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January, 13th
2024

AR3AE100
Architectural
Engineering
Graduation Studio

Geobased Materials

A social-ecological-technological system framework for restoring the value chain of geobased materials

This booklet is designed for the AR3AE100 Architectural Engineering Graduation Studio.

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Cover image Compressed Earth Brick machine during Eart Discovery Workshop BC Materials [Author]

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“Utube”: Clay bricks from Metro3 excavation,
Bruxelles ,2021 [BC Materials]

A social—ecological—technological system framework for restoring the value chain of geobased materials

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Research Paper
Architectural Engineering
Graduation

Abstract

This qualitative research compares the value chains of bricks and geobased building materials through a social-ecological-technological systems (SETs) framework and examines collaborative systems (social), ecosystem services (ecological), and tectonic systems (technological). The study aims to untangle the development and application of earth building materials over time by analysing the interlinkages of these aspects. Medieval guilds offer insights into integrated value chains, with skilled craftsmen overviewing entire value chains, reducing intermediary actors and protecting quality. Ecologically, past practices minimised environmental impacts by building with local materials, contrasting with today's dependence on import. New insights appear regarding the renewability of Dutch River clay, when floodplains are organised efficiently, accompanied with nature development and carbon sequestration. Technologically, the appropriate use of bricks should go together with the reintroduction of geobased materials, from on-site to off-site prefabrication. However, it requires in-depth knowledge of material properties and local resources. Aesthetic choices must be made by regional availability, promoting ecological responsibility, and helping restore a sustainable value chain, collaborating with the biobased industry, partially using the current brick infrastructure. While drawing back on historical ideas, this paper recommends further research on the economical aspects and practical implementation.

Keywords

Geobased Materials (Loam, Rammed Earth, Clay), Social-Ecological-Technological Systems (SETs), Value Chain Restoration, Regenerative Practices, Craftsmanship and Landscape Relations

Introduction

A mason builds a wall of monastery bricks. Etching by Caspar Luyken, after Jan Luyken, from 1694. [Collectie Rijksmuseum]

Unfired clay offers a range of functional advantages, re-emerging as an alternative in the polluting building industry. These include technical advantages like moisture-regulating properties, thermal performance, and acoustic characteristics enhance indoor air quality and comfort, alongside environmental benefits, such as renewability and extraction supporting biodiversity. These qualities make unfired clay important for addressing environmental and human-centred design decisions. [1]

1
Dethier, J. (2020). *The Art of Earth Architecture: Past, Present, Future.* 24.

Christina Eickmeier, a frontrunner in earth building traditions in the Netherlands, introduced the term "geobased" for mineral materials that are extracted responsibly, processed minimally, and use as few additives as possible. The firing process in regular brick production leads to significant CO^2 emissions, while locally sourced geobased products have a low CO^2 impact and iterate closely to their natural cycles. The Global Warming Potential (GWP) of fired clay (523 kg CO^2 eq/m³) compared to unfired clay (91.8 kg CO^2 eq/m³) highlights fired clay's substantial carbon footprint. Nevertheless, Bricks can have a very long lifespan, which makes the material score positive regarding the Environmental Cost Indicator (ECI) [2]. For both products, sourcing materials locally and responsibly can provide ecological benefits, allowing embankments to evolve naturally. Renewed interest in earth-based materials can enrich regional architecture and support nature development.

2
Mulder, K. (2025, 7 januari). *Persoonlijk interview.* Faculteit Bouwkunde.

Maarten Hajer, Professor of Urban Futures at Utrecht University, argues for focusing on (re)organising these value chains. A sustainable industry requires clear value chains, fostered through government and building sector collaboration [3]. Re-positioning "geobased materials" within the circular construction discourse and showcasing their potential can lead to adoption. Earth-based products deserve attention as the Netherlands transitions to sustainable construction practices. *What can we learn from the past? How might a resurgence of Medieval craft guilds contribute to the contemporary performance of regional value chains of geobased materials?*

3
NOS. (2024, 4 december). *Bouwen met biologische materialen is trendy, maar bouwwereld is er niet klaar voor.*

This research aims to describe the development of the value chain of bricks in different time-space categories and the current stances toward geobased materials.

This research questions how the value chain of geobased materials can be restored through a social-ecological-technological system framework analysis, enhancing the regional landscape, and built environment.

Firstly, the work draws back on historical qualitative social, ecological and technological values incorporated in three different time-space categories. Secondly, the barriers to implementation in the current building practice will be identified. Thirdly, a bold vision is prototyped on how a modified value chain of geobased building materials could spatially be translated into a regional architecture. The hypothesis is that the unfired earth faces an image problem due to the absence of coherent value chains and the misalignment of supply and demand. Reorganising this value chain with fewer links and greater transparency is of societal relevance and could provide a viable and sustainable solution to these challenges. In academic terms, an overview of the entire chain of earth building materials, from sustainable excavation to implementation is the research gap.

Methodology

This qualitative research compares the value chains of bricks and geobased building materials on a social, ecological, and technological level. The aim is to gain insight into the development and application of geobased materials over time, focusing on the interplay between these three aspects within the framework of the SETs analysis (Social, Ecological, Technological). SETs analysis is an interdisciplinary research method, in which the social aspect describes collaborative systems, the ecological describes landscape and ecosystem services, and the technical aspect describes tectonic systems, focusing on the production and implementation of building materials. This paper should be conceived as an overview of the evolution within the field of earth building materials. It dives into an integrated system, from which aspects are taken, described and untangled.

<u>Main question</u>
How can the value chain of geobased materials be restored through a social-ecological-technological system framework analysis, enhancing the regional landscape, and built environment?

<u>Sub questions</u>
1. How did brickmakers’ craft guilds historically operate in regional ecosystems? (1300-1798)
2. How does the value chain of bricks currently operate? (post-1920)
3. What are the contemporary dynamics and future pathways in the value chain of geobased building materials?
4. How can the geobased building materials value chain be improved based on new insights?

The primary data collection method will be desk research. This will include three key components:

1. Literature Review: The value chains of bricks and geobased materials will be analysed in different time-space categories through revision of literature, including historical documents, studies on guilds, and reports on ecological and technological developments regarding bricks and geobased materials. The research categorises stakeholders, technological (production processes and implementation), and ecological processes as individual SETs, focusing on main themes and concepts to maintain relevance to the design assignment: Value chain of bricks late medieval (1300-1750) —Value chain of bricks post-1920 (1920-now) —Value chain of geobased materials contemporary dynamics and future pathways
To ensure the study does not get bogged down in the limited historical data on guild organisation but remains relevant to the upcoming design assignment, the focus will primarily be on the main themes and key concepts. The Industrial Revolution (1750–1920) is excluded, as its processes persist in the post-1920 era, with key differences being advancements in machinery, workforce reduction, improved working conditions, and modifications in brick recipes.

2. Prototype (Bold Vision): Based on the findings in chapters 1, 2 and 3 a bold vision is prototyped. This component explores innovative concepts regarding geobased building materials, focusing on their future applications, spatial layout, and impact on the value chain from a social, ecological, and technological perspective.

3. Interviews: Interviews with experts in the earth building construction sector and designers will be conducted informally and openly, involving site visits and on-location discussions on current insights and future visions about the role of geobased materials in the construction industry. (fig. 1)

Fig. 1. *Visit to BC Materials for Earth Discovery Day, compression test for Rammed Earth in steel mould* [Workshop] 2024. Author

Results

3.1 How did brickmakers' craft guilds historically operate in regional ecosystems? (1300-1798)

By the twelfth and thirteenth century, land reclamation, population growth, and urbanisation increased demand for building materials like stone for churches, castles, and other structures. Bricks emerged as a practical alternative and was supported by subsidies, while regulations discouraged combustible materials. Local brick factories widely popped up, supplying municipal and private projects and occasionally exporting their products. [4]

To meet the growing demand for brick construction, guilds emerged as key social structures, fostering innovation and ensuring stability within the industry. The abolition of guilds in 1798 disrupted the traditional transfer of knowledge, previously passed down within closed communities, necessitating written documentation to preserve this expertise. The image of guilds, seen as the scapegoats for obstruct economic progress and maintaining monopolies, is justified by new research that describes their advancement in craftsmanship and organisation [5]. This chapter explores the social, ecological, and technological aspects of the brick value chain organised by craft guilds. [6] (fig. 2, 6)

Social

The social structures varied by city within the Netherlands. Therefore, a broader perspective is applied to understand the overarching impact, identifying the connecting thread throughout the history of the (masonry) craft guilds.
Very often, closely related professions were organised within the same guild structures. For example, in Utrecht, stonemasons, brickmakers, glassmakers, slate roofers, tile layers and pavers were all united in the same craft guild [7]. Some practised these crafts simultaneously. Clustering related professions, streamlined intermediary contact. In addition, they functioned as suppliers of raw commodities and oversaw the extraction of stone quarries (and sometimes also clay extraction areas)[8].

4
Van Hunen, M. (2012). *Historisch metselwerk: Instandhouding, herstel en conservering.* Rijksdienst voor het Cultureel Erfgoed, WBOOKS

5
Epstein, S. R., & Prak, M. (2008). *Guilds, Innovation and the European Economy, 1400–1800*. Cambridge University Press.

6
Stenvert, R. (2012). *Biografie van de baksteen, 1850-2000.* 22.

7
Hollestelle, J. (1961b). *De steenbakkerij in de Nederlanden tot omstreeks 1560.* 161

8
Van Gassen, T. (2012). *De ambachten van de metselaars en timmerlieden in laatmiddeleeuws Gent* (Master's thesis). Universiteit Gent, Faculteit Letteren en Wijsbegeerte. 32

Fig. 2. *Brickmaking. Miniature in a Dutch Bible; circa 1470* [Wien, Nationalbibliothek]

This integrated approach minimised intermediary linkages and ensured better oversight from raw material extraction to final construction. The central task of craft guilds in the Late Middle Ages was to provide a corporate framework for organising urban labour, primarily focused on the economic aspects of work, with five main categorised roles: (1) regulating the profession involved setting the quality and pricing standards to prioritise craftsmanship over competition while controlling materials and tools. (2) Training and admission were managed through supervised apprenticeships leading to mastery. (3) Advocacy focused on protecting members from external competition and resolving internal disputes. (4) Social security provided support during illness or death. (5) Political and social influence was significant, with members often wielding power and organising community events.

Guild structures manifested in two ways: in itinerant or permanent guild organisations. In her dissertation on late medieval Ghent's masonry' and carpenters guilds, Van Gassen describes how builders often formed associations centred around construction sites. In Germany, builders collaborated through stonemason brotherhoods (steinmetzenbruderschaften), having own laws and regulations. These temporary associations lasted for the time the construction project was ongoing.

The boom in building projects (city walls, town halls and guild houses) during the twelfth century created significant employment opportunities, leading to permanent organisations of guilds in cities, protecting and promoting group interests [9]. When constructing a house or church, a skilled brickmaker (bouwmeester) was hired to the location to oversee the project for one or two seasons, he needed to be able to select good raw materials, supervise the clay processing, the drying of the moulded bricks, and firing the kiln. Unskilled labourers were typically recruited to assist with the work [10]. In more permanent corporations a warehouse manager (loodsmeester) was responsible for the management of resources, work distribution, and tools. [11]

In medieval society, wooden construction was of lower social-cultural value, as it was often classified as impermanent, movable property on leased ground. Higher social classes could afford immovable, permanent brick construction, build on private property. In Twente, for example, people eventually started filling wooden frameworks with brick. Technically, this makes little sense:

9
Ibid., 27

10
Hollestelle, J. (1961b). *De steenbakkerij in de Nederlanden tot omstreeks 1560*. 38.

11
Van Gassen, T. (2012). *De ambachten van de metselaars en timmerlieden in laatmiddeleeuws Gent* (Master's thesis). Universiteit Gent, Faculteit Letteren en Wijsbegeerte. 125.

12
Mulder, K. (2025, 7 January). *Persoonlijk interview*. Faculteit Bouwkunde. Appendix II

heavy brick infill for a light wooden frame. But brick carried cultural value. [12] (fig. 3, 4)

Fig. 3. *Architectural Typology of Brick Drying huts (so-called Haaghutten)* [Nederlandse Museummaterieel Database]

Fig. 4. *Timber-framed house filled with bricks instead of rammed earth. (Bakhuuske in Twente)* [Hello Oostmarsum]

Ecological
Solely landowners had the right to extract clay. Only through fees, vassals or tenants (leenheer, pachter) could acquire the right to extract the clay (uittichelen, aftichelen) and produce bricks [13]. After the extractions the excavated pits had to be levelled to function as productive farmland or building land [14]. Sometimes, the price of the clay was therefore not incorporated into the price of the bricks [15]. Whether production of bricks was organised by themselves, was determined by a cost comparison between the purchase of bricks and transport against available labour, raw resources, and fuel [16]. Sometimes, the soil conditions made it possible to build the kiln on the border between clay and peat areas. This allowed them to minimise the transport cost of raw clay and fuel. In other situations, tenants of the brick kilns (ovens) had to plant willow trees on the land near the kilns as fuel. Their pursuit to produce as efficiently as possible, made them use local materials, build on-site factories and reduce transportation distances. Also, their production rate was low compared to daily excavation and production.

