Fibers and Fragments

Weaving local resources into the Arabian Gulf's modern material culture.

by

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ABSTRACT

Considering the constraints of using solely local materials of the Arabian Gulf, this thesis explores two components that constitute a future constructon practice: concrete in compression (mined from demolition sites) and carbon fibers in tension.

The discovery of oil in 1932 accelerated the use of reinforced concrete in the Gulf, which was first spurred by British officials and economic agents in Bahrain . Ninety years later, the construction industry has yet to find a replacement for François Coignet's steel reinforcement bar. Its corrosive nature is exacerbated in harsh climates, and weakens reinforced concrete. This thesis responds to this challenge by drawing lessons from practices of craftworkers before the era of oil extraction in the 1940s . The woven and mortared dwellings using palm fibers, clay, and stone provide productive analogs for the possibilities of using synesthetic fibers and concrete in future construction practices.

The **Crown Jewels** feature a construction system of post-tensioned concrete rubble. Piercing, stringing, threading, weaving and splicing lead to a more effective combination of carbon fibers and concrete fragments. These processes tie the two contrasting materials together:

(1) Concrete derived from demolition of modernist blocks, which are frequently a devalued 'waste' material destined for landfills, and

(2) Carbon fiber, which is a highly valued and energy-intensive counterpart.

Although a technical endeavor, this thesis operates in a geography where Gulf states are trying to reinvent their economies and building practices. Yet, these states still maintain an affinity and adherence to British regulations set during its time as a protectorate. To that end, these proposed systems and materials are in alignment with a nationalist, developmental narrative, which is untethered from foreign norms and rather are rooted in prior material practices and cultures of building of the land.

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Fig 1. Constructive System Sculptural Prototype

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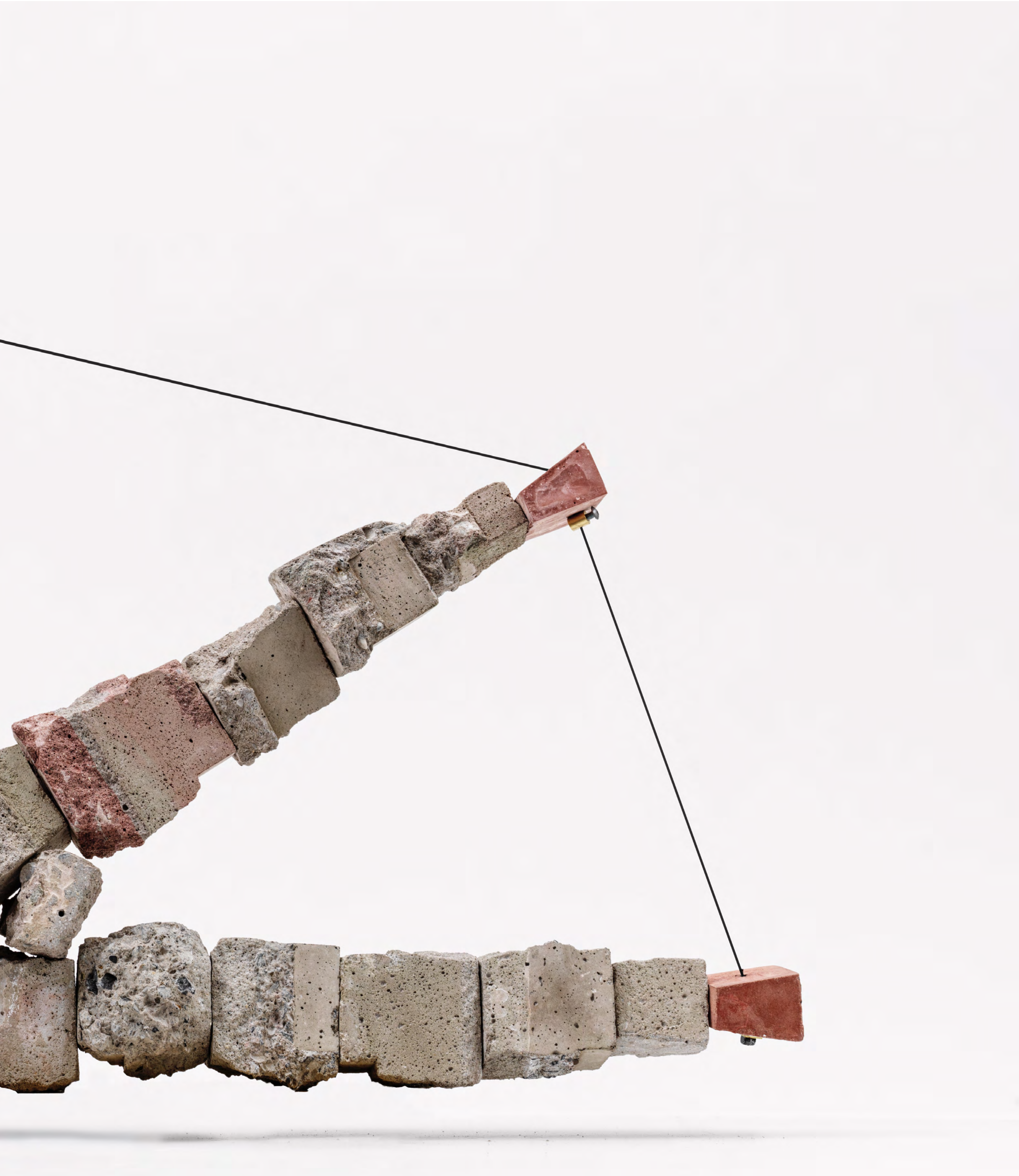


Fig 2. Constructive System 1:5 Section Prototype.

Prelude

Fig 3. Woven Layers of a pre industrial floor system in Bahrain

Prelude is taken from "Material Shifts in the Eastern Arabian Peninsula between 1920-1950" – written for Earth, Reed and Water in Spring 2022.

Introduction

In 1968, 46% of Riyadh City's population resided within walls of clay , whilst 34% inhabited homes built with concrete and cement masonry block units. 24 years later, only 1% of residential architecture was constructed in mud and stone, while the rest was predominantly made from concrete[1]. This statistic demonstrates how the period between the late 1960s and 1990s constituted a point of inflection and change that redefined the urban fabric of not only Riyadh, but many cities across the Arabian Gulf.

This shift may seem rapid when examined within a more comprehensive historical context and timeline. However, the change occurred due to a series of nuanced and layered economic, social, and political processes. Narratives about the region have been reductively focused on the discovery of oil, which use simple dichotomies to illustrate industrial progress, i.e., the "Tents to Skyscrapers[2]" or "Sand to Silicon[3]" frameworks. This paper aims to unravel this history by investigating the intricate details of how the use of cement and concrete emerged and proliferated in the Arabian Peninsula from the 1920s onwards.

Narratives and historical references from several cities, such as Muharraq, Dubai, Riyadh and Doha, along the Eastern side of the Peninsula, are drawn to illustrate this process of material change. Although those cities each have their own idiosyncrasies, they share climactic, economic, and political models, along with relationships of suzerainty to the British Empire.

British correspondence and reports form the dominant archives, where documentary evidence of Gulf history can be found. The oral tradition of sharing stories and transferring knowledge has partially contributed to this lack of records. Nevertheless, interviews with my grandparents, publicly shared personal photographic documentation , archival footage, and personal journal entries have helped piece a more complex story of the adaptation of concrete as the dominant building material in the Gulf. Additionally, the architecture of these transformational years has recently received attention through projects such as the Pearling Path[4] in Muharrraq. These projects have also contributed to conservation and study of some of these intermediate layers of change in the built environment that did not miraculously transition from tents to skyscrapers overnight.

Those structures include the load bearing coral stone and clay walls, as well as remains of pearl merchant houses.

Social media has also contributed considerably to documentation, exemplified by Instagram accounts like aljareesh[5] and feshaker[6] based in Bahrain, which share archival photographs from personal records and documentation of neglected ruins across the country. Some images shared reveal detailed experiments with cement mixes covering earthen construction, to foundations made with

1 Mubarak, "Cultural Adaptation to Housing Needs: A Case Study, Riyadh, Saudi Arabia", 1-6.
2 Rizvi, "From tents to high rise: economic development of the United Arab Emirates", Middle Eastern Studies, 29/4 (1993), 664–78.
3 Sampler and Eigner, "Sand To Silicon" (London: Profile Books, 2003).

4 Mollard, "String of Pearls."
5 Aljareesh, "بيت قديم مبني بالحجارة والجص واجزاء منه مبنية بالطوب، البيت يقع في جزيرة النبي صالح." *Instagram*, May 2022.
6 Feshakar, "منائر المنامة قديما." *Instagram*, April 2022.

