscious future and develop alternative visions.
If for Vitruvius the human body was the right proportion for architecture, what should be the scale of design to address today's environmental challenges? Climate change, species depletion and ocean pollution are global problems. What remains of Vitruvius' ideal of human scale has extended to new global scales and millennial timescales. How can architecture conceptualize a planet where humans have been involved in vast geological forces?
Recognizing the "wastes of ruin" as raw material, this research aims at an alternative material form that recognizes other nonhuman agencies in the process of creation.
What can we recover from the past and how can we reshape or innovate this knowledge to fit present and future needs? Societal challenges such as climate change, land subsidence, CO2 emissions, and fossil fuel scarcity require new sustainable solutions.
In framing research questions and the design of materials and products, it is useful to keep in mind a framework that provides goals for the use of materials and can guide researchers toward identifying new methods and processes to alter the properties of materials and help them find interdisciplinary projects that contribute to building an alternative library of methods and designs that can help create positive impacts toward the future.

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