13
Hollestelle, J. (1961b). *De steenbakkerij in de Nederlanden tot omstreeks 1560*. 40.

14
Ibid., 41.

15
Stenvert, R. (2012). *Biografie van de baksteen, 1850-2000.* 29.

16
Hollestelle, J. (1961b). *De steenbakkerij in de Nederlanden tot omstreeks 1560.* 43.

Technological
The first part of the production process, including excavation and preparation, was a heavy, seasonal task. The second part of the process included moulding, drying, and firing of the bricks. It took place in specially built structures: the moulding hut, drying huts (haaghutten) and various types of kilns. The last part was sorting (tasveld), storing, and transporting, which was not part of when local kilns were used. (fig. 5)

As described in *De steenbakkerij in de Nederlanden tot omstreeks 1560* by Johanna Hollestelle, brick production in the thirteenth century varied due to regional practices and technological factors. Large bricks were common, as they matched natural stone dimensions, supported thick-walled structures, and minimised shrinkage during low-temperature firing. The lean clay mixture of the time also favoured larger bricks. Over time, advancements allowed for smaller, more manageable bricks, ideal for housing and optimising kiln space, reducing fuel consumption. Urban regulations on wall thickness and price controls further standardised brick sizes, such as those established in Delft in 1420, where standard moulds (vormbakken) were displayed in the town hall. [17]

17
Ibid., 78.

Brick colour also reflected regional soil composition and firing temperatures, with iron-rich clay producing red bricks and lime-rich clay yielding yellow ones. Differences arose due to local clay composition; for example, Limburg produced yellow bricks, while Utrecht's bricks were dark brown. Varying kiln temperatures led to mixed colours, initially used in mixed order but later sorted by strength. Darker, stronger bricks became more expensive and Hollestelle suggests that this caused them to be seen as more aesthetically pleasing. [18]

Beyond bricks, the medieval building industry produced roof tiles, floor tiles, and hearthstones, with techniques like oxygen-restricted firing (smoren) and glazing (glazuren) introducing further variations in colour and finish [19]. In the thirteenth century, bricks were used in cities due to the increasing threat of urban fires. Subsidies and bans on combustible materials promoted stone construction, for example in monasteries and churches. Unfired bricks (zonnestenen) were used as infill between timber frames, often in interior walls [20]. In conclusion, medieval regional architecture was characterised by technological variations in brick size, colour, and processing methods were limited and municipal regulations enforced standard brick sizes, linking dimensions to specific regions.

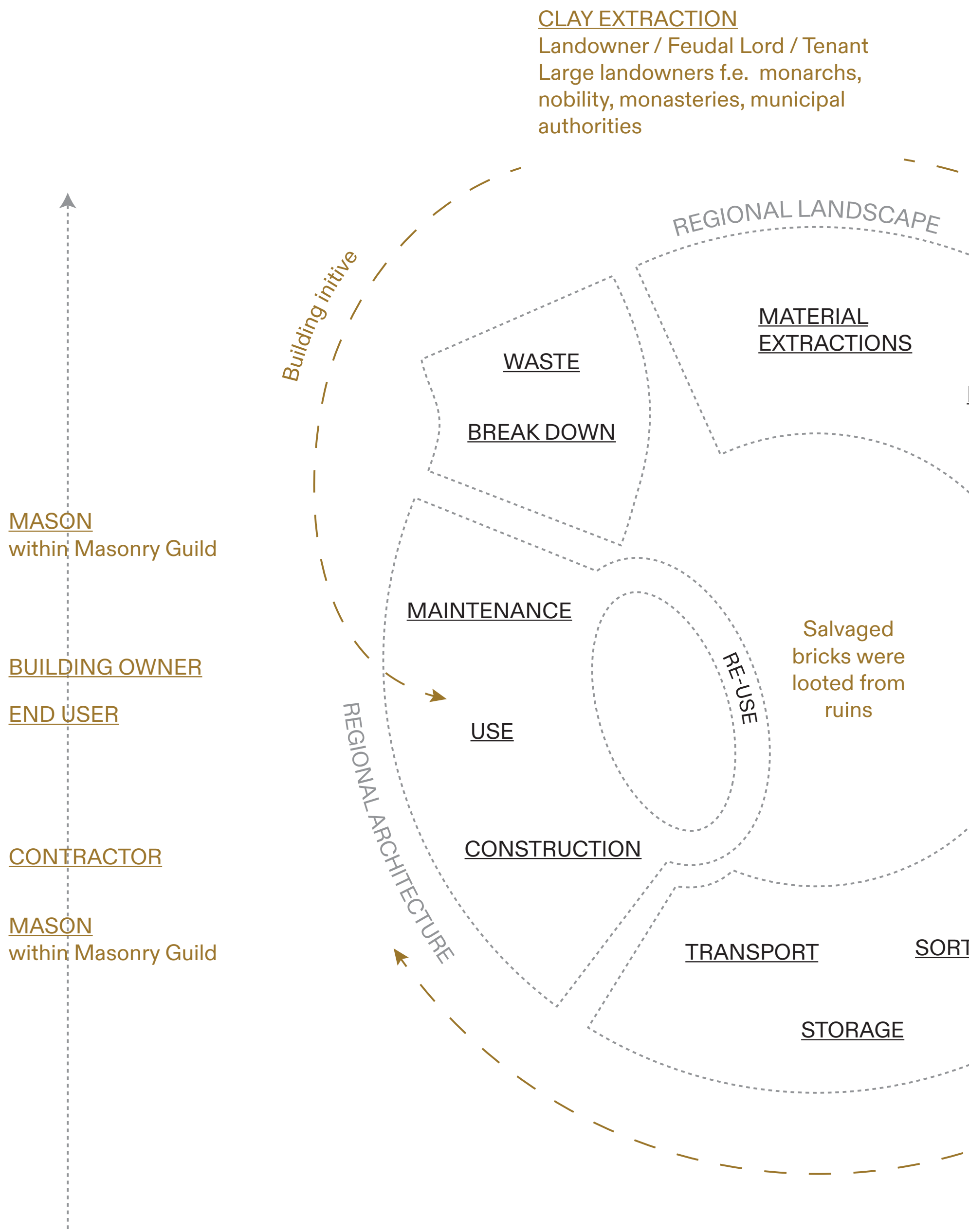
18
Ibid., 98.

19
Ibid., 69.

20
Van Hunen, M. (2012). *Historisch metselwerk: Instandhouding, herstel en conservering.* Rijksdienst voor het Cultureel Erfgoed, WBOOKS.

1. Preparations	2. Processing	3. Aftercare
Seasonal work: April to September. a. Clay extraction b. Mixing with people, horses or oxen. c. Rotting of plant material: Frost and temperature fluctuations in winter cause rotting of the organic matter.	a. Moulding (Vormen / Vormhut) b. Drying on field (Afdragen / Tasveld) c. Cutting in brick drying shed (Opsnijden / Haaghut) d. Firing i. Field kiln (Veldbrandoven) with slabs of peat and sealed with clay. ii. Permanent kilns (Veldoven)	a. Sorting b. Storage c. Transport: in the case of permanent kilns, transport had to be organised. Transport by (water)way via (horse-drawn) boats, carts. Sometimes the bricks could serve as ballast for empty maritime transport. A mutual benefit occurs as the stones could be sold once arrived.

Fig. 5. *Production Process of Bricks Late Medieval Ages* [Author]



CLAY EXTRACTION
Landowner / Feudal Lord / Tenant
Large landowners f.e. monarchs, nobility, monasteries, municipal authorities
REGIONAL LANDSCAPE
Building initive
MATERIAL EXTRACTIONS
WASTE
BREAK DOWN
MASON
within Masonry Guild
MAINTENANCE
RE-USE
Salvaged bricks were looted from ruins
BUILDING OWNER
END USER
USE
REGIONAL ARCHITECTURE
CONTRACTOR
CONSTRUCTION
MASON
within Masonry Guild
TRANSPORT
STORAGE

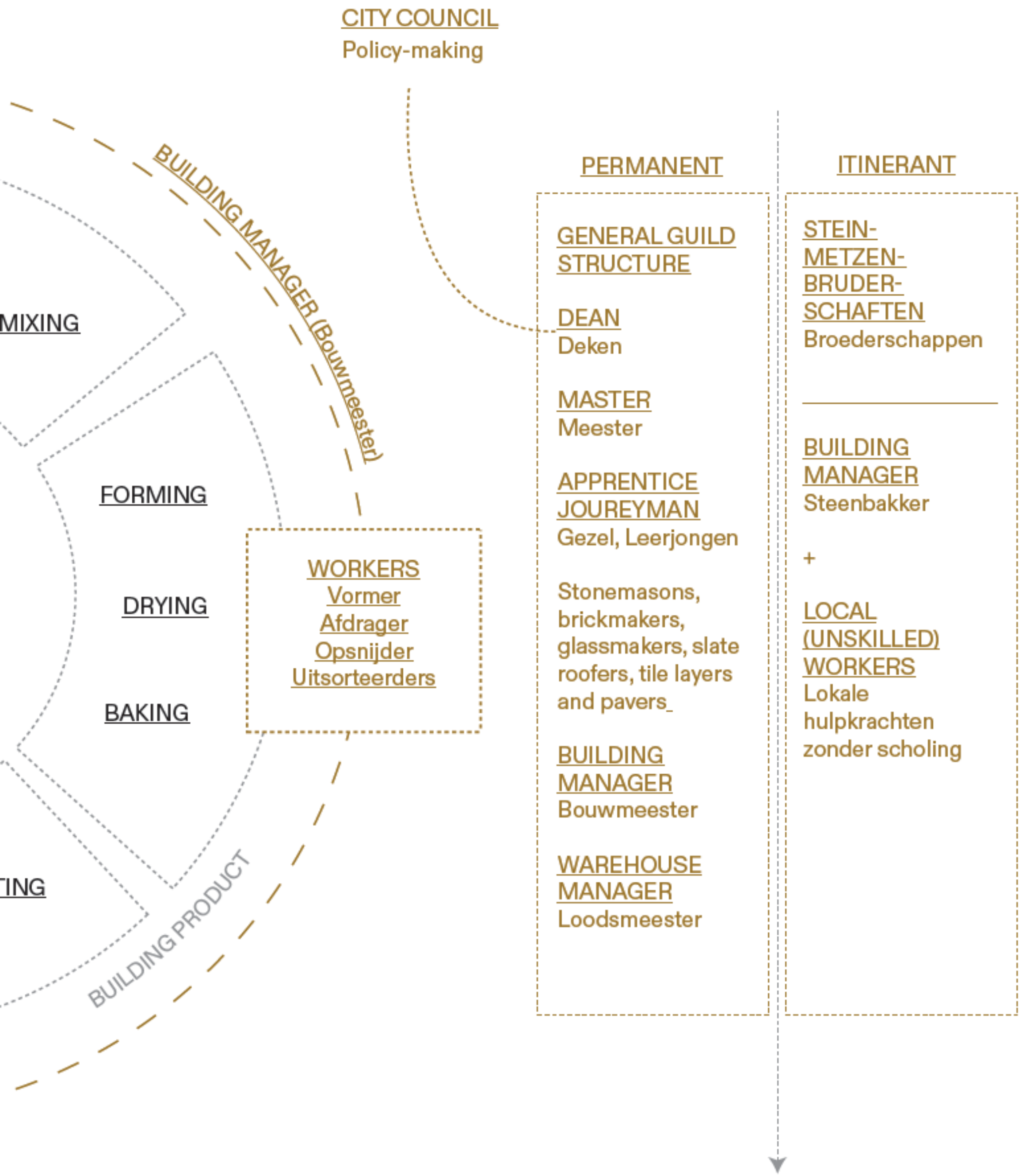


Fig. 6. *Value Chain Bricks Late Medieval Ages* [Author]

3.2 How does the value chain of bricks currently operate? (post-1920)

In the Middle Ages, temporary brick factories were more common than permanent ones. This shifted around the Industrial Revolution, with the introduction of automation and technical processes to the value chain. In the Dutch River areas, permanent brick factories were build, being less reliant on weather conditions and situated closer to resources [21] . For centuries, the Dutch brick production flourished. However, research by Everwijn shows a significant decline in the number of brick factories in the Netherlands, from 585 in 1906 to just 36 active factories in 2012. This decline occurred during the interwar period, the Second World War, post-war reconstruction, and the oil crisis. [22] (fig. 7))

Social

The clay extraction process now involves a growing number of stakeholders, including specialised firms focused solely on clay extraction, soil depots, and brick companies that manage extraction in-house. National and regional governments, water boards, urban planners, and landscape architects play a crucial role in balancing and regulating the extraction process. Many intermediary roles – like mining and transport companies, suppliers, sales agents and waste managers – have entered the value chain.

The industry has expanded, and the process has become more regulated. Centralised brick factories have shifted from manual to highly industrialised operations, requiring only a few machine operators to manage production flows [23]. Factories such as De Rijswaard outsource extraction to K3 (*Delgromij B.V.*), while SMD Group handles transportation and depot construction. Depot monitoring and laboratory research and control is overseen by TCKI (*Technisch Centrum Keramische Industrie*)[24]. As seen, many stakeholders are involved, with the material changing hands several times before reaching the factory.

Construction with bricks can occur in controlled factory settings, as prefabricated panels, or on-site by masons. However, the Netherlands faces a shortage of skilled workers in construction. Wessel Beerendonk, founder of RAP, suggests robotics could address this issue, noting that robots could innovate brick construction through precision and versatility [25]. Steenfabriek De Rijswaard is also experimenting with the PAX

21
Stenvert, R. (2012). *Biografie van de baksteen, 1850-2000.* 31.

22
Ibid.

23
See Appendix I for *Interview Ronald Willemsteijn Steenfabriek De Rijswaard,* the tour in the factory only showed 10 machine operators in comparison to the same amount of factory workers in the postprocessing (stripcutting, sorting and making of retro bricks).