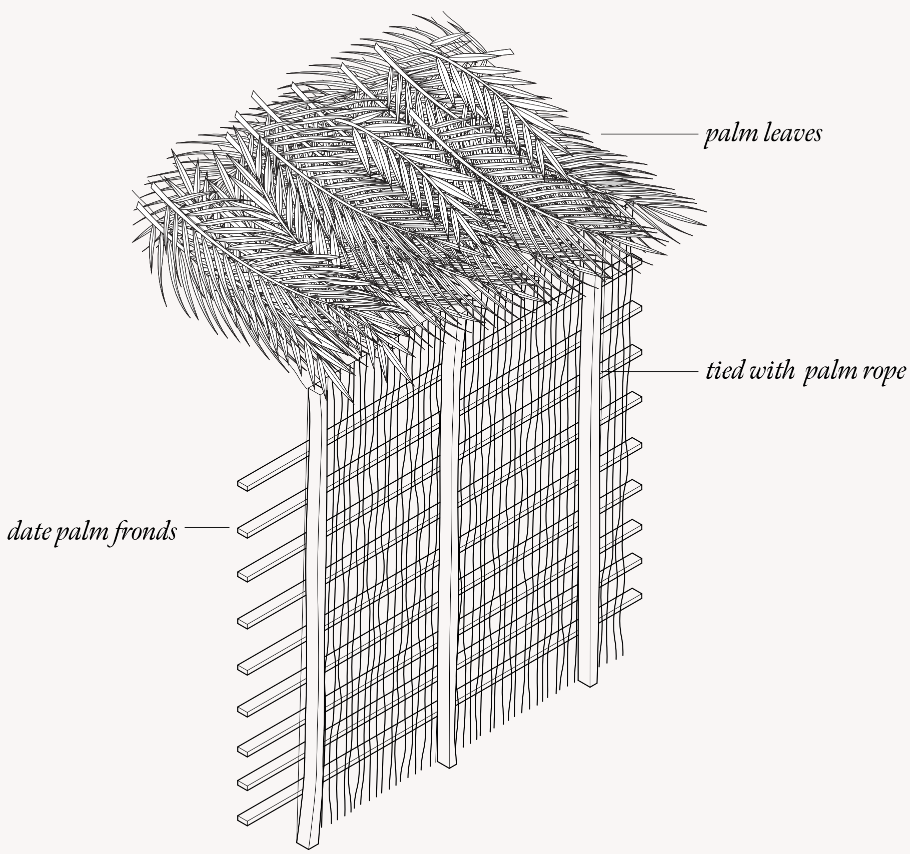


Fig 4. Barasti/Areesh Woven Dwelling System

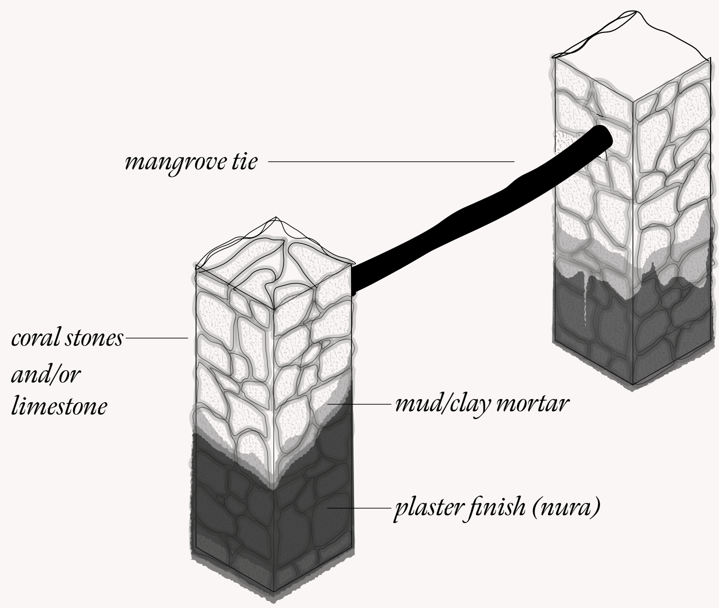


Fig 5. Coral stone and Earthen Construction System

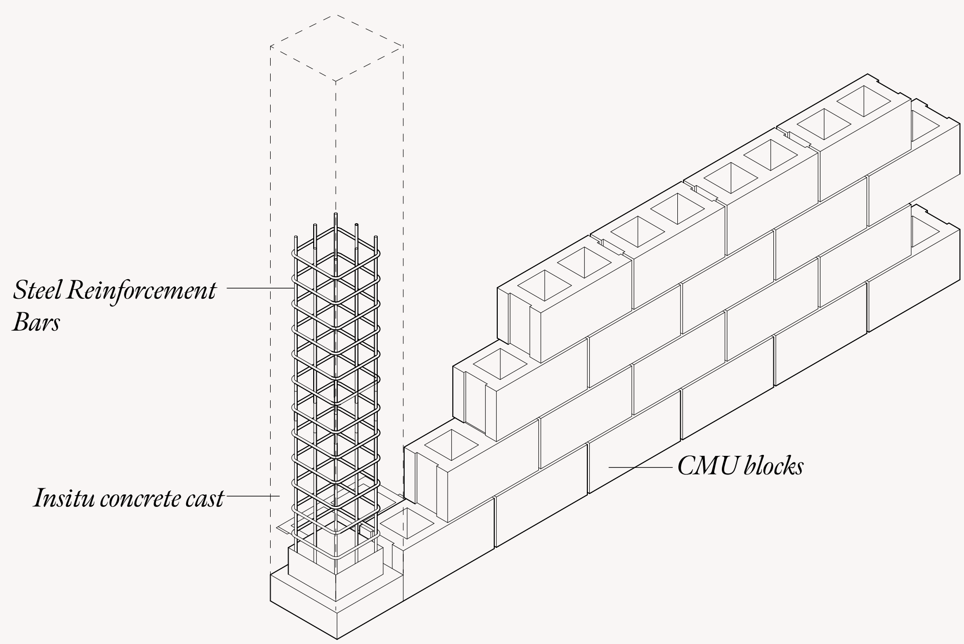


Fig 6. Typical Concrete Construction System

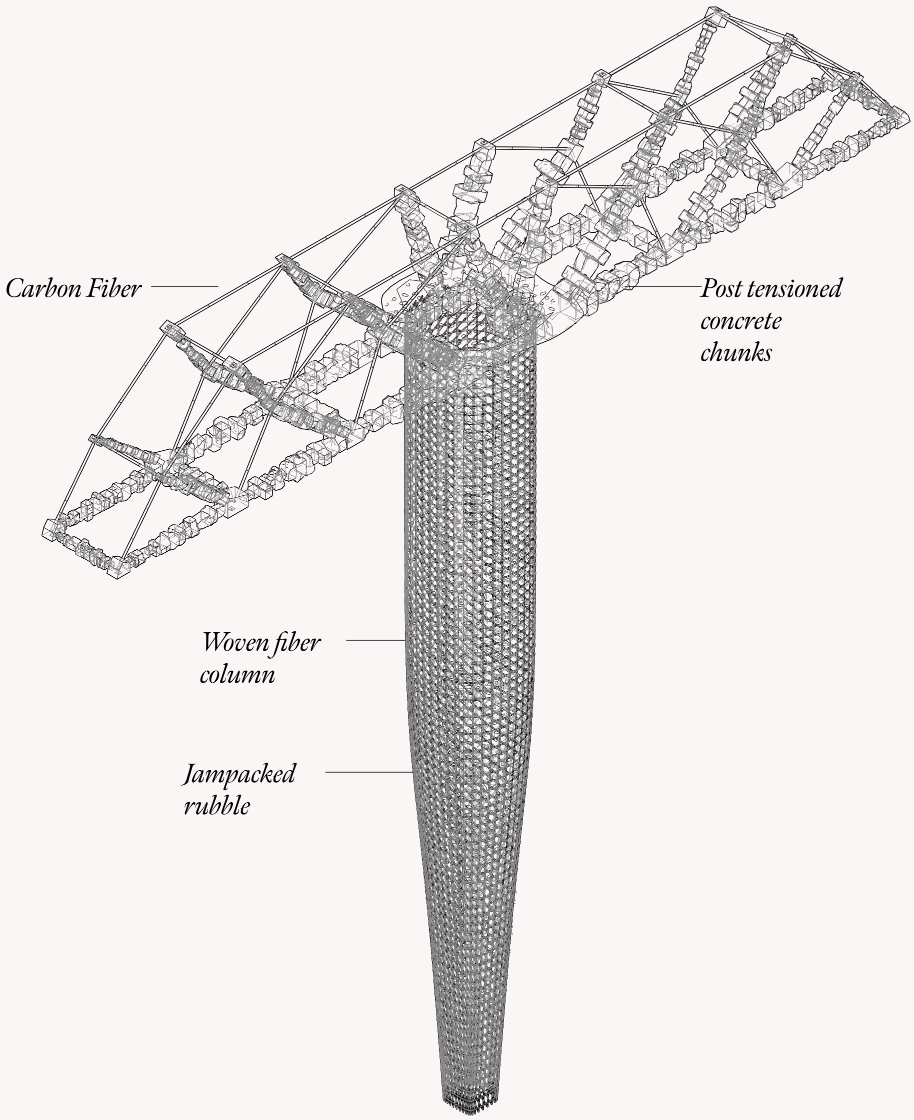
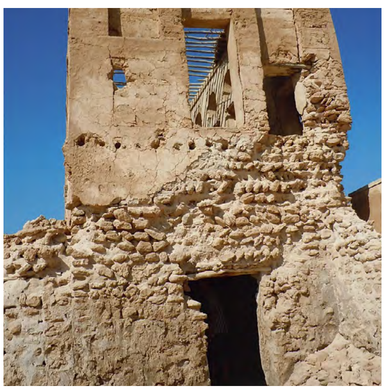


Fig 7. Proposed Assembly System

compacted, discarded oyster shells along the coast. These endeavors historicize artifacts of the built environment, while also cultivating a localized understanding of their value and significance to communities in the Gulf. While a nostalgic fixation on ruins could be scrutinized from the perspective of preservation value, the fact that these built structures have become objects of collective memory for previous generations should not be ignored. The past two generations witnessed this rapid change within their own lifetimes.



Early traces of cement

When Major Frank Holmes, a British-New Zealander mining engineer and geologist, heard rumors of potential oil seepages on the Eastern coast of the Peninsula, he made his way to the region with the mission of securing a concession to search for oil.[7] In 1923, the ruler of Bahrain, Sheikh Hamad bin Isa Al Khalifa agreed to allow Holmes to carry out his fieldwork under one condition. First, he was to assist in building deep-water wells to improve conditions for the population, as well as the irrigation of palm trees for date production. The demand for wells emphasized issues and priorities that had been set by the country's ruling elites. For example, British correspondence identifies how the water available at the time was so brackish that the water consumed by British agents in Bahrain had to be imported from Bombay on steamboats[8].

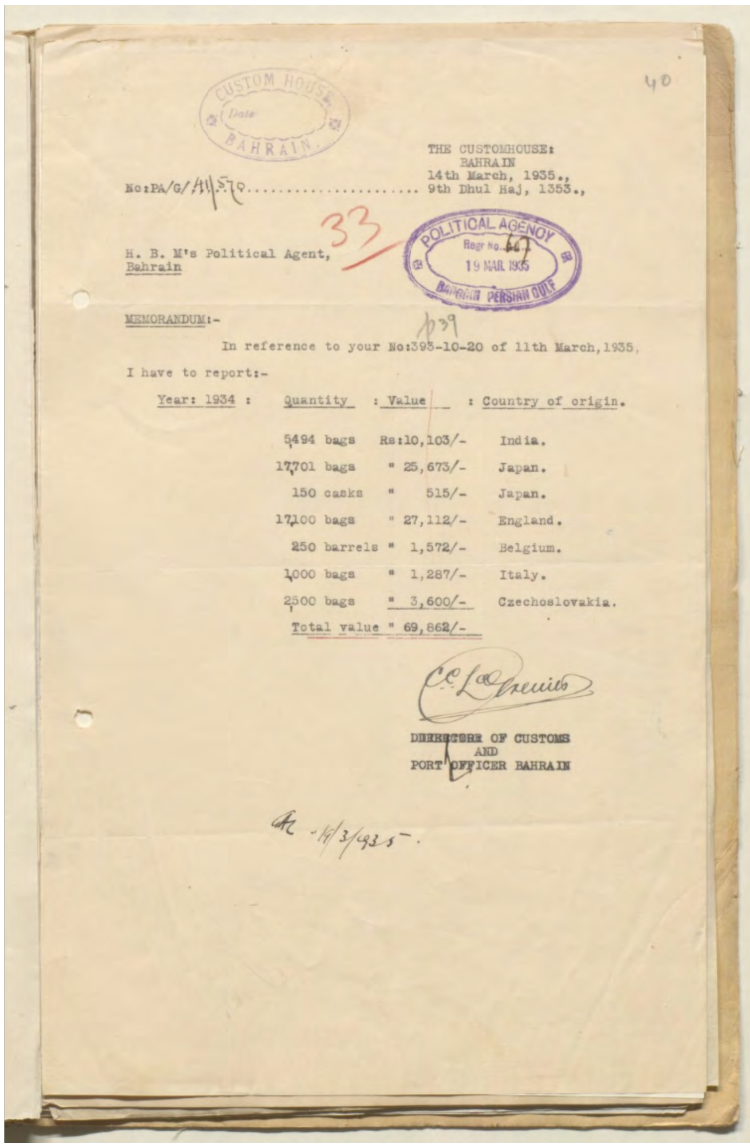
Previously, wells had been lined with load-bearing coral stone, lime and earth construction. When Holmes became involved with building this major infrastructural asset, cement was introduced to line wells and build platforms in 1925.[9] At this point, however, there was no evidence of cement being

Fig 8. Areesh Dwelling in Bahrain

Fig 9. Coral Stone and Clay

Fig 10. Early use of CMU blocks in Saudi Arabia

7 Hobbs, "Water, not Oil, the Most Valuable Resource in the Gulf", *Qatar Digital Library*.
8 Ibid.
9 Ibid.



CUSTOM HOUSE
Date
BAHRAIN.

THE CUSTOMHOUSE:
BAHRAIN
14th March, 1935.,
9th Dhul Haj, 1353.,

No:PA/G/ 41/570.......................

POLITICAL AGENCY
Regr No. 67
19 MAR. 1935
BAHRAIN PERSIAN GULF

H. B. M's Political Agent,
Bahrain

MEMORANDUM:-

In reference to your No:393-10-20 of 11th March, 1935,

I have to report:-

Year: 1934 :	Quantity	: Value	: Country of origin.
	5494 bags	Rs:10,103/-	India.
	17,701 bags	" 25,673/-	Japan.
	150 casks	" 515/-	Japan.
	17,100 bags	" 27,112/-	England.
	250 barrels	" 1,572/-	Belgium.
	1,000 bags	" 1,287/-	Italy.
	2,500 bags	" 3,600/-	Czechoslovakia.
	Total value	" 69,862/-	

C. C. L. de Grenier

DIRECTOR OF CUSTOMS
AND
PORT OFFICER BAHRAIN

Fig 11. Cement Imports into Bahrain in 1935 used predominantly in other construction projects.

There are two pieces of archival footage, which were taken from very different perspectives and decades apart, that speak to the interconnected themes of water and infrastructure. The first, likely a travelogue filmed in the 1930s, is narrated by two British men. They reveal developments in Bahrain, including scenes from Button Bottom Creek, which was used for washing clothes that were beaten against sacks of cement. It also shows the Rafa water well and emphasizes the use of concrete for its construction. Although the Awali housing complex, which employed cement, had already been constructed at this point, the concrete used for the well seems to have been held in high regard, hence its inclusion in this film clip applauding development in the region.

The second archival artifact is from around the 1960s and is narrated by a Bahraini man escorting a friend he made while studying in Europe. This footage visits the same site of the Rafa Water well that remains in use and describes the type of water collection as a "time-honored tradition."[10]

Once again, although the well was not the first to be constructed, its significance as a monument or landmark made with cement is evident and worth further investigation.

Although Romans are often attributed for the earliest use of cement, Nabatean Bedouins[11] had innovated the use of cement mortar even earlier to help withstand harsh conditions and maintain a livelihood in water-scarce desert regions. They used cement mortar to line stones and connect terra cotta pipes that would be waterproof. These pipe networks allowed Nabatean Bedouins to transport water deep into the desert from its source, sustaining inhabitation deeper into the desert compared with other tribes, and thus granting them the added advantage of more mobility that was vital to trade.

Although the use of cement mortar by Nabatean Bedouins and the Rafa water well occurred centuries apart, similar types of needs drove these material shifts and adoption of cement within these communities. Thinking with these transhistorical instances of material adoption and innovation, water provision remains a core political motivation and driver of material change that precedes dwelling or housing construction. And water scarcity continues to be a driving factor of change in the region today.

Infrastructure development in the Gulf expanded the use of cement from small wells to much larger endeavors twenty years later, such as port construction in Dubai[12], Abu Dhabi, and other coastal cities.

British Imperialist Influence

Through the East India Company, trade routes around India from the 1600s onwards led the relationship between the British and the Gulf to grow. The region's proximity to India made it ideal for the former to secure waterways. In 1820, conflicts between the Qawasim tribes at sea and the British arose following British attempts to enter the Strait of Hormuz while evading tolls. Following a forceful entry and British victory, this friction evolved into a treaty between the British and Arab leaders. Arab leaders and rule would be protected in exchange for giving up their right to wage war at sea.[13]

British dominance in the region grew in a similar

10 "Sights of Bahrain, 1960s - Archive Film 1018771", 3:45.

11 Wiener, "The Nabataeans of Ancient Arabia – World History et cetera".

12 Reisz, *Showpiece City: How Architecture Made Dubai*.

13 Allday, "The British in the Gulf: an Overview".

way, but not to the same extent as in India. The Gulf was not a colony per se. Moreover, this evolution emphasized existing trade routes and brought India closer to the Gulf in terms of commerce and labor migration. Comparisons between the colony and protectorate region can be drawn regarding shifts in material culture, industry, and skill development.

India and the evolving wall section

The spread of cement mortars and concrete in India can be compared to that of the Gulf. In some instances, it contrasts with and, in others, foreshadows the events in the Gulf. As illustrated in the timeline, the use of concrete in India followed Europe very shortly. On the other hand, there is a longer lag between Europe and the Gulf. The material lent itself as an aid to the colonial project, so innovations in Britain were simultaneously implemented in India. In the Gulf, however, this only took off in the mid-1900s.

Based on Stuart Tappin's analysis of concrete in India, the first notable example was the Secretariat and Army Headquarters in Simla in 1886.[14] It is important to note that this was around the same time that numerous innovators and entrepreneurs across France, Britain, and the United States filed patents and tested concrete reinforcement systems.[15]

By this point, "mass concrete" in Britain had only been used for foundations and viaducts along railway lines due to its compressive strength. Whilst the structure in India was constituted by iron frames, unreinforced concrete was used for the foundations, walls, and floors, which seems to be in line with practices in Britain. Remarkably, rammed earth, coated with lime and cow dung, filled the voids between the concrete piers three days after the casting process. This combination of concrete and earthen materials conveys the hybridity of the transitional phases, whereby rammed earth had economic benefits. Nonetheless, it was labor-intensive.[16]

Due to more heavy-handed British involvement, in comparison to the Gulf, the documentation tends to be more precise, with detailed drawings dating back to the 1880s. The proportion of concrete in the British Secretariat building is quite predominant rather than supplementary to existing building methods like that of the early uses in the Gulf. In Bahrain, as previously noted, the earliest records of cement date to the wells in the 1920s, although some sources point to its minimal availability earlier in the 20th century. At this point in the 20s, it was already imported and accessible for public use. In contrast, cement in India was only commonly available in the market 40 years after the British first imported it for their governmental landmarks.