24
Ibid.

25
EenVandaag. (2018, 24 september). *Metselrobot moet tekort aan metselaars oplossen.* https://eenvandaag.avrotros.nl/item/metselrobot-moet-tekort-aan-metselaars-oplossen/

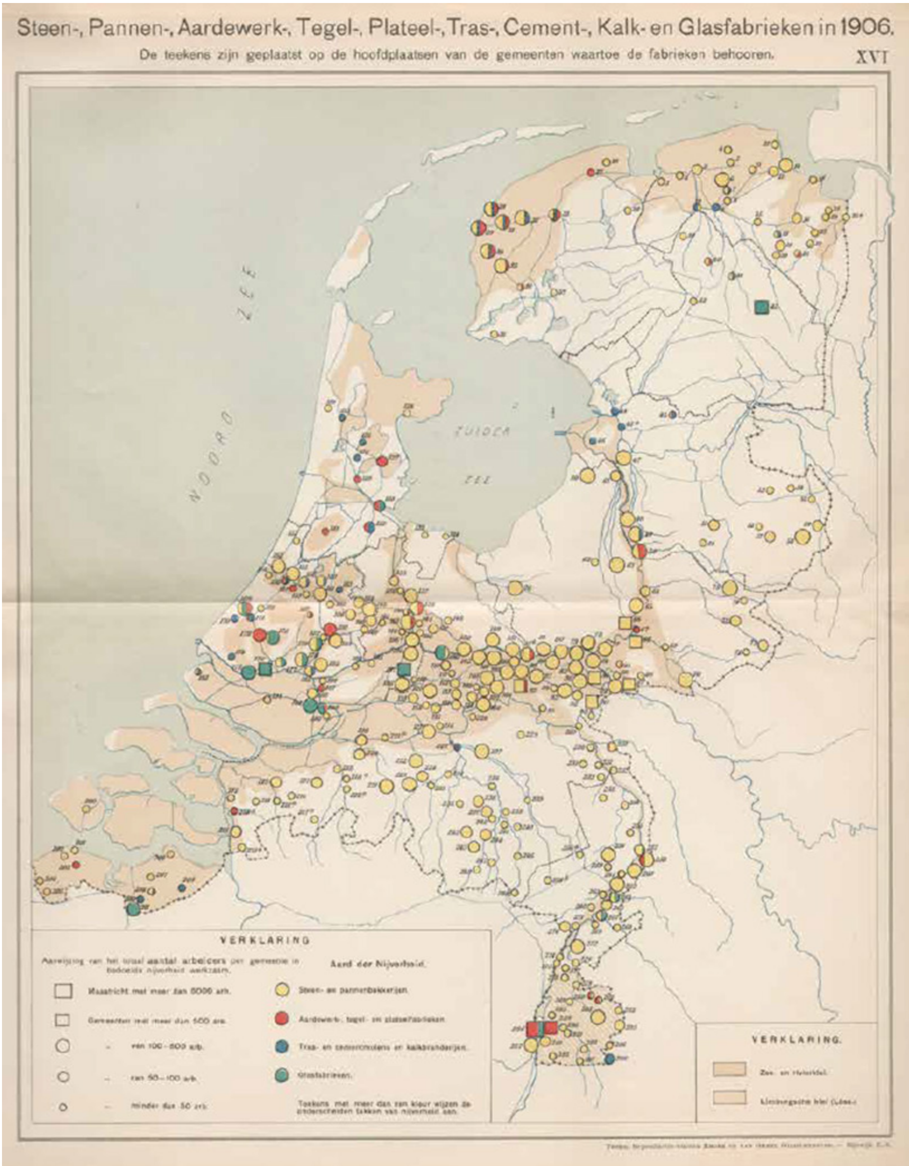


Fig. 7. *Distribution of brick, and related factories in 1906* [Histrosich Metselwerk; Plaat XVI uit de Hisorisch-Economische Atlas van MR. J.C.A. Everwijn]

masonry robot [26]. Lastly, the industry's interests are represented by the umbrella organisation KNB (*Koninklijke Nederlandse Bouwkeramiek*), while the Federation of Dutch Trade Unions (*FNV*) manages employee interests.

Ecological
Three types of extraction are categorised:
Dry extraction: Clay is mined from the surface of geological deposits in quarries found globally [27]. In Material Reform, its renewable character is questioned: "*Whilst new clay deposits are constantly forming in the earth's crust, it is a slow process that takes around 100,000 years in most geological conditions. As this time span years massively exceeds our capacity to plan and maintain material systems, clay is best understood as a non-renewable resource.*"[28] These pits used to have steep banks [29] and are best understood as non-renewable. To enrich the possibilities and product characteristics, Dutch clay types are mixed with transnational imported dry extracted clay for example from Germany (Westerwald). [30]
Wet extraction: The Dutch River Delta system is an exception, as the floodplain structures regenerate clay [31]. Three types of extraction are categorised. Every spring, clay deposits and accumulates in the flood plains of the major Dutch Rivers (Rhine, Meuse, Ijssel, Waal) flood, best understood as renewable.
Secondary extraction: Clay that is largely released during intentional (primary) extractions, for example, as a byproduct of infrastructural works, best understood as non-renewable. However, Willemsteijn (De Rijswaard) indicates that this clay is released in such small, uncontrolled batches, unusable for the brick industry. [32]

Technological
The brick-making process has remained consistent, categorised into manual, semi-industrial, or industrial methods. All methods follow the same basic principles. After extraction, a clay storage is built up in layers. This is followed by mixing, crushing, screening follow to achieve desired qualities like colour and hardness. Small on-site batches could be moulded by manually or with a dry-press machine (Appendix XV). For larger-scale production, soft-mud processing uses moulds for soft clays, while stiff-mud processing extrudes clay with 10-15% water, producing uniform shapes. The formed bricks are fired in kilns, where heat causes the clay to vitrify and harden. Tunnel kilns provide continuous heat, while periodic kilns apply heat

26
See Appendix I for *Interview Ronald Willemsteijn Steenfabriek De Rijswaard*

27
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections.* Oro Editions.

28
Cultures, M. (2022). *Material reform: Building for a Post-carbon Future*. 29.

29
Koninklijke Nederlandse Bouwkeramiek. (2017, May). *Rapportage duurzame kleiwinning.* 68.

30
Koninklijk Verbond van Nederlandse Baksteenfabrikanten (KNB). (2021). *Van Klei tot Baksteen.* 6.

31
Deltares / TNO Geological Survey of the Netherlands, Van Der Meulen, M. J., Wiersma, A. P., Van Der Perk, M., Middelkoop, H., & Hobo, N. (2011). *Sedimentbeheer en de vernieuwbaarheid van klei als grofkeramische grondstof.*

32
See Appendix I for *Interview Ronald Willemsteijn Steenfabriek De Rijswaard*

intermittently. The firing process and kiln type influence the product characteristics. [33] (fig. 8)

The current brick material practice is characterised by a wide selection of forms, colours, sizes and glazing. While the architectural taste of the users, architects and welfare committees influence the outcomes, the materials used are often detached from their original sources. Over time, the centralisation and upscaling of factories have diminished the local character of construction practices, as materials are no longer tied to the places where they are used. Nevertheless, bricks hold high cultural value due to their significant contribution to regional and national architecture. However, as the material and craftsmanship become increasingly rare and expensive, their usage is shifting. In fig. 9, brick façade evolution is visualised by building technologist and brick expert Koen Mulder. Despite bricks' inherent properties—load bearing, fireproof, water-resistant, and durable—they are increasingly used only for decorative purposes. In many cases, behind brick cladding, other materials such as concrete, foam, and petrochemical-derived sheets are used [34]. For the production of brick strips, a new brick is cut on both sides and the middle part is thrown away. [35]

The sector also struggles with reintegrating used bricks into the value chain. This trend is concerning, especially in times of material scarcity and rising costs, leading to wasteful and environmentally damaging construction practices. Bricks can only be reused, once separated from the very strong mortar , but this labour-intensive process is rarely practised (anymore). This causes a negative image for bricks, while they can easily be re-used once the mortar is removed [37]. But most of the time, masonry is downcycled by crushing it into substrates for highways, or sent to landfills. Although non-toxic, this practice wastes the embodied energy invested in the original production [38]. New initiatives like Drystack, replaces mortar with plastic plates, allow the bricks to be disassembled and reused at the end of their lifespan.

33
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections.* Oro Editions. 235.

34
Cultures, M. (2022). *Material reform: Building for a Post-carbon Future.* 31

35
See Appendix I for *Interview Ronald Willemsteijn Steenfabriek De Rijswaard*

36
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections.* Oro Editions. 233.

37
Mulder, K. (2025, 7 January). *Persoonlijk interview*. Faculteit Bouwkunde

38
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections.* Oro Editions. 233.

39
Ibid.

In conclusion, bricks retain cultural value, but are increasingly used in a range of colours and styles, decoratively, with concrete materials replacing functional brick features and local sourcing and craftsmanship are diminishing. Before the widespread use of fossil fuels to power kilns, most of the clay used in construction was local and unfired. There is now a renewed growing interest in the potential of unfired clay, which holds significant promise for contributing to the broader shift toward regenerative construction practices. [39]

1. Site Excavation	2. Clay Storage	3. Processing	4. Firing
- Industrial mixing begins with the extraction of clay and shale, which are then crushed, prepared, screened, and combined with water on a large scale using industrial techniques to meet commercial standards.	- Clay is stored in depots, where it is blended to meet the specific requirements of brick production, including factors like colour, size, and hardness. To ensure high-quality bricks, the clay's composition is carefully adjusted concerning eight key elements: coarse sand, fine sand, silt, organic matter, iron oxide, lime, sulphur, and surface area.	a. Soft-mud Processing - For clays that are too soft to be extruded or have additional water content, a moulding process is used. Sand or water is applied to prevent the clay from sticking to the mould, resulting in either 'sand- or water-struck' bricks. b. Stiff-mud Processing - Clays with a moisture content of 10 to 15% are passed through a de-airing chamber and then extruded through a die. The continuous clay extrusion is cut into various shapes and sizes, making this the primary method for industrial brick manufacturing.	- The clay and shale mixtures are transformed into durable, rigid bricks through high-temperature firing in a kiln. During the firing process, the clay particles partially melt and fuse. The type of kiln used—whether a tunnel kiln with continuous heat or a periodic kiln with intermittent heat—affects the variety and uniformity of the final product.

Fig. 8. *Production Process of Bricks post-1920*
[Author]

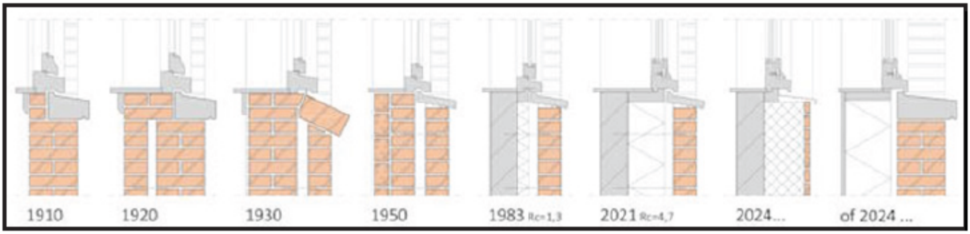
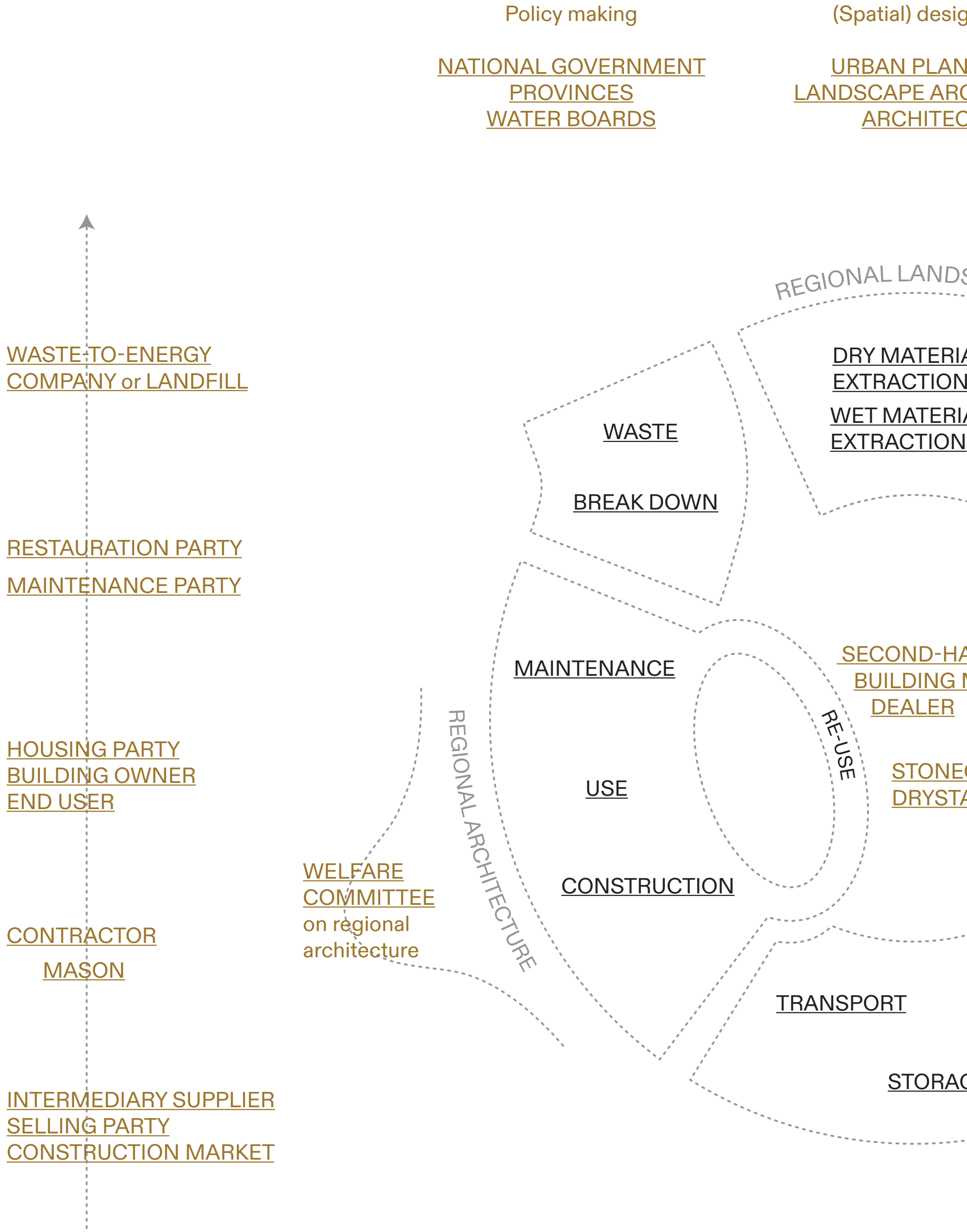


Fig. 9. *Evolution of the brick facade* [Koen Mulder]



Policy making
NATIONAL GOVERNMENT
PROVINCES
WATER BOARDS
(Spatial) desig
URBAN PLAN
LANDSCAPE ARC
ARCHITEC
REGIONAL LANDS
WASTE-TO-ENERGY COMPANY or LANDFILL
RESTAURATION PARTY
MAINTENANCE PARTY
HOUSING PARTY
BUILDING OWNER
END USER
CONTRACTOR
MASON
INTERMEDIARY SUPPLIER
SELLING PARTY
CONSTRUCTION MARKET
WELFARE COMMITTEE on regional architecture
REGIONAL ARCHITECTURE
WASTE
BREAK DOWN
DRY MATERIA
EXTRACTION
WET MATERIA
EXTRACTION
MAINTENANCE
USE
CONSTRUCTION
RE-USE
SECOND-HA
BUILDING M
DEALER
STONEC
DRYSTA
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STORAG

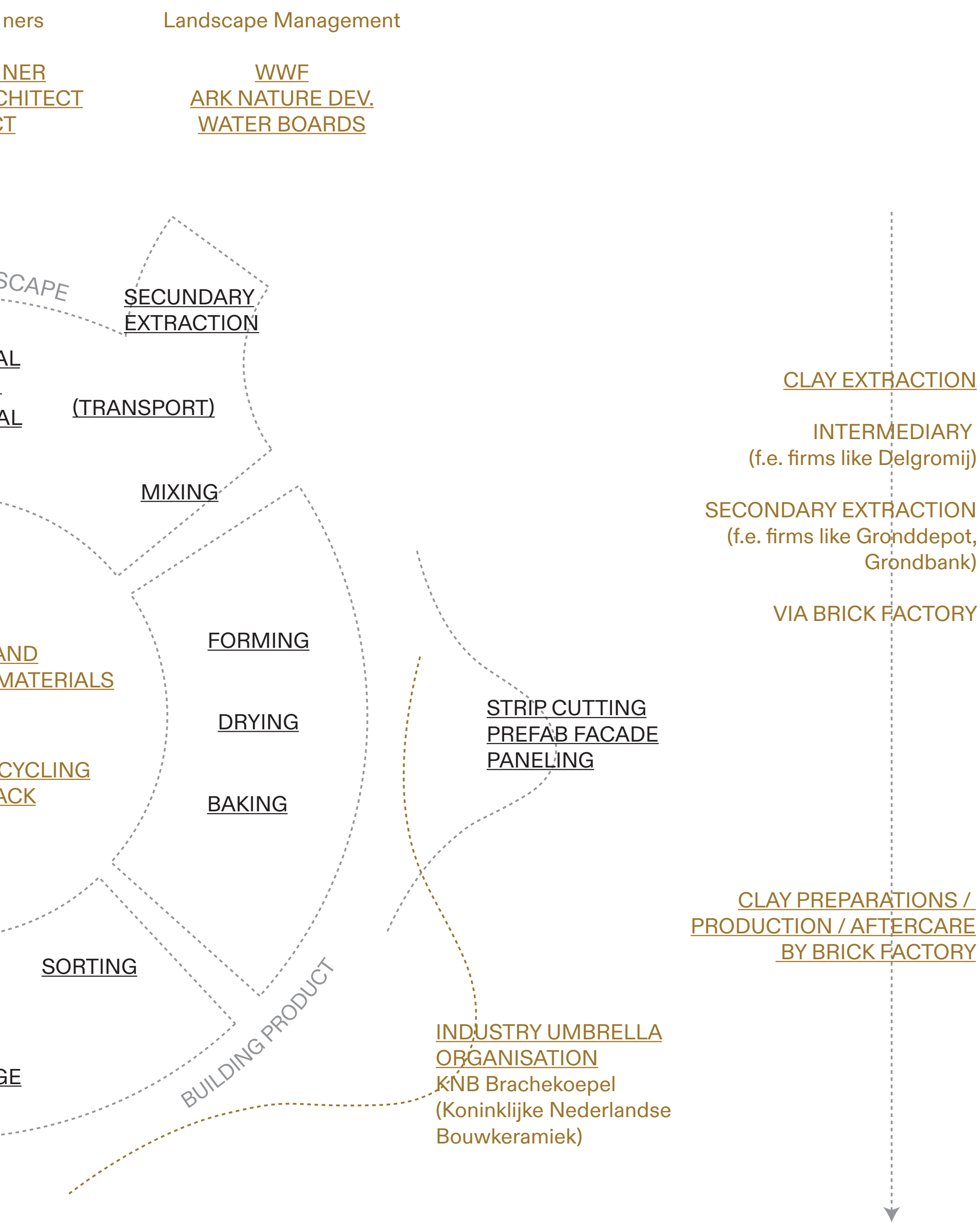


Fig. 10. *Value Chain Bricks post-1920* [Author]

3.3 What are the contemporary dynamics and future pathways in the value chain of geobased building materials?

Ecological architecture has become a dominant theme, from the 1970's onwards. Starting as a niche interest, earth architecture became of higher value after CRAterre's 1980 handbooks and a young collective (re)embracing earth building materials in 2010 [40]. Political institutions, the construction industry, and earth architects have increasingly collaborated to disrupt traditional alliances and building standards [41]. New extraction methods and studies on Dutch clay renewability by Deltares and KNB should help boost the image [42]. However, earth building materials still need to prove their potential to a hesitant public. The strong cultural value of bricks and scepticism from users and construction parties present challenges.

Social

The value chain of geobased materials faces challenges in integrating social, ecological, and technological aspects (SETs), hindered by contemporary preferences and uninformed policymakers. Luckily, geobased construction is an emerging trend with growing attention from the industry. Although clay plaster, clay-based panels and clay bricks are already widely in us, the Netherlands has a hesitancy to set clear policy goals, that might be caused by lack of visibility. The National German Institute for Standardization (DIN) that approved clay bricks for load-bearing structures up to five stories in 2023, and France is also incorporating biobased and geobased materials into policies and tenders [43]. Hajer emphasises the need to focus on organising value chains, where close collaboration between the government and the construction sector is crucial [44,45].

To the public, as Martin Rauch notes, the proximity to the earth retains its appeal *is simply too inconvenient for people used to higher levels of comfort* [46]. However, showcasing exemplary earth buildings can drive public awareness and policy support. This could be either with on-site construction practices or off-site prefabrication. On-site construction, being intuitive and basic, can engage local, unskilled workers, providing significant value to the community. By involving the end-user in the construction process, a sense of ownership, deeper appreciation and, understanding for the geobased materials and methods is created.

40
Dethier, J. (2020). *The Art of Earth Architecture: Past, Present, Future.* 24

41
Ibid., 358.

42
Deltares / TNO Geological Survey of the Netherlands, Van Der Meulen, M. J., Wiersma, A. P., Van Der Perk, M., Middelkoop, H., & Hobo, N. (2011). *Sedimentbeheer en de vernieuwbaarheid van klei als grofkeramische grondstof.*

43
Ministerie van Binnenlandse Zaken. (2024b, juli 5). *Christina Eickmeier: Geobased - van aarde.* Projecten | College van Rijksadviseurs.

44
Maarten Hajer, Professor of Urban Futures at Utrecht University, as introduced in the introduction

45
NOS. (2024, 4 december). *Bouwen met biologische materialen is trendy, maar bouwwereld is er niet klaar voor.*

46
Kapfinger, O., & Sauer, M. (2022). *Martin Rauch: Refined Earth: Construction & Design of Rammed Earth. Detail.* 56.

On the other end, entire building processes happening within the factories, and off-site prefabrication in a factory setting can offer safer and more inclusive working environments, highlighting the social benefits of both approaches [47] . Promoting the origin of earth materials alongside their sale simplifies the system. With countries like France and Germany updating building norms to support earth construction, the Netherlands is in a good position to adopt similar measures, advancing sustainable and healthy construction practices.

47
Cultures, M. (2022). *Material reform: Building for a Post-carbon Future.* 99.

Ecological

Clay extraction involves two interrelated aspects: the extraction process itself and the resulting landscapes left behind. Regarding the resulting landscape, a paradigm shift is noticed, as in the mid-1990s, ARK Nature Development, the World Wildlife Fund, and the clay extractors joined forces [48]. By extracting the clay, forming terraces (reliëfvolgend ontkleien)[49], a more varied biotope will develop in years. Different water levels form habitats for different flora and fauna.

48
Koninklijke Nederlandse Bouwkeramiek. (2017, May). Rapportage duurzame kleiwinning.

49
Koninklijk Verbond van Nederlandse Baksteenfabrikanten (KNB). (2021). *Van Klei tot Baksteen.* 6.

This new integrated approach highlights the potential of renewable clay extraction for environmental protection and resource management. Clay, a renewable resource, is extracted mainly from riverbanks in the Netherlands, the only active terrestrial depositional environment for clay. Research from Deltares, TNO, Utrecht University, and Wageningen University – funded by KNB - reveals that from 1850 to the present, less clay has been extracted than generated. However, extraction now surpasses regeneration, though clay remains regenerative when considering natural regeneration, increased sedimentation from the Room for the River initiatives, and declining extraction levels. The research speaks of maximum regeneration 1 cm/yr, and 75 km2, flood plain area excavations of 1.5m depth to cover the current demand for production (0.7 million m3). That is approximately 1/6 of the entire flood plain area in the Netherlands. [50]

50
Deltares / TNO Geological Survey of the Netherlands, Van Der Meulen, M. J., Wiersma, A. P., Van Der Perk, M., Middelkoop, H., & Hobo, N. (2011). *Sedimentbeheer en de vernieuwbaarheid van klei als grofkeramische grondstof.*

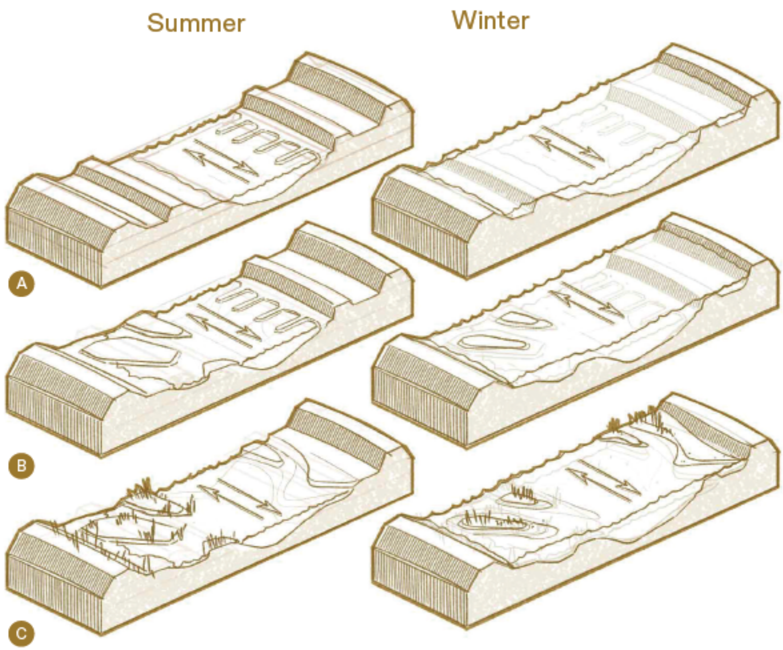
Humans play a key role in managing these natural processes, and a shared vision on sediment management is essential for aligning the interests of river managers and the ceramics industry. Optimizing regeneration through repurposing clay extraction sites is a key recommendation of their research. [51]

51
Ibid.

52
Koninklijke Nederlandse Bouwkeramiek. (2017, May). Rapportage duurzame kleiwinning.

53
Cultures, M. (2022). *Material reform: Building for a Post-carbon Future.* 99.

In conclusion, clay extraction's sustainability is linked to the strategic location of extraction sites in the river floodplain, which fosters a synergy between flood safety, ecological development, and resource extraction. This system benefits biodiversity, carbon sequestration, and overall ecosystem health [52] . Additionally, unfired clay offers a sustainable end-of-life solution, naturally breaking down, and returning minerals to the clay cycle [53] . (fig. 12, 11)