This discrepancy reveals potential reasons for the experimental approach in the early uses of cement in Bahrain. The island's inhabitants started utilizing cement by intertwining it with current modes of construction at the time. To understand this better, it is helpful to briefly step aside and delve into the general building typologies and materials of the early 1900s.

Masonry structures that used clay (teen), locally sourced coral or limestone, and sea 2-inch bedrock strata (farsh) for infill formed most dwellings. The stone walls were rendered with a layer of mud, then another of mud along with gypsum, and lastly, a mixture of gypsum (juss) and lime (nurah) to

14 Tappin, "The Early Use of Reinforced Concrete in India", 79-98.

15 McGowan, "Historic concrete structures: 9,000 years of building".

16 Tappin, "The Early Use of Reinforced Concrete in India", 79-98.

smoothen the outer surfaces[17].

Between the 1920s and 1940s, attempts at achieving 'durability' and the smoothness of modernity encouraged the application of cement coating surfaces to earthen structures.[18] Issues like delamination of the cement mortar layer from the earth and stone base started to occur. Salt accumulation behind the cement and the weight of the Portland cement being higher than the lime provoked such problems.[19] Significant condensation also arose because the cement render blocked the porosity the fully earthen layers provided.

Regardless of its pitfalls, this misuse of the material suggests a certain autonomy that the Bahraini population had in incorporating cement that came early in the introduction of the material. Whereas in India, years of governmental control of cement import led to its accessibility. One could speculate that the level of control and colonialism in India surpassed that of the Gulf at the time, causing this restriction.

Despite the issues involved with the cement render and earthen hybridity, further experimentation was carried out to use the material. Eventually, it seeped past the surface and was used as a mortar to hold the cut stone or coral elements together. This signified a major shift whereby cement began to consume more of the wall section leading to a loss of familiarity with the original earthen wall or pier.[20]

In some instances, selective use of concrete can be observed as window and doorway lintels resting on the coral stone walls. Changes took the form of material layering as well as structural bricolage[21].

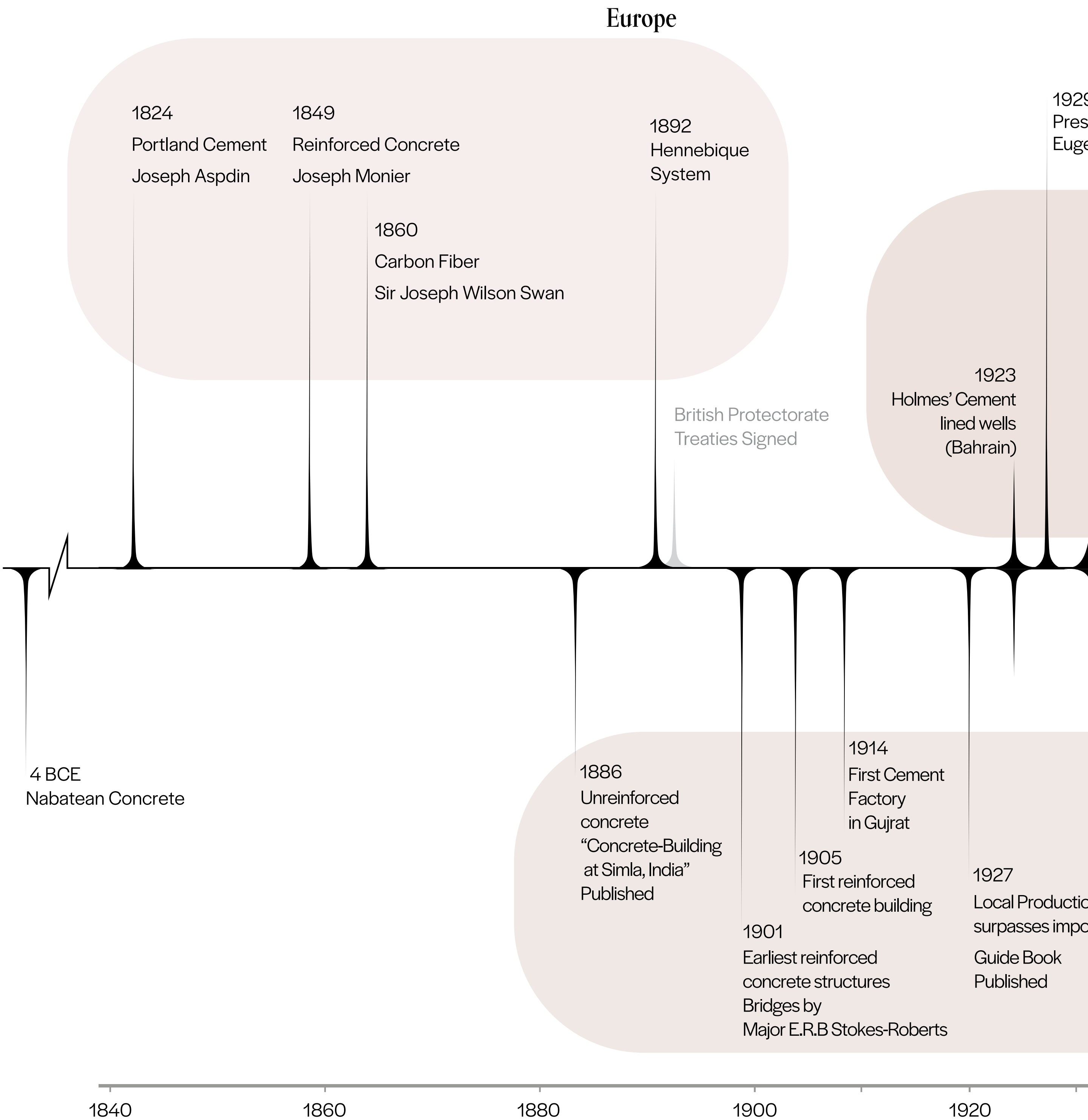
This type of bricolage is not unusual in the city's architecture. Pearling merchants who could afford higher-priced materials would trade larger redwood and teak from Indonesia and India. Those materials enabled monumental houses, where larger spans could be achieved because of the introduction of more robust materials. Master builders and craftspeople from Egypt, Iran, and Syria migrated into the country to lead and guide local builders with the ornamentation and construction of the larger structures.[22]

Note that the material shifts have been attributed to Bahrain, as it is arguably the vanguard in terms of recorded deviations of practices in the region. It can be speculated that the small size of the island and its prime location accelerated the trade of new materials like cement. These changes occurred before the discovery of oil in 1932. Therefore, the country was naturally inclined toward testing new methods and materials, as it had been in prior decades.

The point of inflection

Undeniably though, following the point of inflection with the discovery of oil, the country saw significant shifts starting with Awali, which was built in the late 1930s. The expatriate 'oil settlement' is now on the Tentative List of UNESCO World Heritage Sites.[23] At this point, we begin to see the dominant use of concrete masonry block units and reinforced concrete in the town following the urban form of

17 Yarwood, "AlMuharraq: architexture, urbanism and society in a historic Arabic town".
18 Chemali, "The Technical Revolution in Bahrain", 20-35.
19 Ibid.
20 "Interview with Ahmed Alkhaja".
21 Fareed, "Muharraq History and Traditional Architecture - Conservation operations".
22 "Interview with Ahmed Alkhaja".
23 UNESCO Word Heritage Centre, "Awali oil Settlement".


Europe
1824
Portland Cement
Joseph Aspdin
1849
Reinforced Concrete
Joseph Monier
1860
Carbon Fiber
Sir Joseph Wilson Swan
1892
Hennebique
System
British Protectorate
Treaties Signed
1923
Holmes' Cement
lined wells
(Bahrain)
4 BCE
Nabatean Concrete
1886
Unreinforced
concrete
"Concrete-Building
at Simla, India"
Published
1901
Earliest reinforced
concrete structures
Bridges by
Major E.R.B Stokes-Roberts
1905
First reinforced
concrete building
1914
First Cement
Factory
in Gujrat
1927
Guide Book
Published
1840
1860
1880
1900
1920

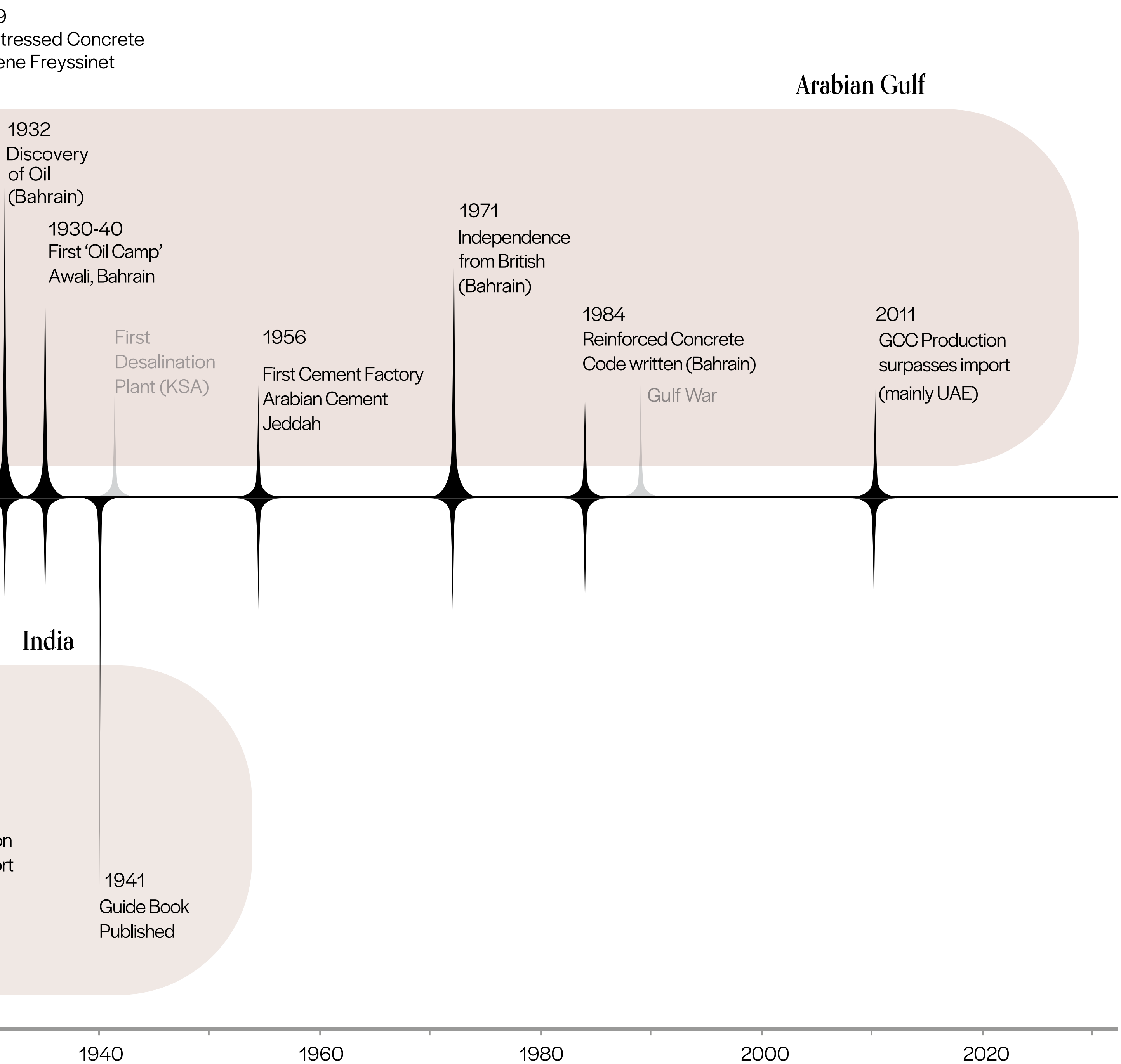


Fig 12. A timeline indicating key moments from the history of concrete in Europe, India and the Arabian Gulf.

the British Garden City Movement first proposed by Ebenezer Howard.[24]

Interestingly, from this point onwards, it is easier to find records and documentation of major buildings such as hospitals, political agencies, and landmarks. Those structures were erected through British influence, one of which is Bab Al Bahrain designed by Charles Belgrave, imitating the Gateway to India. Unsurprisingly, it is evident that the British wanted to benefit from the newfound oil. One of the ways it did so was by using cement as a sudden growth catalyzer in the "right" ways, going by British codes and following the developments in the European continent. We can compare this to the Secretariat and Army Base commissioned by the British in India using concrete. The imposition of such landmarks on the place imported means of construction along with their powerful presence.

Similar patterns to Awali can be observed in Saudi Arabia, where palaces started using concrete in the 1940s and the Aramco camps and housing initiatives in the 1950s.[25] Cement and the use of concrete became increasingly abundant, to the point of local production. The discussion of the numerous Western urban planning consultancies and the advocation of concrete has been deliberately omitted in this paper. Instead, the focus has been on the 1920s to 1950s. These transitional years (regarding material use and early oil discovery) reveal the range of construction materials and methods. As images show from the 1940s, the earthen architecture of coral and mud, arish Barasti[26] structures, and concrete were all erected simultaneously based on wealth and expertise. This period hints at an incremental change and iterative process based on trial and error. As my grandfather notes, early concrete mixes included unwashed sand and seawater. Gradually, the population understood the repercussions this had on the quality of the structures and experimented with different combinations. There was also ongoing experimentation with using recycled steel from India for reinforcement. The trial was structurally unfavorable due to the degraded quality of steel. Rather than iterating on the process, the way was paved for virgin materials that met the standards set by regulation.