A Current layout of Dutch floodplain systems, with clay deposition

B Partial rearrangement of floodplains, in combination with Room for the River

C Clay deposition (regrowth) and nature development in former floodplain

Fig. 11. *Regenerative landscape processes of Clay Extraction in Dutch River Floodplains* [Author]

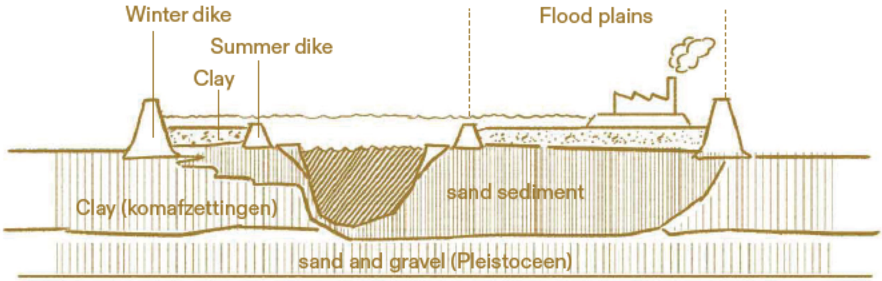


Fig. 12. *Dutch River Floodplains* [Author, based on Report Deltares]

Technological

The value chain of geobased materials (fig. 19) is not a one-to-one translation of the industry into the future for bricks, but a broader approach to possibilities with loam, which is a mixture composed of mostly sand, silt, and clay (fig. 15). Technically, geobased materials are strong, durable, repairable, and recyclable, while also being communal and easy to handle. In terms of comfort and aesthetics, earth materials are warm, sensual, hygienic, and comfortable. However, there are limitations, such as the height and width of earth structures often require supplementation with wood, concrete, or steel, primarily due to regulations. [54]

The production process of geobased materials is shown in figure 18, in which the flowchart of the Biogenic Manual of House Sections [55] is reorganised, supplemented, and enhanced. Versatile earth-based include interior or exterior stucco, loam panels, loam bricks, (prefabricated) rammed earth walls (self-supporting or partition walls), floors (and stairs). The value chain of earth building materials ranges from fully on-site processes to off-site production.

On-site production is often for small-scale, non-repetitive projects and utilises local materials, using hand tools or semi-industrial technologies. On the opposite, off-site technologies are based on panel systems that are fabricated in controlled factory environments, therefore being able to increase scale and sophistication. Larger building parts or complete buildings can be produced indoor, fostering new, more inclusive and collaborative construction cultures [56]. In the Ricola Herb Centre,

54
Dethier, J. (2020). *The Art of Earth Architecture: Past, Present, Future.* 24.

55
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections.* Oro Editions. 233.

56
Cultures, M. (2022). *Material reform: Building for a Post-carbon Future.* 92.

Martin Rauch, (Lehm Ton Erde) has built prefabricated rammed earth walls.

Combining geobased materials with biobased ones (e.g., plant fibres or wood) results in endless building possibilities. For instance, timber frame constructions can be filled with a mixture of straw and loam. Unlike the light, combustible nature of fibres and wood, loam adds non-combustibility and thermal mass [57], complementing these materials. Hybrid systems like wattle and daub, lath and pug, and cob have been widely used in European countries such as France, Germany, and the UK. Other combinations are found in combinations between load bearing, external brick facades and geobased material interior walls, in which both of the materials is best used according to their intrinsic material properties. [58]

The process of ramming earth creates structures that can withstand time and weather, but is more susceptible to erosion, unlike fired bricks. Given the Dutch climate and geobased moisture sensitivity, interior applications are most suitable like load-bearing walls, flooring, or stucco. Nevertheless, Martin Rauch demonstrates external façades of rammed earth, following basic rules. Using projecting roofs or caps prevents the walls from (standing) water damage and seepage. Using a water-resistant plinth prevents splashing, rising damp and groundwater with capillary action. Integrating erosion checks (trass-lime or fired clay) slows down water runoff, in a process called calculated erosion, which anticipates the effects of erosion in the design and maintenance. Designing with the prevailing wind direction—the windward side erodes faster— could reduce maintenance. The eroded earth returns to the soil, maintaining its place in the natural cycle. [59] (fig. 16, 17)

Earth materials must re-enter the (digital) catalogues. Although loam stucco and panels become more prevalent in the building sector, rammed earth and loam bricks remain niche in the Netherlands. These materials are often associated with ecological architecture and alternative living communities, but they seem exceptionally far from contemporary tastes, with most people living in cities.

57
Ministerie van Binnenlandse Zaken. (2024b, juli 5). *Christina Eickmeier: Geobased - van aarde.* Projecten | College van Rijksadviseurs.

58
Nijs, L. (2024, september 19). *MasterClass Baksteen: Lieven Nijs, BLAF architecten - Big Brick Hybrid Tannat* [Video]. YouTube.

59
Kapfinger, O., & Sauer, M. (2022). *Martin Rauch: Refined Earth: Construction & Design of Rammed Earth.* Detail. 65.

		BUILDING MATERIAL	BUILDING ELEMENT	BUILDING	EXAMPLE
ON-SITE	A	Building site	Building site	Building site	Compressed Earth Block
	B	Factory	Building site	Building site	Industrialised Loam Bricks
	C	Factory	Factory	Building site	Prefabricated Rammed earth wall
OFF-SITE	D	Factory	Factory	Factory	Prefabricated house

Fig. 13. *On-Site versus Off-Site Building* [Author]

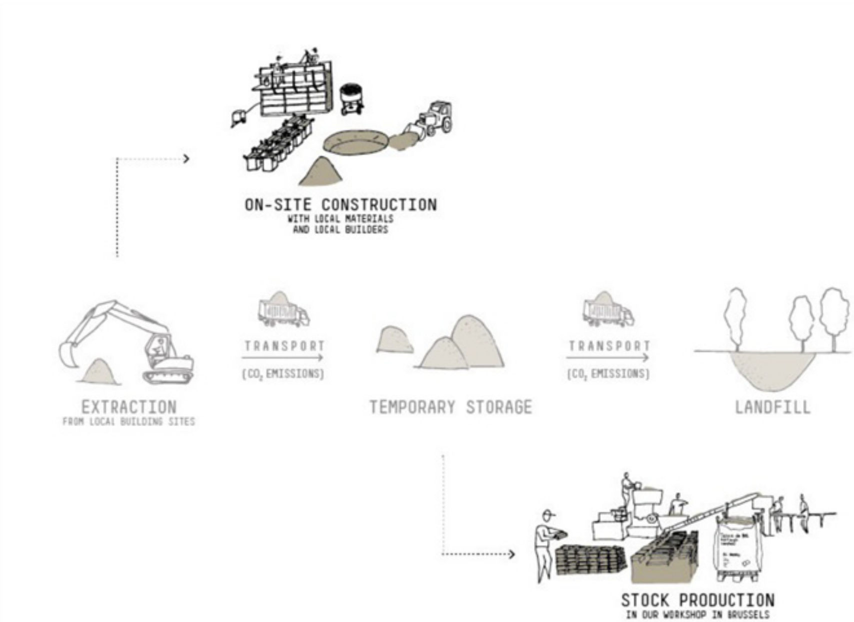


Fig. 14. *On-Site versus Off-Site Building* [BC Materials]

Fig. 15. *Resources and particle size of Geobased Building Materials* [BC Materials]

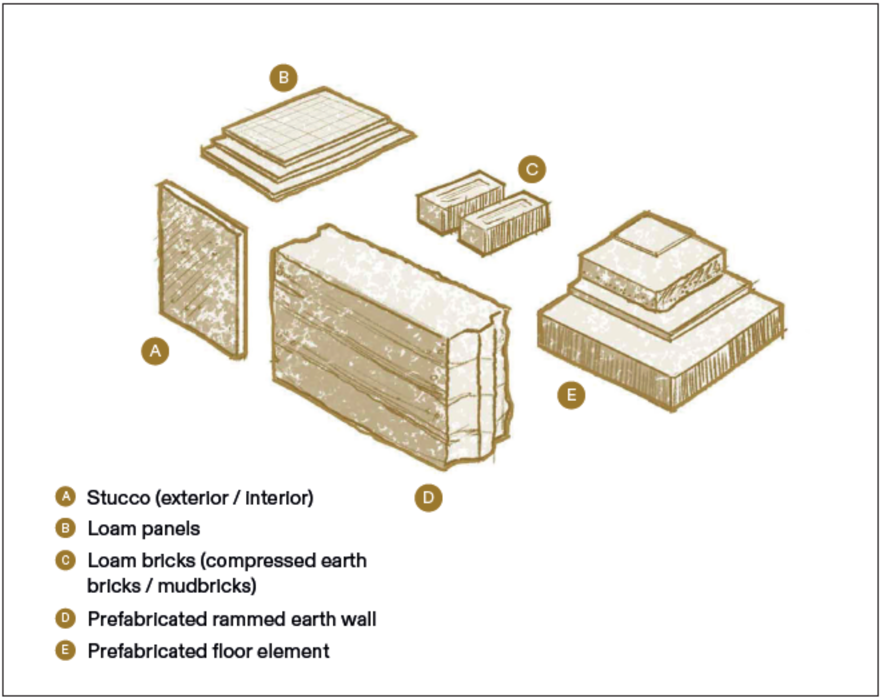
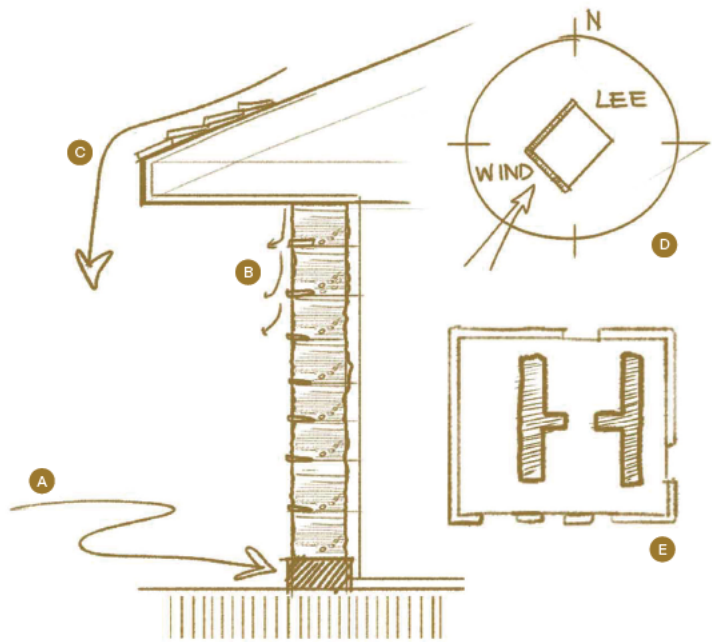


Fig. 16. *Geobased Building Materials* [Author, text from Martin Rauch: Refined Earth: Construction & Design of Rammed Earth]



- **A** Since splash and rising damp also affect the wall, the plinths should be water resistant.
- **B** Erosion check created by protruding ceramic tiles.
- **C** A roof must be formed such that no rainwater can collect, permeate the construction, or drain from the coping across the rammed surface in significant quantities
- **D** The windward side of a building will be far more eroded by driving rain than will the leeward aspects.
- **E** Indoor application is recommended in wet climate conditions.

Fig. 17. *Rules for Application of Geobased Building Materials* [Author, text from Martin Rauch: Refined Earth: Construction & Design of Rammed Earth]

WET CLAY EXTRACTIONS
Clay is a renewable resource. This means that we can extract clay without it running out. If we were not to extract the clay, the risk of flooding would increase over time (Deltaris report). Clay extraction therefore prevents flooding and also leads to an increase in nature and biodiversity (RDK, 9).

DRY CLAY EXTRACTIONS

SECONDARY EXTRACTION
In the Netherlands, according to the Reporting Point for the Soil Quality Decree (Bbk), approximately 40 to 45 million tons of clean and slightly contaminated soil and dredged material are released annually through earthmoving activities for nature development and construction projects. This material can be directly reused and utilized as a raw material for various forms of earth construction, in compliance with laws and regulations (BTMS, 10).

DISASSEMBLED EARTH MATERIAL

ADDITIVES
Water

ADDITIVES
Various plant fibers or stabilizing compounds can be added to change the performance of the final mix. (MBHS, 209)

MANUAL

SEMI-INDUSTRIAL (LOCALITY)

INDUSTRIAL

MANUAL MIXING

Clay and shale can be prepared and mixed with water in smaller batches. (MBHS)

SEMI-INDUSTRIAL MIXING

Raw materials. All mixers are capable of mixing clay, sand, water, lime, cement and straw. (Oskam)

INDUSTRIAL MIXING

Extracted clay and shale is crushed, prepared, screened, and mixed with water at large scale using industrial processes to meet commercial standards.