The importation and imposition of British codes and standards in the case of Bahrain impeded this research, trial, and sense of openness. Suddenly, there was heavy-handed involvement that determined benchmarks. A comparison can be drawn to the use of bamboo reinforcement in India, which was tested in 1929. This practice did not have the space to flourish in a context where the British use of steel reinforcement dictated that India's construction industry had to follow the same means.[27]

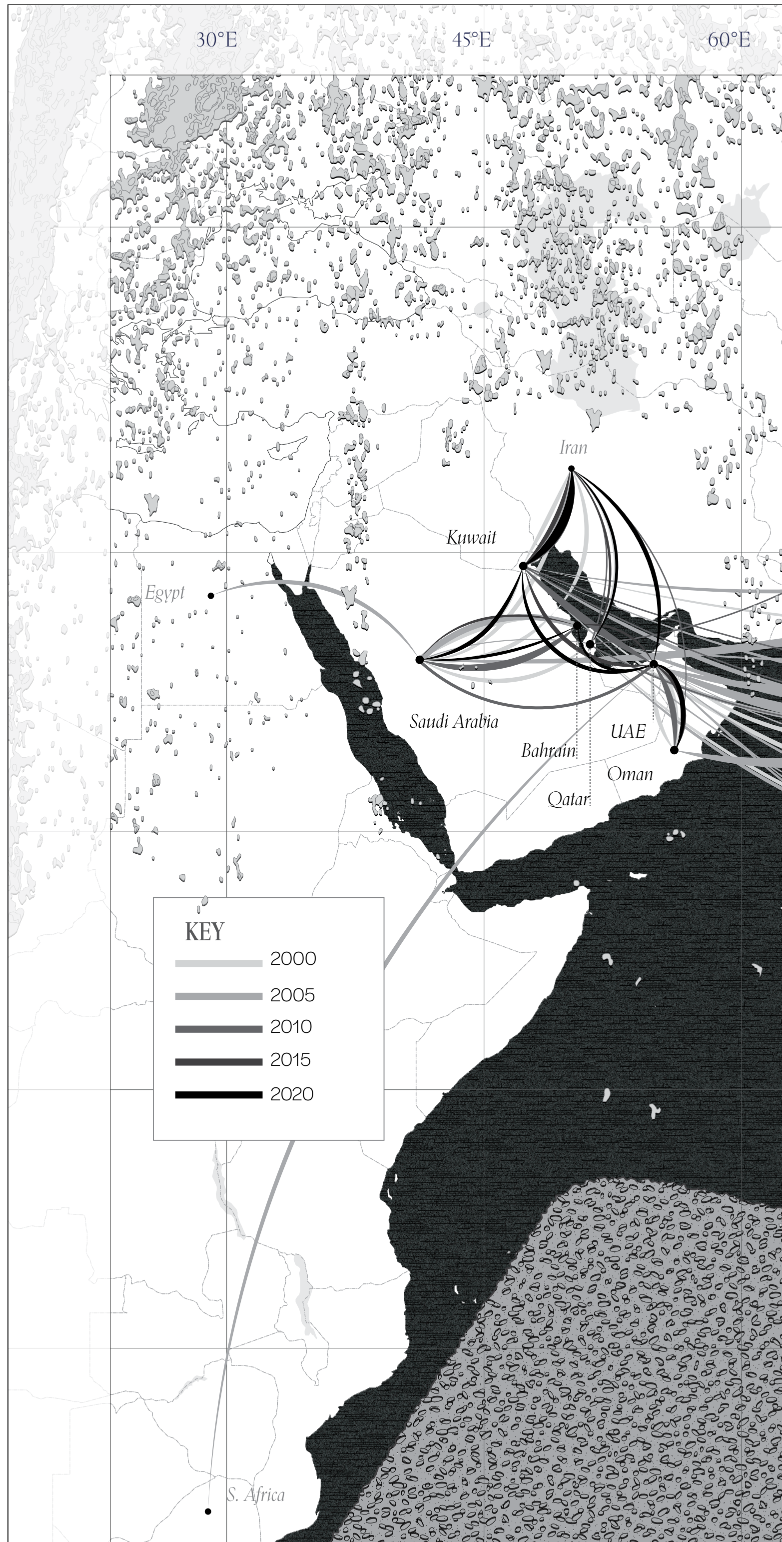
24 Howard, *Garden Cities of Tomorrow: A Peaceful Path to Real Reform*.
25 Alsayer, "Architecture, Environment, Development: The United States and the Making of Modern Arabia, 1949-1961."
26 Fuccaro, *Histories of City and State in the Persian Gulf: Manama since 1800*.
27 Tappin, "The Early Use of Reinforced Concrete in India", 79-98.

Conclusion

To conclude, I ask what would have been had the unregulated development and experimentation with cement in the Gulf continued. Here, the critique is of how concrete's mainstream use unfolded rather than the material itself. Once those standards were set, they have not changed much until today, and the reliance on Western techniques and consultancy continues. Ironically, the research institutes that the Gulf seeks advice from today use this experimental approach of "Testing to Failure[28]" as its inhabitants once did.

As new materials develop with the advent of technology, they will inevitably arrive on the Gulf's shores, and industry will incorporate them. As the rest of the world questions how to construct anew, will inhabitants of the Gulf regain autonomy over material experimentation and openness? Or will they find the answers in what the West offers and imposes once more?

28 Hirschman, "Testing to Failure: Design and Research in MIT's Department of Architecture".



Cement Trade Routes To the Gulf Cooperation Council Countries be

As the rest of the world questions how to construct anew, will inhabitants of the Gulf regain autonomy over material experimentation and openness? Or will they find the answers in what the West offers and imposes once more?

Fig 13. Mapping of the sources of cement imported into the Arabian Gulf between 2000 and 2020, indicating a contraction to local sourcing.

Concrete: Remnants of Renewal

Fig 14. Demolition of the city of Jeddah.

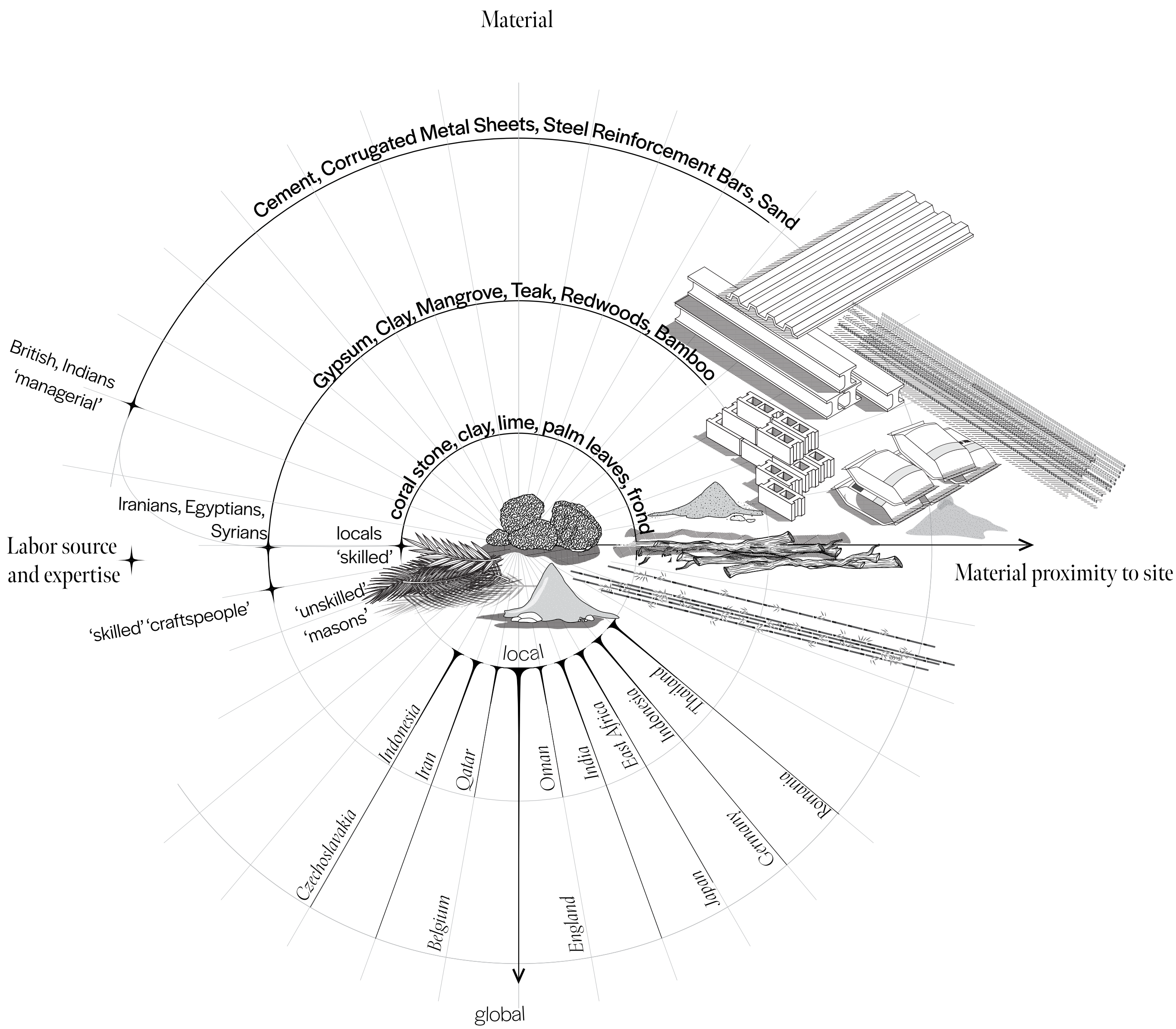


Fig 15.   Sources of materials and expertise categorised in concentric rings, from local to global.

On local sourcing

Abiding by local material palettes, this thesis makes several remarks. An apparent alibi is a prevalent advocacy for local sourcing as a sustainable practice. It speaks to the local climate and endurance of material 'of the land'. In European and North American contexts, this has supported the increased use of renewable sources such as timber instead of steel or concrete. Moreover, it has increased interest and popularity in 'vernacular' construction methods, whereby a presumed lack of mobility birthed resourcefulness and material economy.

Secondly and more importantly for this thesis, local resources make an implicit political statement on self-sufficiency. A particular form of independence is gained by relying on materials from the land it sits on alone. For the Arabian Gulf, local materials offer an opportunity to construct a national narrative around constructive systems.

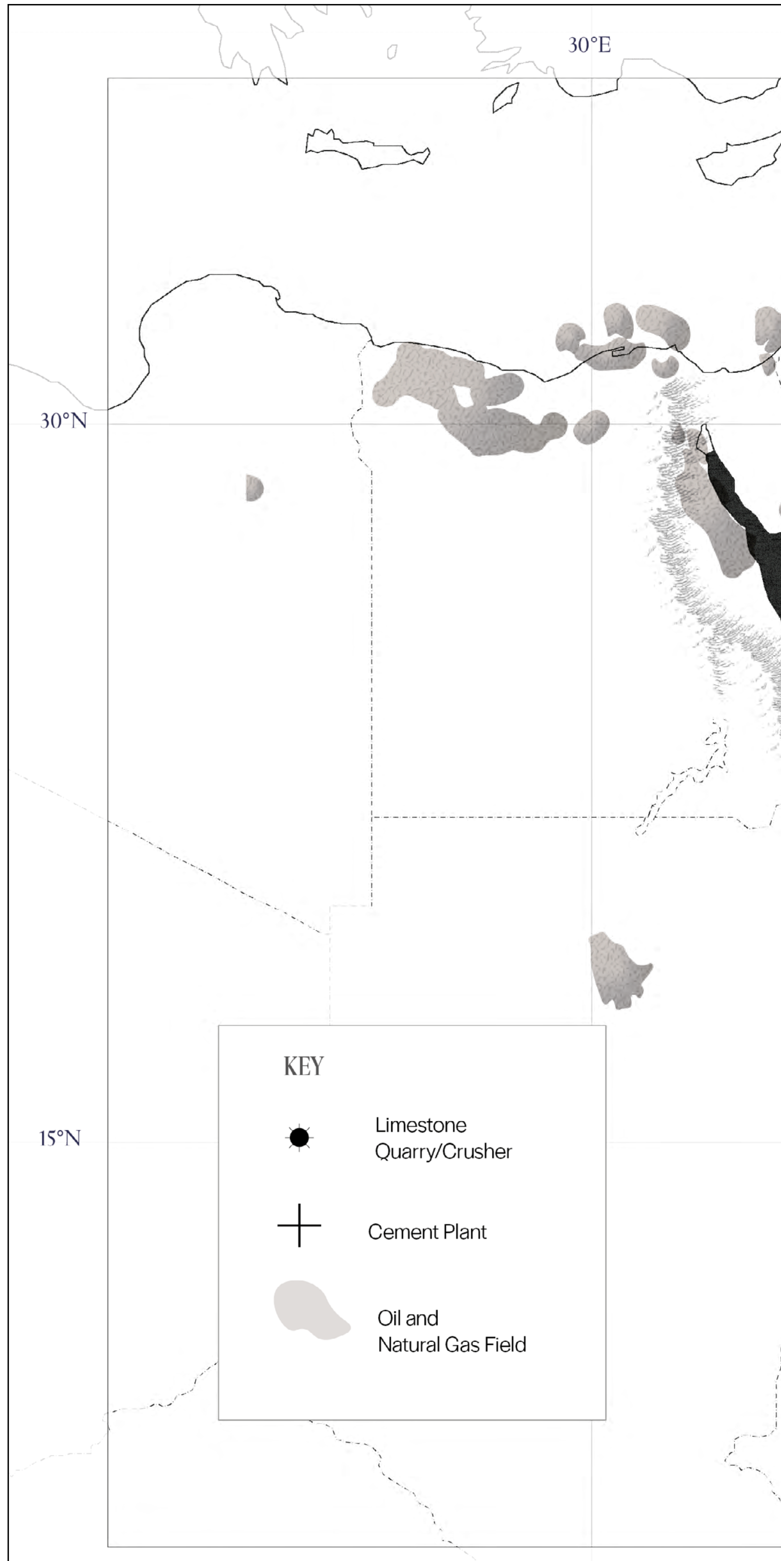
Whilst the building sector is responsible for 40% of carbon emissions, 8% are attributed to cement production[1]. Those high emissions present a dilemma to a region that has been and continues to rely on reinforced concrete technology to develop and expand its cities. As highlighted in the prelude, concrete has been 'naturalized' in the Gulf. From an imported commodity, it is now exported. Concrete's established presence is supported by its ease and speed of construction, along with its durability in one of the hottest and harshest climates. It has come to be the Arabian Gulf vernacular.