PULVERIZING

The Oskam pulverizers are simple, robust machines that work very energy efficient. They have been developed to crush or grind materials to a grain size or size as desired. (Oskam)

PREFA
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RAMM
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autom

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Fig. 18. *Production Process geobased materials contemporary dynamics and future pathways* [Author]

IN FACTORY

ON SITE

AB RAMMED EARTH WALL
pricated pot. including heathing,
g, insulation

MED EARTH TAMPING
mixing, the material is pressed into
orary formwork. Successive layers are
ressed, either by hand or by machine,
e the final form is achieved. (MBHS,209)

D-MOLDED (EARTH BLOCK CASTING)
oil mixture is pressed into forms to
blocks, either through manual or
nated processes. (MBHS,209)

PRESS PROCESS
ore rigid clays with lower percentages
ter, bricks are stamped by pressure
steel molds. (MBHS,235)

PRESSED EARTH BLOCK MACHINES
nachine is able to produce blocks with
of the earth's surface. The capacity of
nachine set is 20 small houses per
n. The total production costs can be
ed by 20-30%. In addition, one small
e saves an average of 15 trees. (Oskam)

-MUD PROCESSING
that are too soft to be extruded or have
onally added water, a mold process is
Sand or water are used to keep the mud
sticking to the mold, producing
-struck' or 'water-struck' bricks. (MBHS)

F-MUD PROCESSING
with 10 to 15% water is pushed through a
ing chamber before being extruded
gh a die. The continuous cla extrusion is
cut into different shapes and sizes. This
dominant method of industrialized brick
ation. (MBHS,209)

RINTING
otic arm or 3D printing extrudes the soil
re, slowly building a wall one thin layer
me. Soil mixture and printing time are
inated to ensure coherence of final
(MBHS, 209)

MORTAR

AIR-DRYING

Blocks are cured or dried before they are used for construction. Depending on climate, no kiln drying may be required (BMHS)

INDUSTRIAL DRYING

...
...
...

BUILDING PRODUCTS

STUCCO (EXT/INT)

LOAM PANELS

LOAM BRICKS

RAMMED EARTH WALL (SELF-SUPPORTING PARTITION WALLS)

RAMMED EARTH FLOOR

PREFABRICATED WALL- AND FLOOR ELEMENTS

Complemented, based on
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections*. Oro Editions. 233.

Innovation

UNIVERSITIES
RESEARCH FIRMS (f.e. Deltaris)
ARCHITECTURE FIRMS
GEOBASED INSTITUTE
BOARD OF GOVERNMENT
ARCHITECT + ADVISORS
College van Rijksbouwmeester
en Rijksadviseurs
Programmalijn:
Een nieuwe bouwcultuur

Policy making

NATIONAL GOVERNMENT
PROVINCES
WATER BOARDS

WASTE-TO-ENERGY COMPANY

RESTAURATION PARTY

MAINTENANCE PARTY

HOUSING PARTY
BUILDING OWNER
END USER

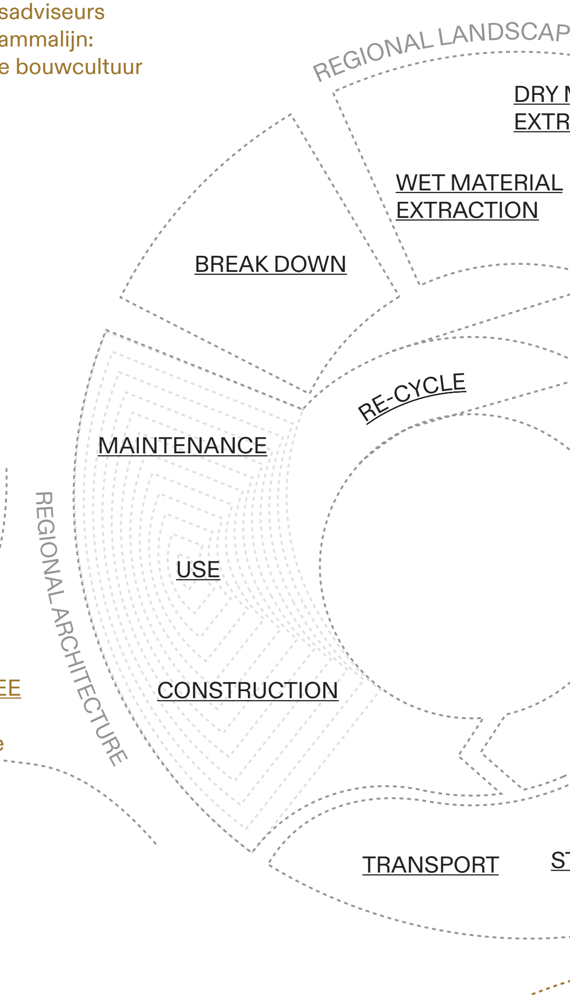
CONTRACTOR

MASON

GEOBASED AMBASSADOR

SELLING PARTY
CONSTRUCTION MARKET

WELFARE COMMITTEE on regional architecture



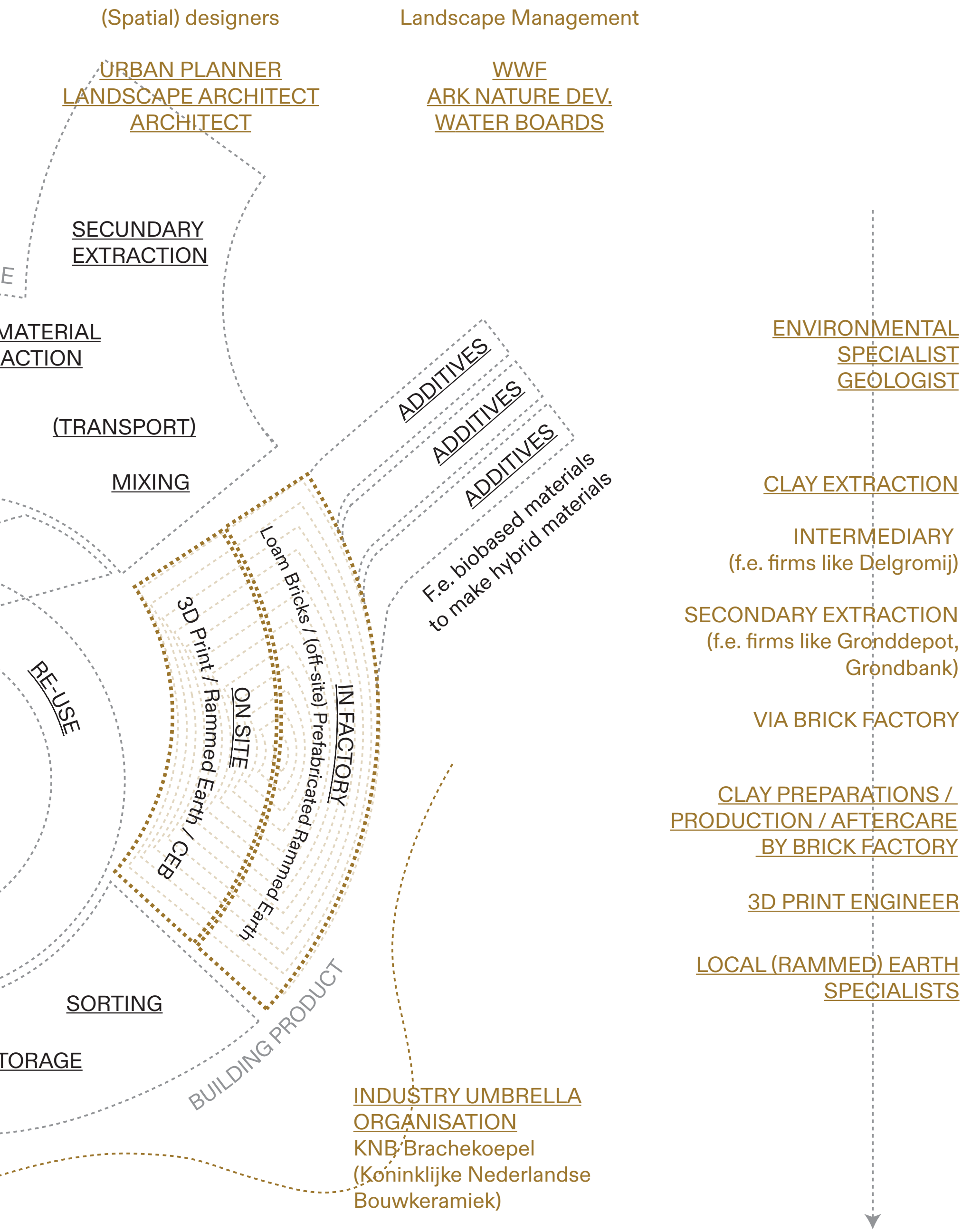


Fig. 19. *Value chain of geobased materials contemporary dynamics and future pathways* [Author]

3.4 How can the geobased building materials value chain be improved based on new insights?

Social
If a brickmakers' guild for geobased materials would resurge, some interesting key concepts could be reintroduced: itinerant corporations travelling to the construction site; assisting the geobased material project with their knowledge; skilled brickmaker (Bouwmeester) having oversight on the entire process and lastly organising closely related crafts together allowing them to exchange hybrids and combinations. In the current brick value chain, automatisation, scaling, and specialisation have individuals to be removed from the process and fragmented value chain partners are highly focused on their market. However, it becomes clear that advantages can be gained precisely through a comprehensive view of the entire value chain.

Our institutional structures and knowledge systems are currently often based on single-domain principles. They are increasingly incapable of making sense of complex SETs and managing them effectively [60]. But now, think of a new institute called "*Institute of Renewed Craftsmanship and Landscape Relations*", with different departments such as geobased and biobased building materials. The institute specialise in each of the crafts/ materials, but they should keep close mutual relations with similar institutes, just like the closely related crafts organised within one guild. Ambassadors from the "*Institute of Renewed Craftsmanship and Landscape Relations*" travelling to both governments/architecture firms/construction companies/building sites to assist in the implementation of the geobased and biobased materials. They also function as facilitators (oliemannetje) to increase visibility, enhancing the image of the materials and initiating pilots.

60
Chester, M.V., Miller, T.R., Muñoz-Erickson, T.A. et al. *Sensemaking for entangled urban social, ecological, and technological systems in the Anthropocene.* npj Urban Sustain 3, 39 (2023). https://doi.org/10.1038/s42949-023-00120-1

Ecological
Skilled environmental specialists, landscape designers and ecologists are crucial for effective organisation of landscape planning, wet extraction and nature development of Dutch River flood plains, enhances biodiversity and carbon sequestration. Taking the Room for the River as an opportunity, the flood plains should be reorganised in a way that boosts the renewability of clay. Extraction should be organised in phases, allowing to restore nature in between. Additionally, local availability

of secondary sourced clay should be monitored and tested for possible applications in the built environment. It is important to encourage the use of locally sourced, geobased materials, such as loam bricks, that reflect the local landscape. This approach would entail fewer options, but a more locally responsible selection, aligning material choices with regional context and sustainability principles.

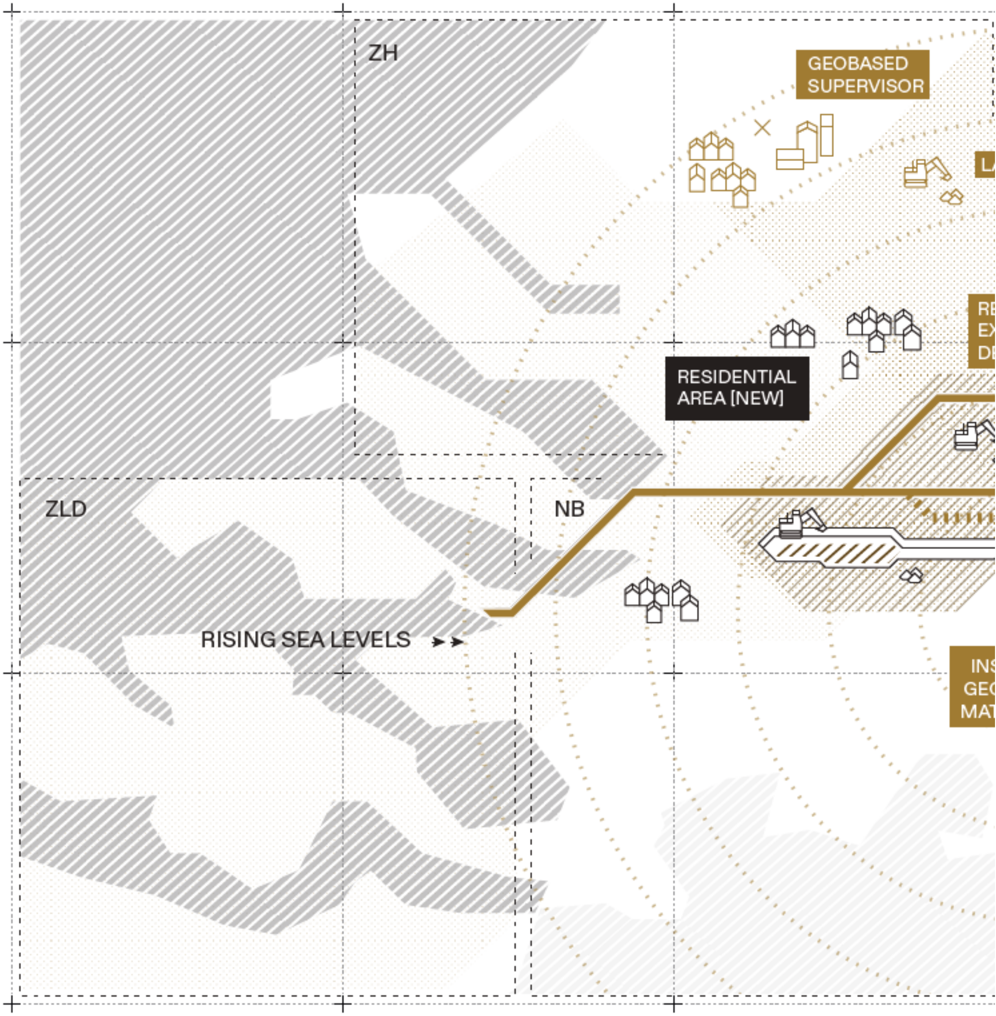
Technological
This bold vision sees a future where geobased building materials are embraced for their versatility and sustainability. The diverse applications of either on-site construction of unique eye-catching architecture next to prefabricated rammed earth construction for load-bearing structures up to five stories.