Whilst less arid and more moderate climate zones may look at forestry for answers to the challenges of carbon emissions, this is not an option for the Gulf. Therefore, we ask, how can we build better with the resources we do have?

1 IEA, "Global Energy and CO2 Status Report 2018."

Concrete: inherited remnants of renewal

The investigations in this thesis begin by looking into the use of concrete debris, with the speculation that cities will transform into quarries for materials. Demolition waste in concrete chunks or rubble would be incorporated instead of assuming a continuation of current practice. Although the use of fresh cement in concrete construction will continue, in this thesis, I study inevitable material flows that will stem from the deconstruction of midcentury modernist structures. A recent prominent example of this is the Bahrain International Airport's original terminal building which was torn down as the new larger terminal was erected. Another example conveying the ease of



Sites of Limestone Extraction and Cement Production in the Gulf Coop

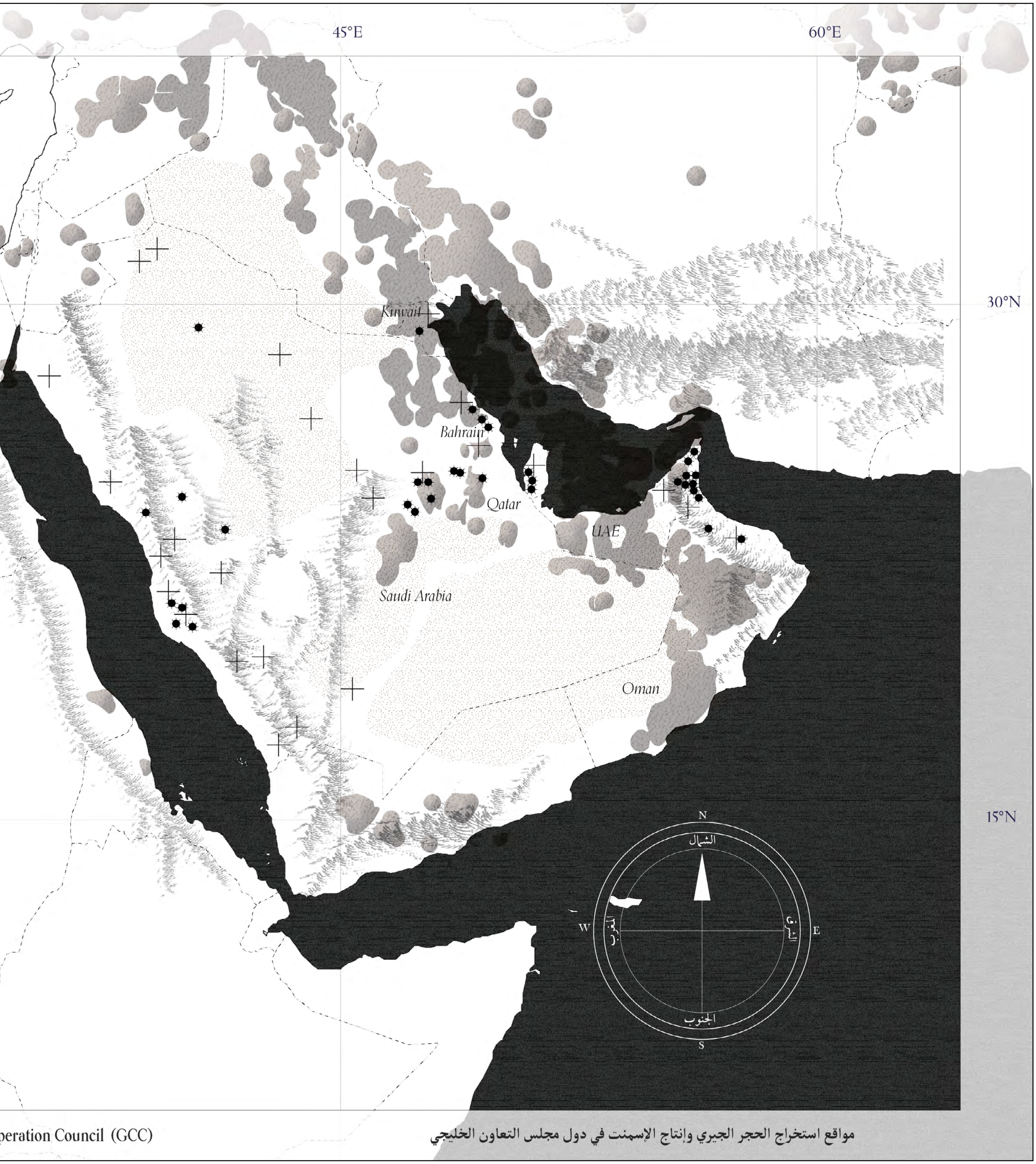


Fig 16. Mapping of natural resources including limestone quarries and processing plants along with oil fields.

Fig 17. Demolition of Mina Plaza Towers

Whilst less arid and more moderate climate zones may look at forestry for answers to the challenges of carbon emissions, this is not an option for the Gulf. Therefore, we ask, how can we build better with the resources we do have?

Fig 18. Photographs shot ten seconds apart

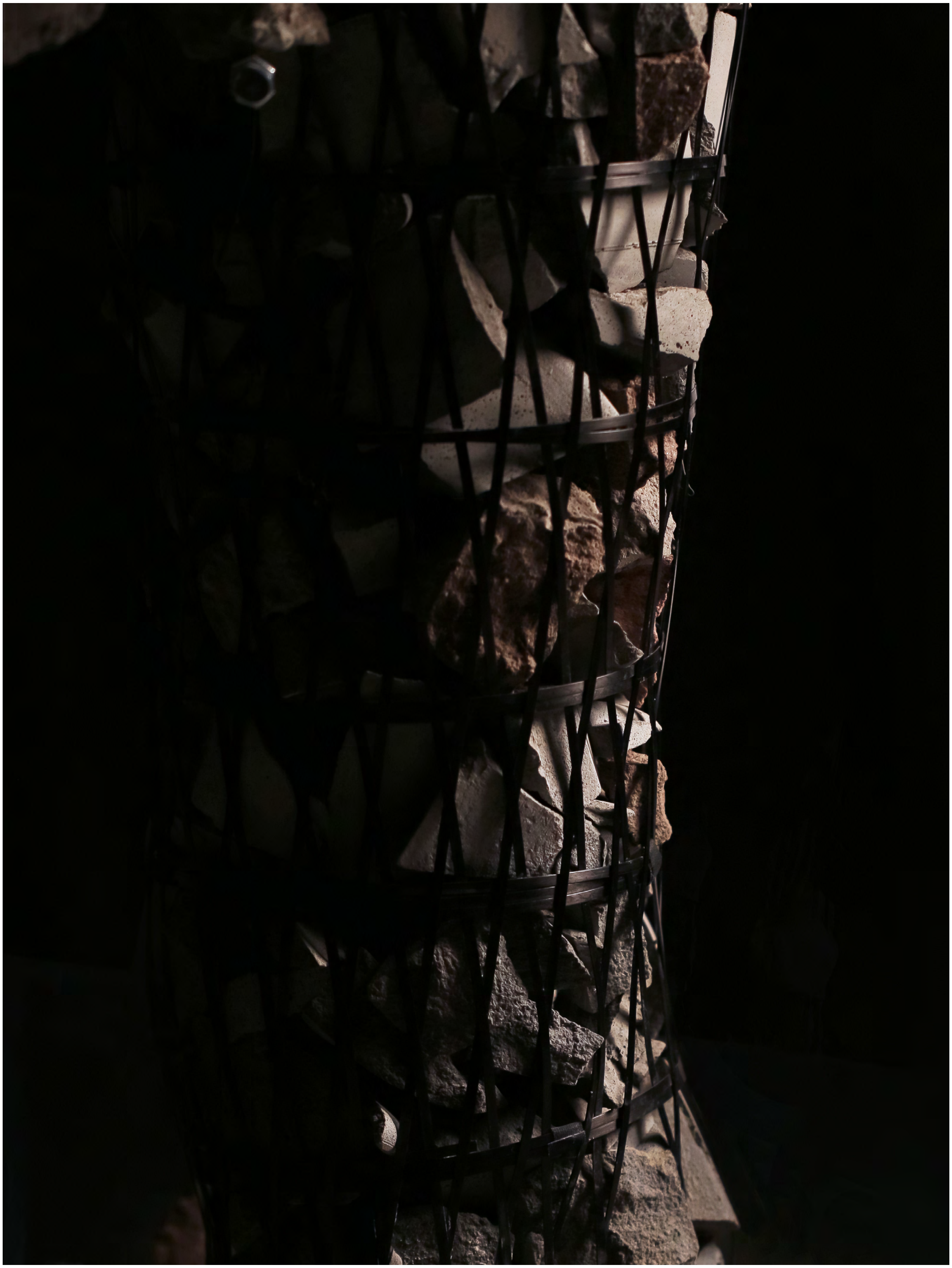


Fig 19. Crushed Concrete encased in a woven carbon fiber contrapment.

Every act of demolition as a material mining endeavor.

demolition is the Mina Plaza Towers in Abu Dhabi. In 10 seconds, the unfinished 144 floors were brought to the ground and destined to landfill. The event was considered a significant feat, achieving the Guinness World Record for the largest demolition using explosives[2]. Jeddah and Mecca have also recently experienced large-scale overhauls whereby demolition tore down buildings extending to an urban scale [3].

Although the volume of this demolition waste has not been quantified, the images alone allow us to gauge the amount and question the afterlife of these heritage structures.

2 Reynolds and Dajani, "Mina Plaza Demolition."
3 Gulf News Report, "Saudi Arabia Pays SR516.5m to Residents of Developed Neighbourhoods in Jeddah."

Petroleum : Regionalist Material Narrative

Fig 20. Poster *Translation: Our Oil is Arabian, Our Construction is Arabian*

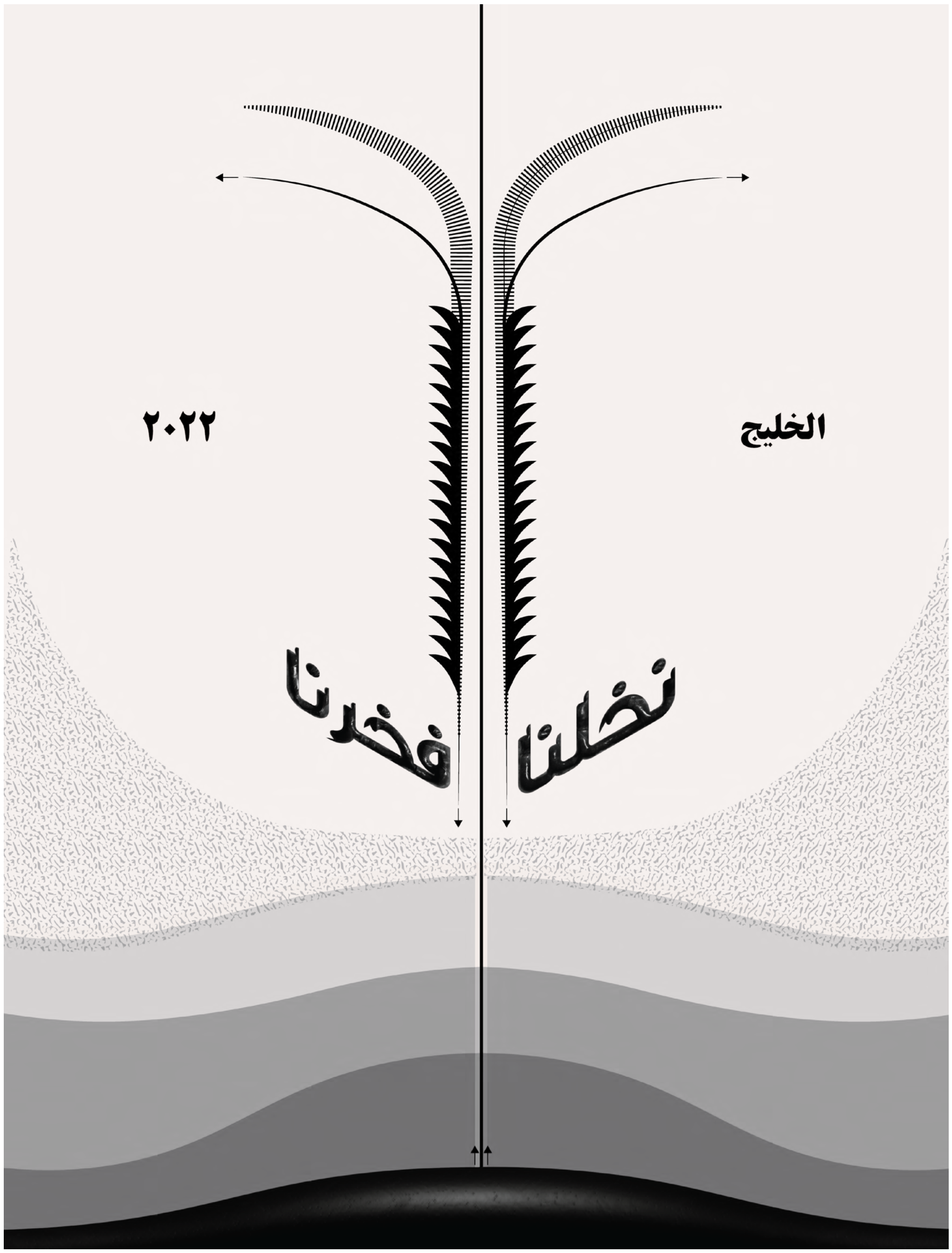
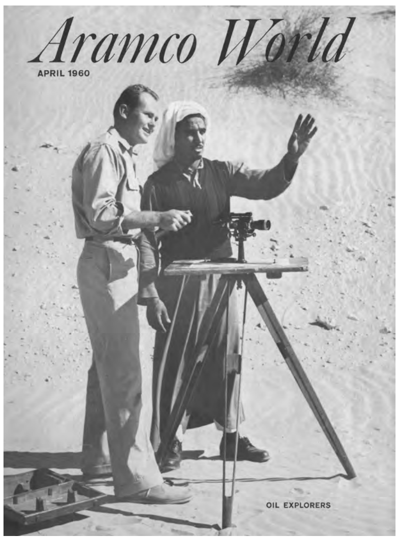


Fig 21. Poster Translation: Our Palms, Our Pride.

Dominating literature on the Arabian Gulf, transcending all themes and subject matter, fuel has been a formative character in the region's last century. When looking at the region's long history, dating back to ancient civilization, this period is relatively short. Yet, the structures that have risen, cities that have grown, and the populations that have multiplied make it an admittedly instrumental century 'following the discovery of oil'.

Fossil fuels, in the form of natural gas and petroleum in the Gulf, have contributed to the formation of transnational bonds and conflicts. Coupled with the current vulnerability of energy markets, this has led to fluctuations in GCC countries' political and economic dominance or inferiority. Nonetheless, with the upsurge in renewable energy sources, large oil companies, particularly Saudi Aramco, have planned for diversification and investment in carbon fibre production. Obtaining carbon fiber is energy-intensive, and it would need to operate at scale for production to be worthwhile. It continues a lineage of extraction, giving it a stained reputation. However, in the Gulf, it is a locally present and accessible material that can provide longevity to structures and enhance existing building practices. Currently, it is a regionally mined resource that is globally distributed. In this thesis, I propose that it is mined and used locally. In doing so, the development of expertise and specialization is allowed.



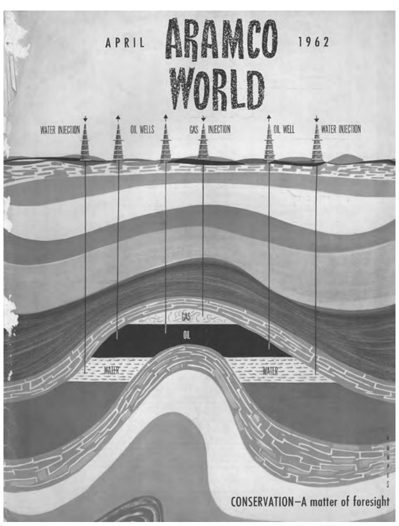


Fig 22. Aramco World Cover April 1960
Fig 23. Aramco World Cover April 1962

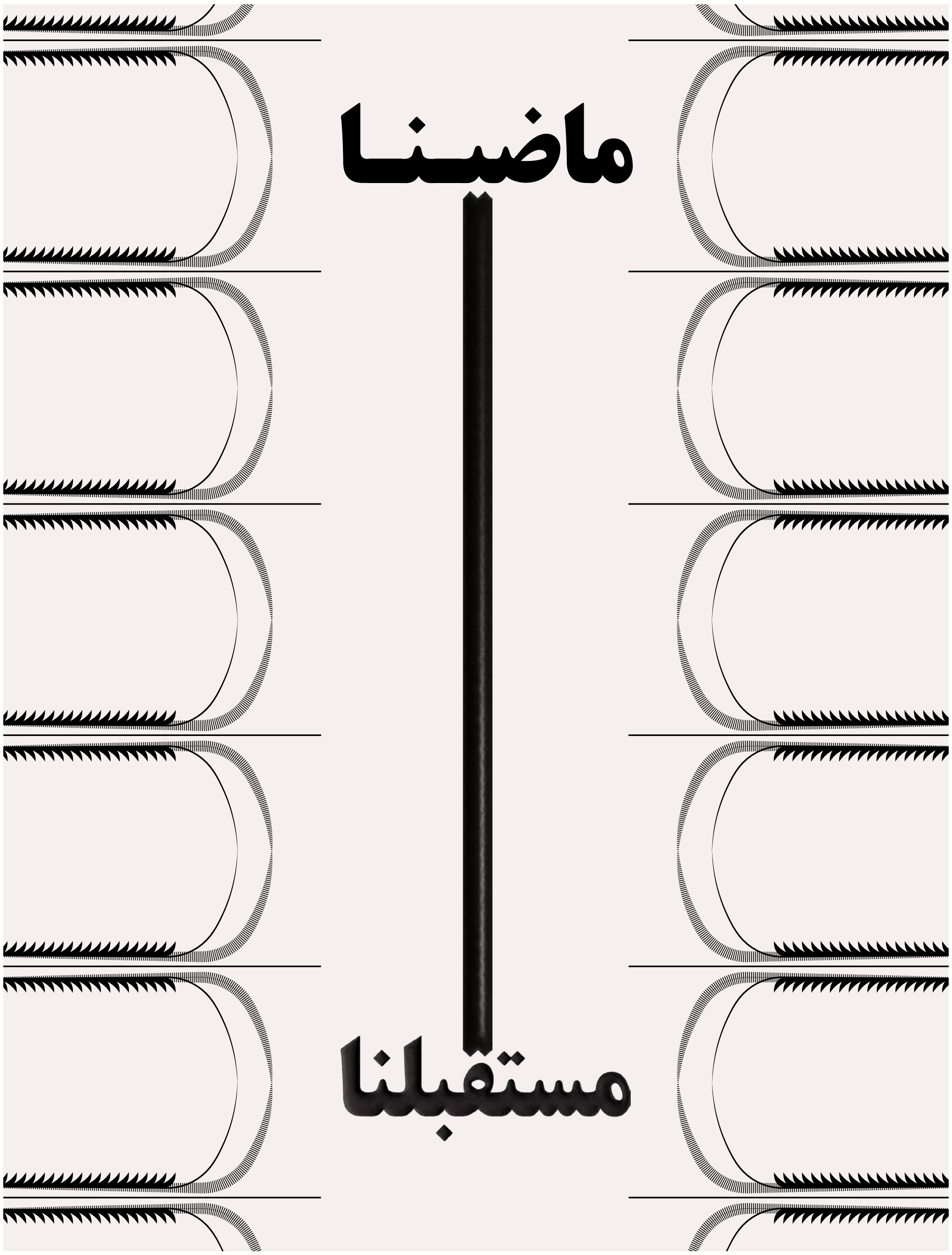


Fig 24. Poster Translation: Our Past Our Future.

Petroleum as a future piece of tangible and intangible heritage.

Petroleum played a prominent role in transforming the urban fabric, economies and occupations of the Gulf. It completely changed the living standards of populations. Yet, most people who benefitted from this material extraction have never interacted with or witnessed it in its raw form. Some may directly work with it, stumble upon pipelines along roads, or meander around refineries in the peripheries, but the closest most get is when filling a car tank with fuel. There are pragmatic and logistical justifications for this proximity. However, it exemplifies how abstract the oil economy is to many people. Despite being deeply intrusive to the land in the extraction process, the everyday evidence of its existence is either intangible (through energy) or both intangible and consequential (through economic fluctuation). The tangible remnants are remote mining sites and the impending climatic impacts of refining.

Whilst processing fossil fuels for building materials will remain an extractive practice, it would contribute towards a tangible manifestation that demystifies the petroleum substance. Moreover, the infrastructure to produce carbon fiber already exists, making it a viable industry for the near future.

As an ode to Aramco World's magazine covers, these posters allude to an approach that guided the methodology carried out in the thesis. Aramco World was launched as a means of promoting the growing oil industry[4]. It interlaced interests and events in Saudi Arabia with international topics of interest. Locally, it announced extraction activity and the arrival of a new demographic of experts residing in specially demarcated camps. Globally it portrayed a shifting culture and image of Saudi Arabia as it entered the energy market.

The poster proclaiming *"Our Palms, Our Pride"* paradoxically places the palm tree at the center of the oil extraction site. It reveals several layers of extraction; the tree for its fruit and fiber, the ground for limestone and cement, and the oil field for fuel. The tree, an emblem often celebrated for its heritage value and symbol of prosperity, is placed within the context of the oil field. This composition allows us to view them equally as natural resources of the land.

However, the native common knowledge of the two resources differs immensely. Due to its accessibility for centuries, the date palm has much stronger historical roots. On the other hand, oil is not as approachable a material and requires much more calibrated and industrial tools to exploit it. The Gulf inherited much of the methods and techniques to process it from the foreign experts that arrived in the early oil days.

Returning to the date palm tree, the familiarity of the resource meant that historically, the indigenous exploitation of the tree had been ingeniously resourceful. Beyond the fruit itself being used as food, the seeds were crushed into a powder used to make bread during poor harvests and drought periods. [5]

Fibers from the trunk were soaked in water and spun to be used for ropes. Fronds were sliced and soaked to make malleable elements woven into cages and fish traps. The leaves were dried and dyed to make coiled baskets and mats. Most people were

4 Aramco World, "AramcoWorld - Arab & Islamic Cultures & Connections."

5 Ahmed Alkhaja, Interview with Ahmed Al Khaja about indigenous practices.

Fig 25. Poster Translation: The Gulf's Jewels- Vision 2030

aware of these practices, and expertise in them was developed. In the Summer of 2022, I spent some time with the few remaining practising weavers to understand and document the processes.

Whilst the same commonplace know-how cannot simply be expected regarding the oil industry, a group of specialists can emerge. The general population may not all develop a sound understanding of the material in construction; however, advocating for local experimentation and investigation into its use allows for expertise to be developed. Locally tailored solutions rather than foreign-imposed ones would dictate how our resources may be used. Then, there is an opportunity for this industry to form and grow past the region. This proposition comes as a reaction to and contrasts with the globally designed one size fits all solution that the region currently employs in concrete construction. Thus, can we imagine a future where the resourcefulness of the palm tree connoisseurs is applied to the energy industry? A future where gas flaring is not an option and one where extraction is made more worthwhile.

Weaving:

Transcending geography, time, and function

Fig 26. Triaxially woven sliced palm tree fronds and rattan

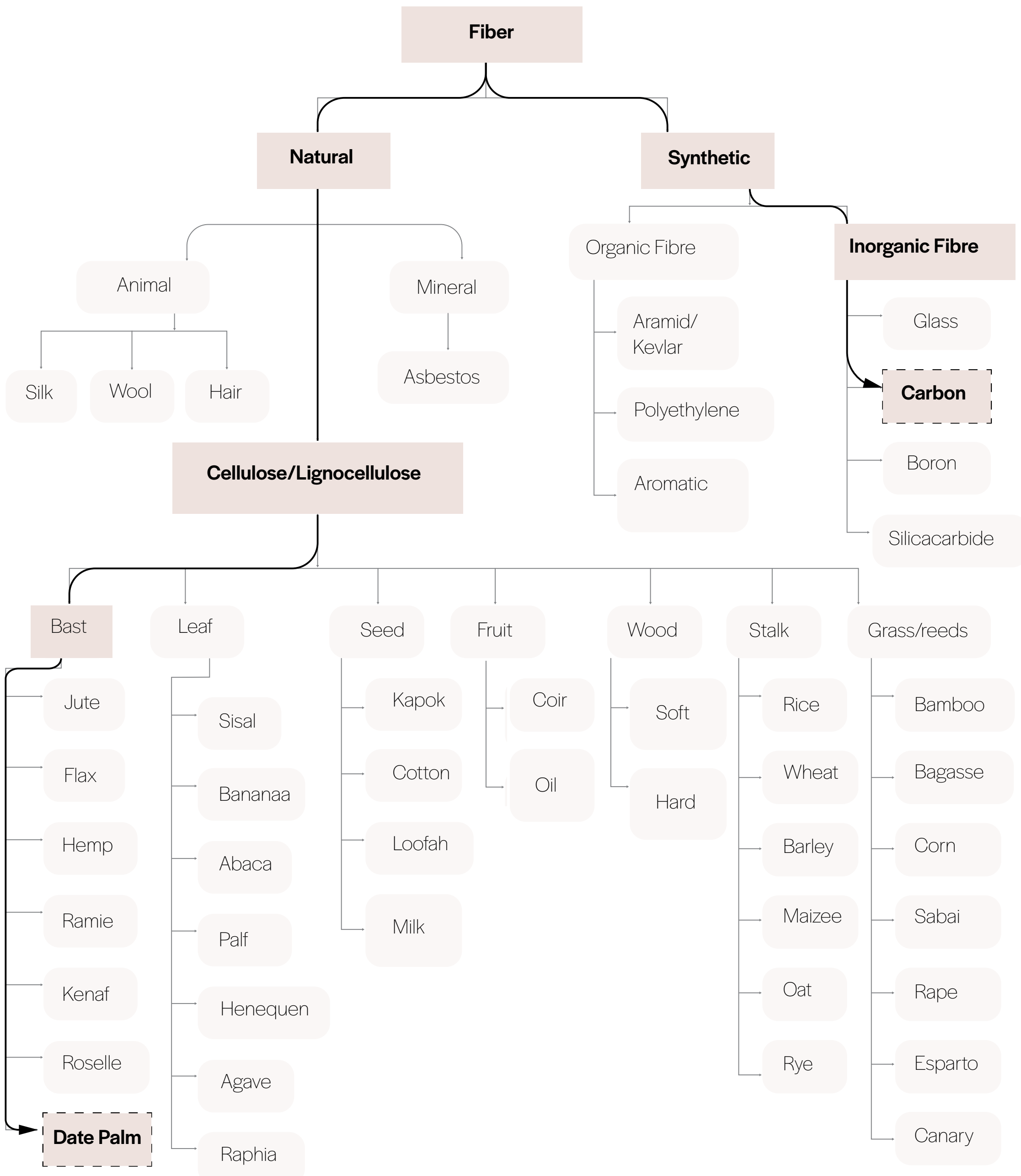


Fig 27. Fiber type chart

Working with fibers has an ancient history across the globe. Weaving practices have traditionally used natural fibers, dependent on geography and availability. Historically, whole date palm tree utilization has occurred in Bahrain and the wider GCC region. The various byproducts include palm leaves, fronds, sheathing, and trunk. Based on properties like strength, stiffness, and malleability, these went through different degrees of processing, such as slicing, soaking, and spinning. The products included poultry cages, fish traps, ropes, baskets, and mats. Some of these, like the mats, extended to a large scale, whereby they were used within composite floor systems along with woven fronds on mangrove beams.