The current brick infrastructure, however, could play a huge role in partially producing (unfired) loam bricks, by simply changing their recipes – the viscosity and physical stresses of loam bricks differ from the brick recipes – and not proceed the firing process. BC Materials used brick factories for the 'Utube' project, in which they tried to research and develop a system of loam bricks with local material, competing with the market, maintaining excellent environmental features and technical performance [61]. Imagine how (re)development of current production facilities and new factories for hybrid materials could enhance availability of local materials.

61
Van der Linden, J. (2024, 27 september). *Earth Discovery Day* [Workshop]. Organised by BC Materials, Brussel, België.

Rather than the current practice, where bricks are predominantly used in a low-value manner based on their cultural significance, neglecting their inherent material properties, the sector should revalue inherent material properties. Still, their weather resistance gives them a significant benefit compared to the geobased materials that are mostly very vulnerable to water. Outdoor usage in the wet Dutch climate is therefore only possible when building principles (fig. 17) are carefully integrated into the design. It seems self-evident that a brick façade, with load-bearing, impact resistant and moisture regulating properties can cooperate with a geobased partition wall, being protected from weather, providing comfort, hygiene and interior aesthetics.

It is the responsibility from architects to find the right balance between materials and inspire the public, showing the opportunities of locally sourced materials. Design studio Atelier NL researched the differences between types of Dutch sand and types of Dutch clay. Their work proves how differences in extracted materials in different parts of the Netherlands could provide unique characteristics, which could be both functional and aesthetic advantages. In collaboration with Rokus Oskam, CHRITH Architects carried out similar research, focussing on the loam bricks.



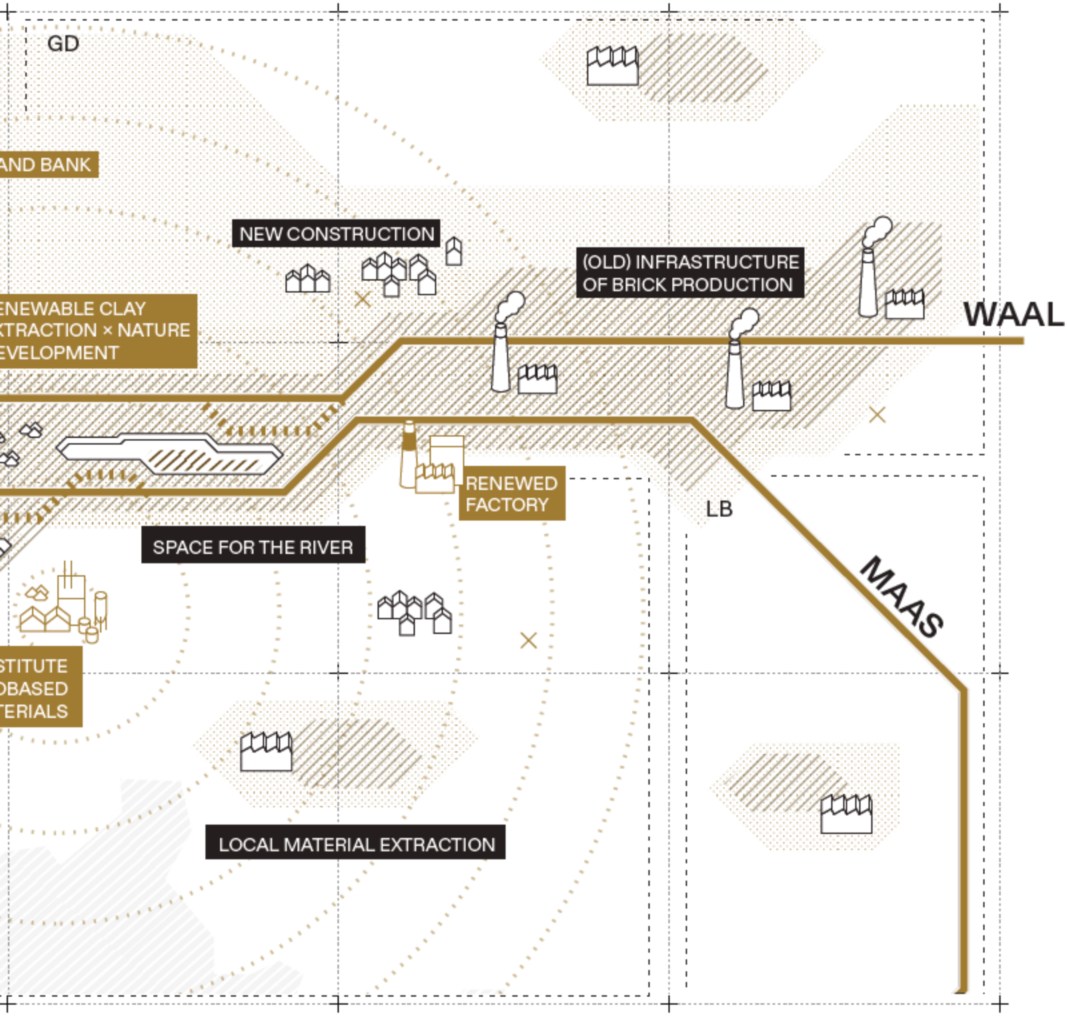
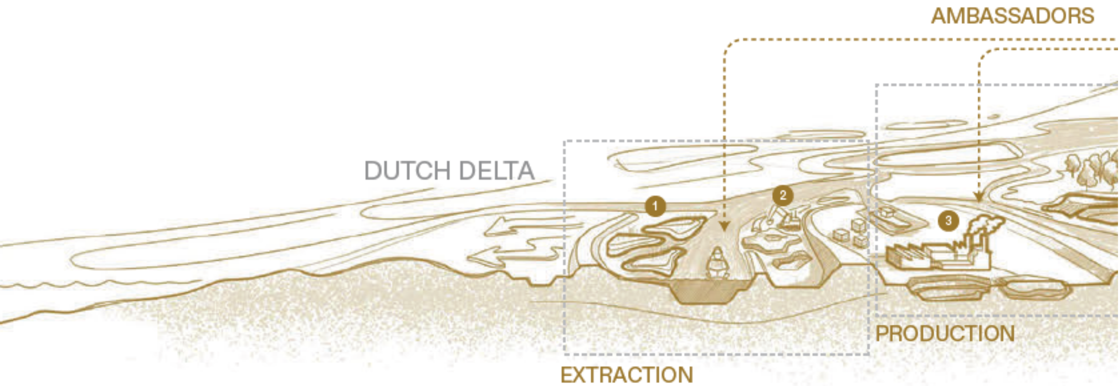
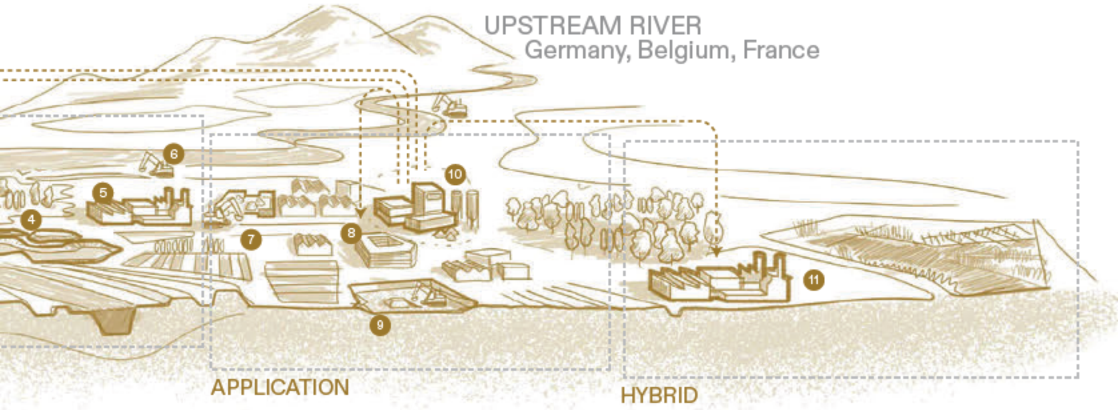


Fig. 20. *Spatial Layout of Bold Vision* [Author]



1. Clay deposition (regrowth) and nature development in former floodplain
2. (Phased) wet extraction in flood plains // Room for the River secures flood safety
3. Re-using current brick factories infrastructure to produce geobased materials
4. Former clay pits (dry extraction) is reduced and becomes nature development
5. Factories for prefabricated (off-site) building materials
6. Ups exc gra Out



stream avation of vel, sand. tside NL

7 Land banks play an important role in distribution of resources

8 Application in low-rise dwelling to showcase potential

9 Secondary extraction: largely released during intentional (primary) extractions

10 Institute for geobased materials // institute for renewed craftmanship and landscape relations

11 Production location for hybrid building materials

Fig. 21. *Spatial Layout of Bold Vision* [Author]

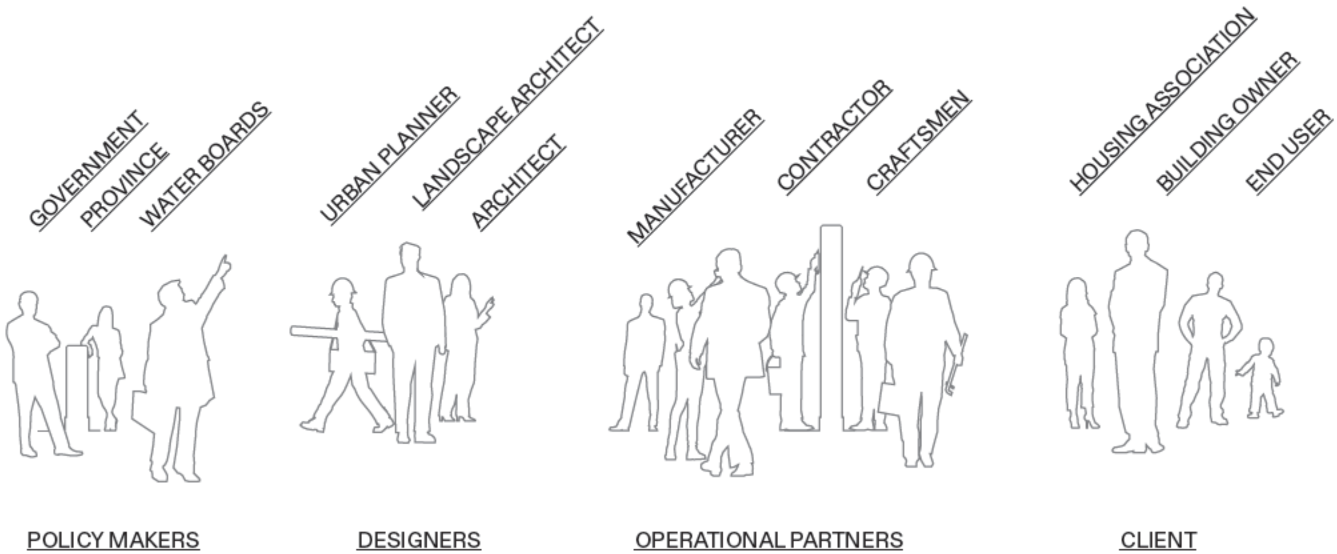

GOVERNMENT
PROVINCE
WATER BOARDS
URBAN PLANNER
LANDSCAPE ARCHITECT
ARCHITECT
MANUFACTURER
CONTRACTOR
CRAFTSMEN
HOUSING ASSOCIATION
BUILDING OWNER
END USER
POLICY MAKERS
DESIGNERS
OPERATIONAL PARTNERS
CLIENT

Fig. 22. *Actors in Bold Vision* [Author]

Conclusion

Although guilds provided some valuable insights, the guilds ultimately served more as a starting point than a true goal in themselves. The outcome in bold vision could be seen as a kind of 'renewed guild'. This paper answers the question: How can the value chain of geobased materials be restored through a social-ecological-technological system framework analysis?

Socially, today's fragmented, transnational value chains rely heavily on intermediaries, obscuring the path from raw clay to the final product and hindering alignment between supply and demand. Unlike France and Germany, where vibrant traditions sustain local practices, Dutch geobased value chains have disappeared. Restoring the value chain of geobased materials requires a more integrated approach, inspired by the Late Middle Ages. Related professions worked together with skilled supervision, reducing intermediary parties and ensuring quality control from material extraction to construction. Guilds functioned either itinerant or permanent, skilled brickmakers were invited to the construction site and guilds also influenced politics from within. Intervention from the Board of Government Architects ("*Een Nieuwe Bouwcultuur*") can initiate pilots and foster collaboration between local authorities and contractors, rebuilding transparent and sustainable value chains, to create visibility.

Ecologically, medieval brick production had a low environmental impact due to its reliance on local materials and small-scale operations, which minimised transport and reduced ecological strain. This contrasts with the contemporary Dutch production, relying heavily on imported clay, neglecting local (uncontrolled) resources and ecological restoration. Sustainable clay extraction

Fig. 23. LOT 8 Renovation of the former 'Magasin Electrique' for Atelier LUMA: new workspace for the design and research laboratory Atelier Luma, including workshops for timber, metal, ceramic, and textile, alongside dedicated algae and mycelium laboratories, meeting rooms, desk and production space, library and resource centre. [BC Architects]

in Dutch floodplains, with proper technical management and skilled oversight, can enhance ecosystems, support biodiversity, and sequester carbon. Also, secondary extraction clay is perfectly used in geobased materials on-site. Integrating these practices, supported by KNB and shared publicly, can rebuild a circular value chain, reducing imports and prioritizing local materials for a more sustainable future.