Although the material composition of natural fibers differs from synthetic ones, the principles behind assembly techniques are transferable. For example, in traditional weaving practices, individual strands are layered and woven in multiple directions to create a triaxial formation. It would not be as stiff if the same number of strands were used in a unidirectional bundle. The layering of the fiber leverages assembly to accentuate the structural potential of the material. A network is built whereby the overlaps create stiffness. Configuring the fibers in multi-directional arrays makes a larger volume than the loose material without any interconnection.

The key learning is that weaving utilizes space as a material along with the fibers. This is important considering achieving material efficiency. Depending on the ratios and densities, a woven form can range from complete 'solidity' to more 'porous' surfaces. The genius of these assemblages is evident by merely the fact that the same weave pattern can be traced across the globe. The same 'triaxial' weave is referred to as Kagome in Japan[6],

6 Schnabl, "Weaving with Nanothreads."

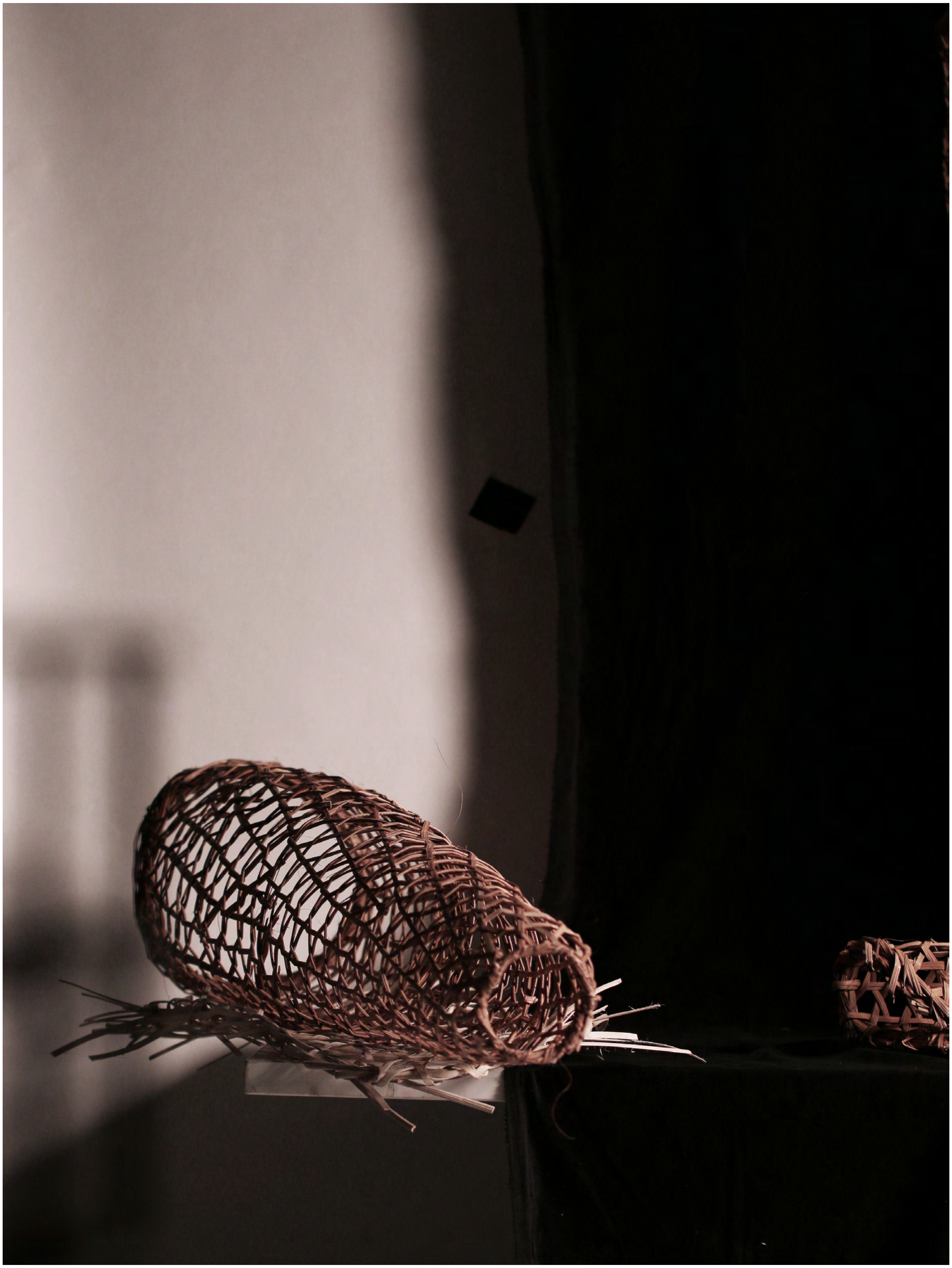


Fig 28. Triaxially woven column cage

Anyam Gila in Indonesia[7], and Hiyakat Al Slal (حياكة السلال)[8] in the Arabian Gulf to name a few. The aerospace industry has already appropriated these methods into producing vessels made of carbon fiber composites using filament winding[9].

Implementing this weaving technique would offer pathways to use local materials and borrow from the expertise that has been passed on over generations. Construction labor remains a complex issue, with complete reliance on migrant workers who construct following practices predominantly rooted in the West. This is not a claim to shift the labour force to a more localized one. However, resolving and implementing large-scale weaving will require the knowledge and intuition of those who have locally practised it for years. Therefore, introducing these techniques to construction would allow the translation of historic craftsmanship into an industrialized form. There is no implication that the burden of labor will shift to craftspeople. That would be an oversimplification of a complex industry. Instead, it is a suggestion to operate within peripheries and use the familiarity of the technique that the weavers hold, translating it into robotic or other forms of fabrication. Such a practice is not intended to revive the craft. Instead, it is to use carbon, a fibrous material in assemblies that best exemplify its strength and qualities.

7 “Basket | British Museum.”
8 Muntathar Alsayed, Interview with Muntathar about Basket Weaving.
9 Sator Aerospace Company “Grid Structures – Sator.”

Steel Rebar Deficiencies

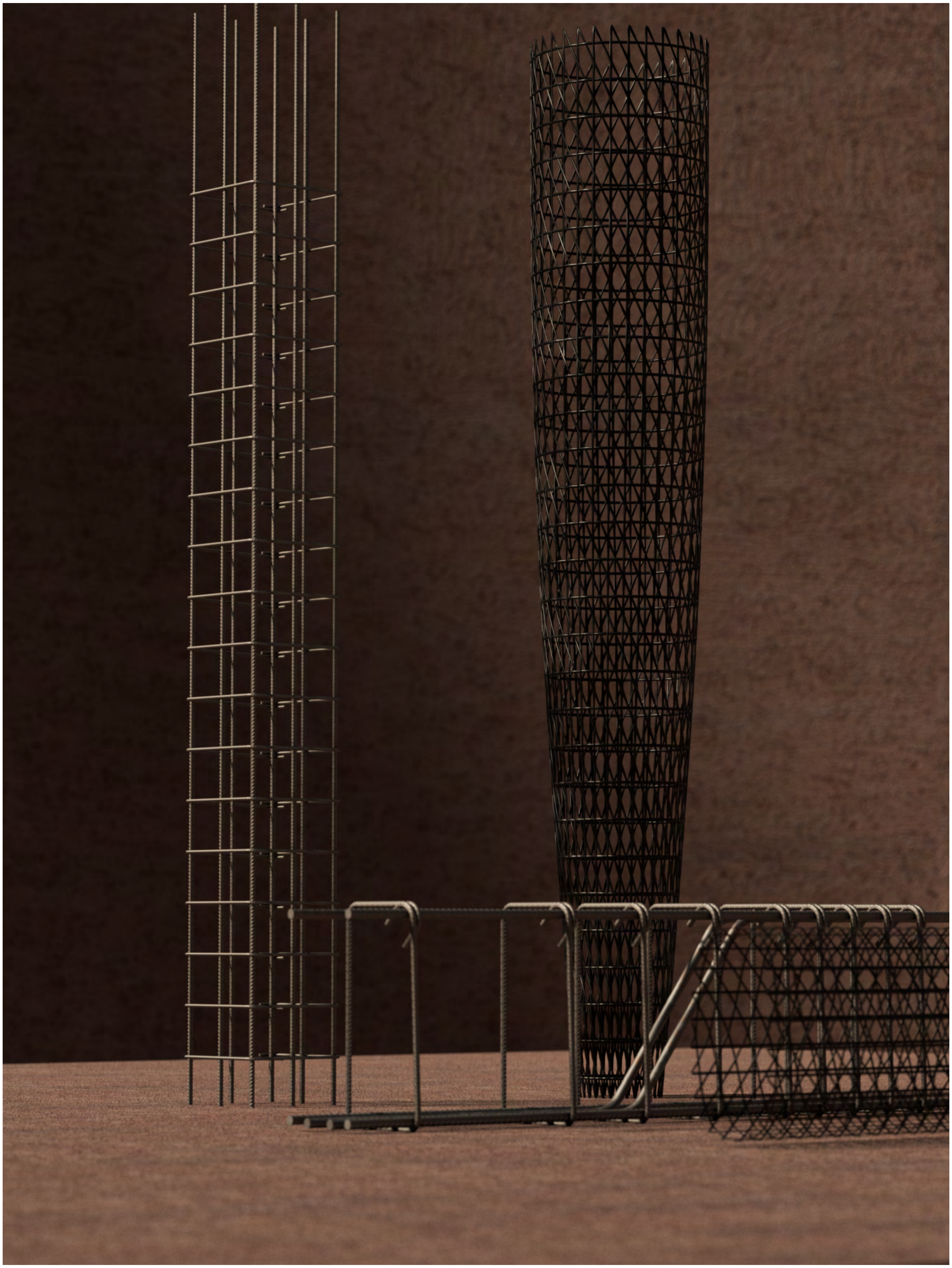


Fig 29. Comparison of steel reinforcement bars and woven carbon fibers.

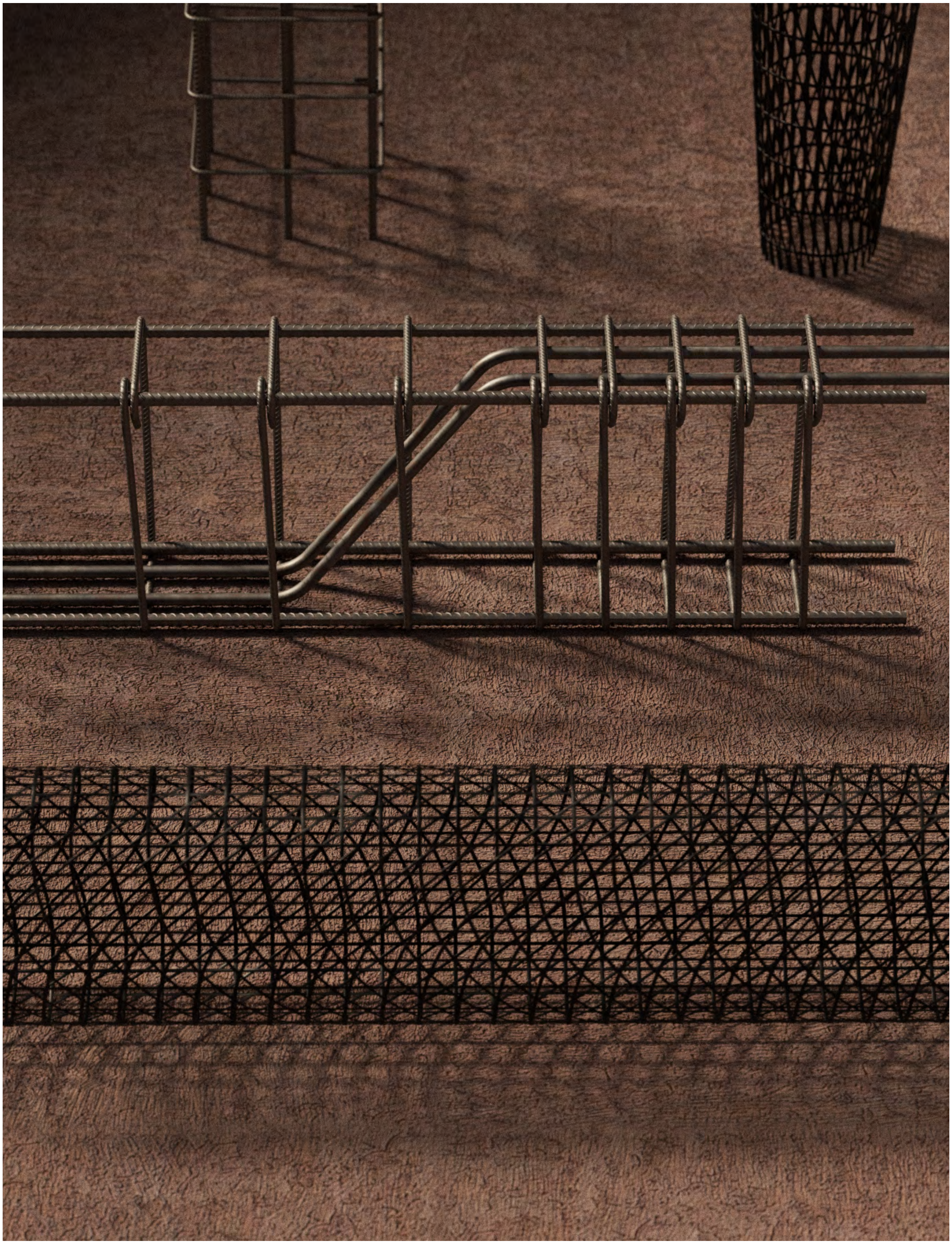


Fig 30.   Top, Steel Reinforcement Bars with Stirrups . Bottom,   Hypothetical Woven Carbon Reinforcement Network

In 1849, Joseph Monier, a Parisian gardener, invented reinforced concrete when he built concrete pots with iron mesh reinforcement. Over the 19th century, this innovation developed across the United States and Europe until the system became more commonplace[10].