Technologically, medieval brick production had limited variations in size, colour, and methods, ensuring consistency and aligning with local resources, streamlining the value chain. Differences arose from local clay composition, with municipal regulations enforcing standard brick sizes linked to specific regions. Today, brickmaking methods remain similar but with declining local sourcing and craftsmanship. Bricks are increasingly decorative, and challenges in reintegrating used bricks persist, making geobased materials a better zero-waste alternative. Geobased construction, offers a range of possibilities from on-site, community building to off-site prefabrication, combining traditional earth materials like rammed earth, loam bricks, and hybrid systems, balancing innovation and tradition. However, it requires in-depth knowledge of material properties and local resources. Aesthetic choices should be informed by regional availability, promoting ecological responsibility and helping restore a sustainable value chain. Technological solutions are found in hybrid structures, for example where loadbearing brick façade is combined with geobased interior walls.

Each of these researched periods features a specifically good performance on one of the themes, respectively social (medieval times), technological (post-1920), ecological (future) and to restore the value chain, learnings the described learnings should be considered. In a bold vision, ambassadors from the "*Institute of Renewed Craftsmanship and Landscape Relations*" travel to architecture firms, construction sites, and building companies, assisting with the integration of geobased and biobased materials. They act as facilitators, raising the profile of these materials and initiating pilot projects. This institute fosters close relationships with similar organisations, creating a network for collaboration. Ecologically, skilled environmental specialists and landscape designers guide sustainable material extraction. Technologically, existing production facilities are redeveloped alongside (new) factories for hybrid materials. Bricks will shift from cultural symbols to locally sourced, sustainable materials that reflect regional landscapes, reducing choices but fostering responsibility. When you overlay the cycle of material harvesting with the cycle of building material production and the life cycle of buildings – and thereby start linking the SETs (social-ecological-technological) – the benefits become clear to the public.

Fig. 24. Green Agreement: Collaboration for nature conservation and sustainability, signed by various nature organizations and companies [Kleiwinning.nl]

Fig. 25. Retrospective: Martin Rauch, prefabricated rammed earth elements for Ricola Herb Centre [The Architectural Review]

Discussion

This research can be perceived as a theoretical, figurative exercise to showcase how organisational learnings can be taken from value chains of bricks and geobased materials. The research gives valuable insights into depicting the entire (circular) process from extraction to production and implementation. Furthermore, this research complements the available information, for example complementation of the production process of geobased materials in the Manual of Biogenic Housing Section with many steps and options. Also, the research is taking one step further in looking at the implementation of the materials, clearly describing how the products have been implemented in the building industry per time-space category.

However, the broad scope of the research question poses some difficulties regarding the foundation for the conclusions, which sometimes lay more difficult in practice than proposed in this writing.

The scope of the study is not focussed on building technological characteristics of either bricks or geobased materials. Therefore, the study lacks depth regarding a substantive comparison between bricks and for example unfired loam bricks. Compressive strength is important to understand in which cases loam bricks could replace fired bricks, and when not to. While sharing similarities in their material basis, bricks are distinguished from earth blocks by their conversion under heat to create a building material that is more durable and resistant to water and weathering [62]. Although, a comparison between bricks and geobased materials is not the aim of my research, a more detailed comparison could have given more relevance to the paper. In the second chapter, the life cycle of bricks themselves appears to be quite negative while further investigation shows that the mortar is too strong, making masonry in total hard to recycle [63]. This way, we learn that not only the geobased cycle could take learnings from its past, but also the post-1920 phase could learn a lot from

62
Lewis, P., Tsurumaki, M., & Lewis, D. J. (2022). *Manual of Biogenic House Sections.* Oro Editions.

63
Mulder, K. (2025, 7 January). *Persoonlijk interview.* Faculteit Bouwkunde. (Appendix II)

former days when stones were easily re-used, as the brick bond is more important for stability and strength.

Regarding the information on renewability of clay, the research of Deltares is funded by the KNB. More objective sources would have strengthened this part. Also information on amounts and regeneration time of clay could have been beneficial for practical implementation and viability of the stated information.

Considering the research method, the focus was on social-ecological-technological aspects, that finally resulted in a depiction of an ideal scenario, free from economic limitations. However, the financial aspect of the building industry is very relevant for understanding the practice, as Koen Mulder describes. Currently, taxes are levied on labour instead of material. In addition, land rates often dictate how we deal with bricks as a result.

The hypothesis, that the unfired earth faces an image problem due to the absence of coherent value chains and the misalignment of supply and demand, seems to resonate in the voices of Maarten Hajer, Christinia Eickmeier and Martin Rauch. However, obtaining and processing of clay in the local landscape is difficult and can only be done considered in combination with the product type and life cycle.

The research addresses the research gap of entanglement/absence in the value chain by creating understanding that the bottleneck is formed in visibility and hesitation in Dutch regulation.

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Appendix I

<u>Report Visit to Steenfabriek De Rijswaard – December 20, 2024</u>

Op 20 december 2024 werd de Steenfabriek De Rijswaard bezocht en een rondleiding gekregen van Ronald Willemsteijn. Ronald laat mij het gehele proces zien. We starten bij de diverse kleibulten, zoals rode, gele, bronzen en oranje klei, die de kleur en het uiterlijk van de geproduceerde stenen, opgebouwd als lasagne, daar vindt de eerste voorsortering plaats. Het TCKI: Technisch Centrum Keramische Industrie speelt een belangrijke rol in de monitoring van die kleibulten en technologische ontwikkeling van de keramische industrie. We lopen door de fabriek en zien alle stappen van een vormbaksteen. Het halffabricaat (de groenling of vormeling) zijn, volgens Ronald, echter niet echt bruikbaar, omdat ze bij vocht instorten en weer in klei veranderen. Toch mochten fabrieksarbeiders deze groenlingen meenemen om huizen van te bouwen. Ik zie een grote waarde van al best een serieus halffabricaat! In de hele fabriek komen we weinig machine-operators tegen. Na het verpakken, opslaan en transporteren is er nog een afdeling waar een gedeelte van de stenen passeert: de nabewerking (retrostenen, steen strips en gemixte sorteringen) kleine batches nabewerking, relatief in het proces heel veel arbeid verricht moet worden. De zijkanten van gloednieuwe stenen worden verzaagd waarbij het middenstuk direct als afval dient. We hebben een discussie over hoe architecten hun wensen bij moeten bijstellen, met als gevolg dat de keuze in materialen wordt beperkt. Dit kan helpen om de afhankelijkheid van transnationale klei te verminderen, wat de ecologische en economische impact zou kunnen verlagen. We lopen naar de showroom waar nog veel meer kleuren, afmetingen, afwerkingen op tafel komen. Je kan met onze Nederlandse klei en verschillende technieken ook al veel verschillende stenen maken! Zo zorgt de 'wasserstrich' techniek ervoor dat de natuurlijke kleikleur, aangezien de vormbak dan niet bezand hoeft te worden, beter naar voren komt. Dit zorgt voor een authentiekere uitstraling van de stenen. Waar volgens Ronald een angel zit is onder andere het uitgeven van een vergunningsprocedure door gemeente en provincie: Het verkrijgen van een vergunning voor kleiafgraving door de provincie duurt doorgaans ongeveer 10 jaar. Ronald vertelt dat er veel van de bakstenen wordt geëxporteerd naar landen als Duitsland, België en het Verenigd Koninkrijk.

Het bezoek gaf waardevolle inzichten in de kleiproductie, de uitdagingen rond vergunningen en de noodzaak voor verandering in de bouwsector.

Fig. 7. *Unfired loam bricks (vormelingen) look like endproducts* [Author]

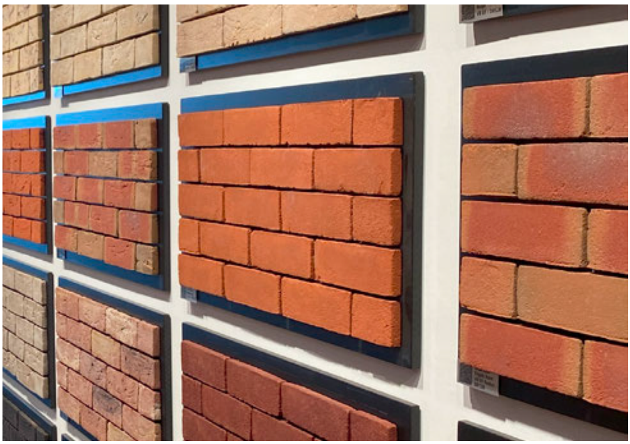

Fig. 8. *Endless possibilities in the showroom of the Baksteenfabriek de Rijswaard* [Author]

Appendix II

<u>Report Interview Koen Mulder – January 7, 2025</u>

Steward Brand, met name de inzichten dat bouwen met steen betekent dat je iets waardevasts overdraagt van generatie op generatie. Baksteen heeft veel economische maar ook maatschappelijke culturele waarde.

Van oudsher zijn de regels voor stenen huizen heel anders dan voor houten huizen. Stenen huizen zijn namelijk permanent, onroerend goed. De grond onder houten huizen werd ook vaak gepacht. Omdat er dus geen ‘vaste grond’ onder de voeten zat, werden houten huizen gezien als roerend goed. Je kon de vakwerken afbreken en de leem-stro-pakketten vulde je weer in op de nieuwe plek. Er waren dan regels, bijvoorbeeld dat je de balken van je huis niet mag opstoken. Zodoende zat er dus ook een soort klassenverschil/sociale component aan die huizen. Wat er dus gebeurde in Twente is bijvoorbeeld dat er op een gegeven moment mensen die houten vakwerken zijn gaan invullen met baksteen. Dat is technisch gezien eigenlijk volkomen onlogisch: zware baksteen invulling voor een licht houten frame. Maar de baksteen had culturele waarde!

Wat er in het vroeger in Mesopotamië werd gedaan en wat wellicht nu nog steeds relevant is; buitenschil van baksteen en de binnenwanden van ongebakken leemstenen. Lieve Nijs (Blaf Architecten) zijn dit als het ware aan het herontdekken. Je kan dan een buitenschil van baksteen en binnenmuren van kalkhennep en hout maken.

Eigenlijk gaat het best goed met de baksteen. Het scoort best heel aardig op de MKI (milieukostenindicatie) omdat ze zo lang meegaan. Het grote probleem zit hem in de cementindustrie. De mortel is te hard. De kunst zit hem erin om de sterkte uit het metselverband te halen i.p.v. uit de mortel. Systemen als Dry stack zijn een goed alternatief. Zo kunnen de stenen in theorie oneindig mee. Vroeger waren er vaste beroepen voor steenbikkers en werden stenen eindeloos hergebruikt.

In een ideaal scenario wordt er belasting geheven op materiaal in plaats van arbeid. Van oudsher is bakstenen maken een heel arbeidsintensief, zwaar beroep. In Nederlandse steden is oppervlakte prijs voor de grond bepalend. Je kan vaak beter een gebouw afbreken en er een betonnen gebouw voor terug zetten.

Op mijn vraag hoe hij denkt over het profileren van hernieuwbaarheid van klei vindt Koen in tegenstelling tot mijn verwachting, dat de sector er prima in slaagt om hernieuwbaarheid te promoten. KNB heeft er een video over.

Dan nog even over die ongebakken steen. Hij heeft vele malen lagere druksterkte dan een baksteen en is uiterst gevoelig voor vocht. Je hoeft dan geen rekening te houden met knik, maar je moet wel onderaan dik beginnen en dan verslanken naar boven toe. In Nederland, vinden we dat zonde van onze ruimte.

Gezaagde baksteenstrips is Koen geen fan van, maar wel van de overgebleven binnenkant

Appendix III

Transcript of the Lecture MasterClass Brick: Lieven Nijs, BLAF architects - Big Brick Hybrid Tannat (2024, September 19).

Evolutie van de baksteen muren en facades: Wat er in het bouwen vandaag op het spel staat: isolatie, luchtdichtheid, thermische onderbrekingen, geveldragers, ankers, zonweringen, folie, slabben. Spouwmuur heeft het met glans overleefd, zonder gezichtsverlies. Maar niet zonder meer, toenemende complexiteit en foutenlasten als gevolg van het uitelkaar drijven van de twee spouwbladen, leiden tot oplopende kosten die ervoor zorgen dat we het gestapelde dunne gevelblad links laten liggen. Die evolutie gaat op de koop toe gepaard om geschoolde vaklui te vinden. Logische evolutie dat we opschuiven naar de praktijk van het bekleden.

Lieve Nijs van Blaf architecten heeft proefondervindelijk ontdekt dat houten binnenspouwbladen met zware bakstenen gevels contra-intuitief is; zij willen nieuwbouw testen; baksteen schil en houtskelet als invulling definitief thermisch en structureel van elkaar waren losgemaakt. Een gestapelde zelfdragende gevelmuur. Muur zo vlak mogelijk aan de binnenkant, voorzie vochtkeringen en wachtfolies in de voeten en leg ook eerst het dak erop. Duw alle relief naar de buitenkant van de schil waardoor de lastendaling afleesbaar blijft. Je kan in droge omstandigheden werken aan het skeletbouw: FUTURE RUIN. Idee van Jan Peter Wingender om gevels weer zelfdragend te maken. Brick Bank. Maar voor het toepassen, moeten er dus twee keer zo veel stenen worden gebruikt, maar daarvoor realiseerde Blaf een bigbrick