As previously stated, the arrival of reinforced concrete on the shores of the Gulf was accelerated by British advisors during the protectorate status of the region. The unfolding of the concrete and cement industry was foreshadowed by the events in India 40 years prior when it was a British colony. The Gulf took on concrete construction quickly. The issues and failures around the system emerged years later and have since been iterated. Appropriate storage and processing of cement and sourcing of other raw materials have improved the quality of the construction. However, what remains to be the weakness in concrete construction today, is the steel reinforcement bar.

Reinforced concrete is a composite material. Concrete is a 'matrix', and steel reinforcement bars are the 'fibers'. Together, the pair form what defines a composite's assemblage. A comparison can be made to composites used in aerospace and automobile manufacturing, where resin is the 'matrix' and carbon nanotubes are the 'fibers'. Another example is wattle and daub, whereby the former is the fiber and the latter the matrix.

The fibers carry the tensile stresses in composites, whilst the matrix takes compressive stresses. In the case of reinforced concrete, withstanding the harsh climate of the Gulf, the steel reinforcement bar is susceptible to corrosion. Corrosion causes the steel to react and expand in volume, exerting destructive stresses on the concrete surrounding it, leading it to break[11]. This process also weakens the tensile element within the reinforced concrete. Thus, causing the concrete to crack as it attempts to take on tensile forces, which it is not equipped for due to its material properties.

According to the local architecture and engineering practice, MSCEB in Bahrain, many structures as recent as "10-15 years old suffer from excessive and premature corrosion". The types of corrosion that occur include chloride attacks, sulfate attacks and carbonation[12]. The speed at which this happens depends on how long the elements make their way through the concrete. Corrosion occurs pretty early in a climate of harsh heat and high water salinity.

Measures are put in place to reduce concrete porosity, make it denser, or increase concrete cover around the reinforcement to circumvent corrosion issues. Solutions as such encourage the use of even more concrete. Although the material is locally sourced and is an adapted vernacular, its production remains extremely carbon and energy intensive. Considering the detrimental effects of cement, its use should be more resourceful. Therefore, the steel reinforcement bar should be rethought rather than adding more mass and casting more concrete to solve the issue of a tensile member's failure.

Fusion-bonded epoxy rebars (FBECR) were introduced to the Gulf in the 1980s to improve the steel's performance in concrete. The coating is applied to protect it, reducing susceptibility to early corrosion. Production of these epoxies also became localized, with several plants built in the UAE as early as the 1990s[13].

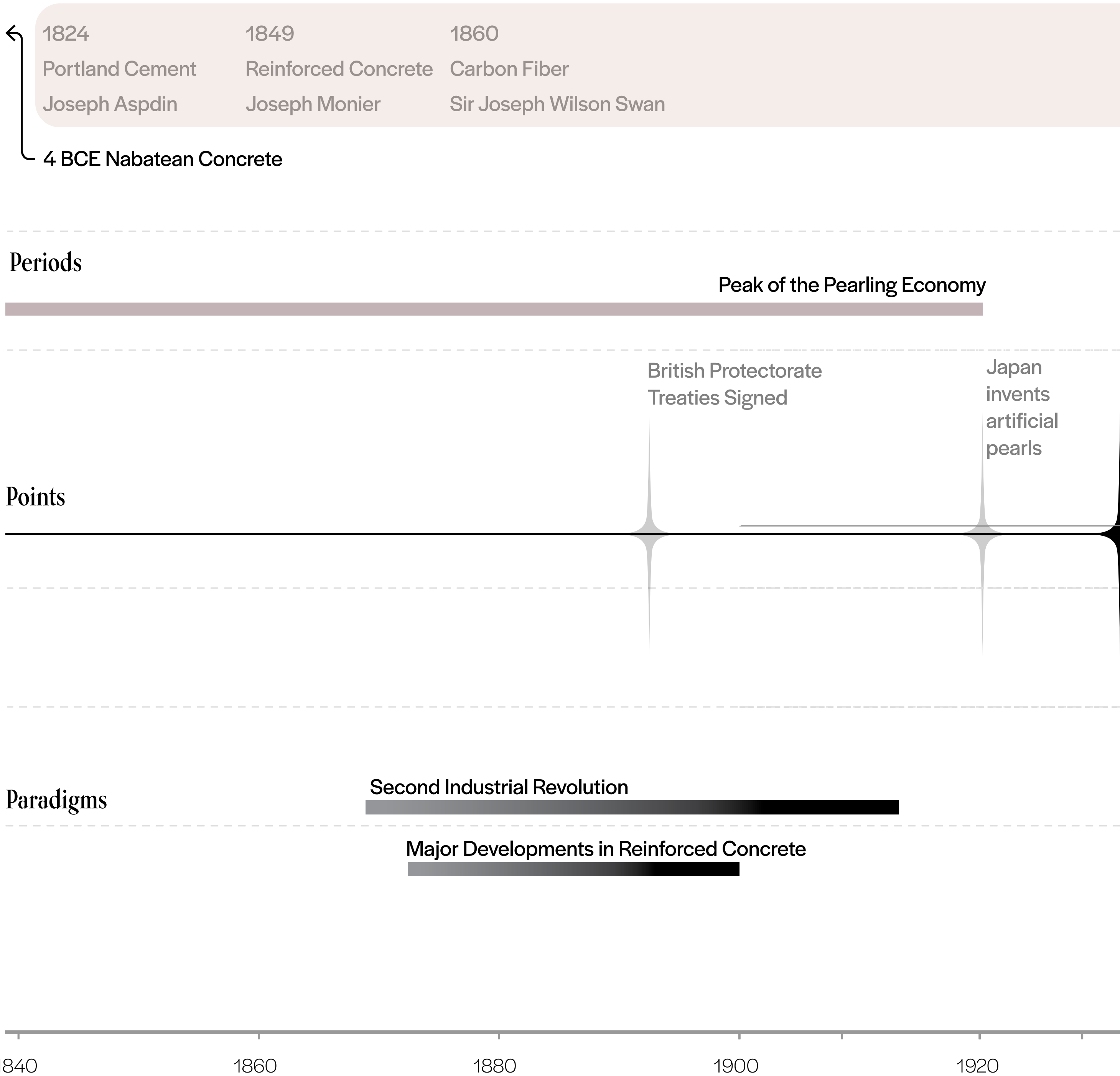
10 Komara, "Concrete and the Engineered Picturesque the Parc Des Buttes Chaumont (Paris, 1867)."

11 Li, Wang, and Li, "Model for Cover Cracking Due to Corrosion Expansion and Uniform Stresses at Infinity."

12 *Premature Corrosion of Concrete*.

13 Al-Gahtani, "Environmental Consideration for the use of epoxy coated rebars (FBECR) in the Gulf Region."

Concrete technological development



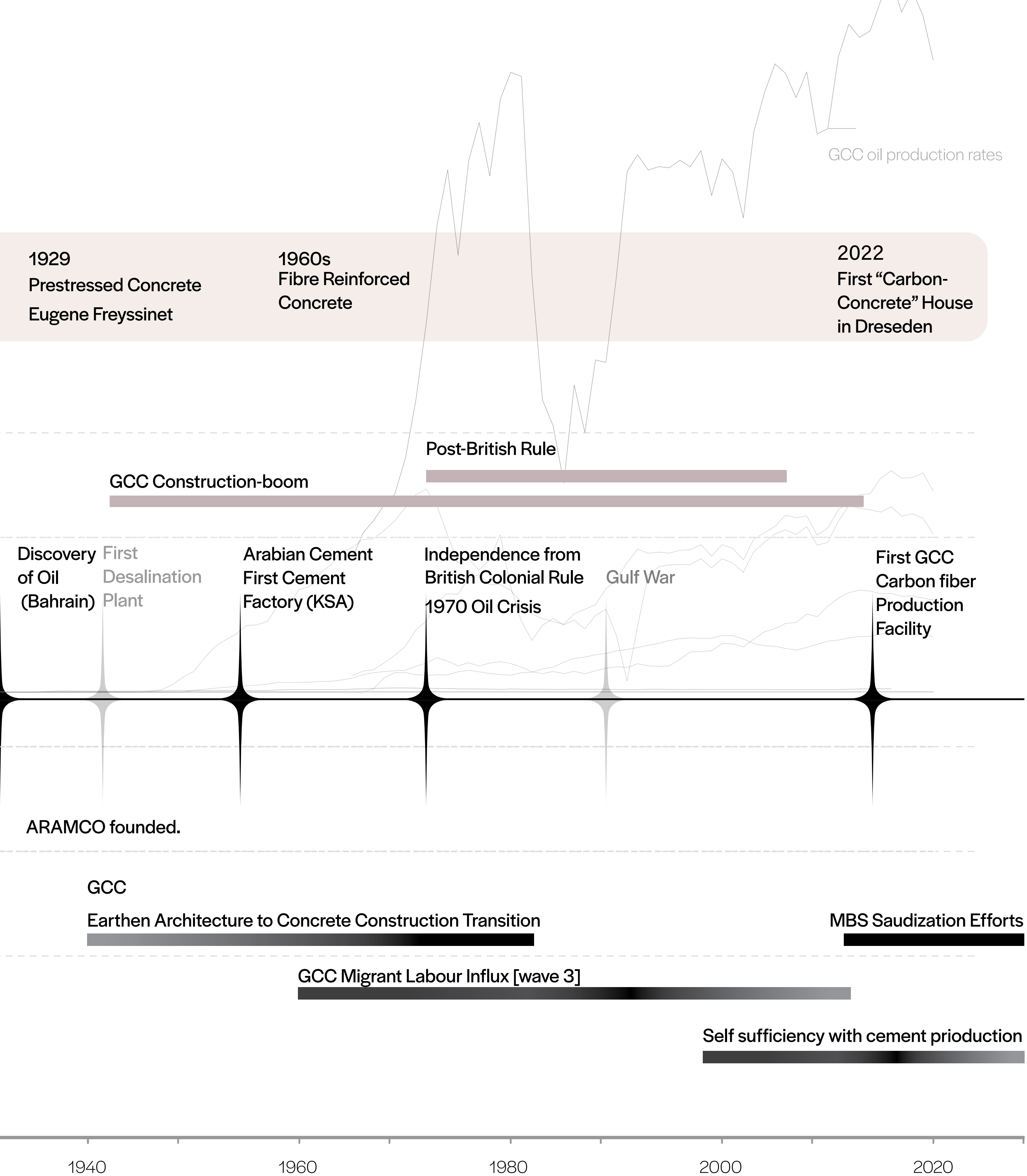
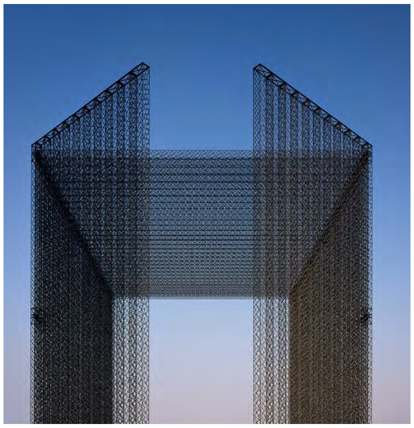


Fig 31. Timeline of Concrete Development alongside Geopolitical and Economic Events and Periods

Fibers



Dubai 2020 Expo Entry Portals

Asif Khan

Scale: Large

ICD ITKE Research Pavilion

Achim Menges

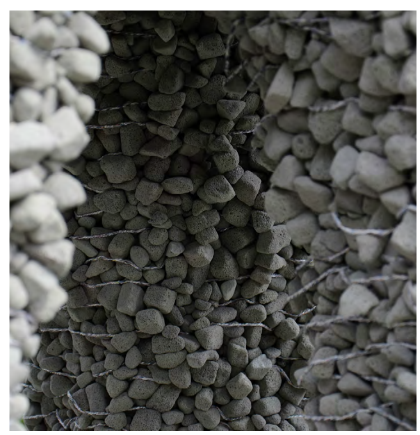
Scale: Medium Prototypical

Filament Wound Reinforcements

John Orr

Scale: Small Prototypical

Fragments



Ningbo Historic Museum

Amateur Architecture

Scale: Large

Re-Crete Bridge

EPFL

Scale: Medium Prototypical

Rock Print

Gramazio Kohler and Skylar Tibbits

Scale: Medium Prototypical

Fig 32. Literature/Precedent Review of Tangential Work

Regionalist Constructive Systems: The marriage of carbon and concrete

In the Arabian Gulf, carbon fiber is a more suitable candidate for concrete reinforcement than steel. This is because it is a locally sourced alternative that is not prone to corrosion. It has the potential to reduce concrete cover (the minimum depth from the edge of a concrete element to the nearest reinforcement bar) in structural components, making them lighter whilst withstanding the same forces. Though there is the capacity for efficiency improvements in material production, it remains energy-intensive today. Nonetheless, this work operates under the speculation that these enhancements will be achieved.

It is tempting to replace steel, in its current bar form, with another bar made of carbon, a promising alternative. Operating with business as usual, the same labor and methods could be conformed to. However, the material behaves differently and warrants an assembly more attuned to its characteristics. As mentioned earlier, weaving lends itself as a technique used to assemble fibers for centuries. In the realm of digital fabrication, Achim Menges has demonstrated the application of wound carbon fibers to build lightweight structures with the aid of robotics[14]. The Dubai 2020 Expo Entry Portals designed by Asif Khan are a testament to the scalability of the material[15]. However, since carbon nanotubes are strong in tension and weak in compression, these projects rely on the matrix used for the carbon fiber. The Expo entry portals are also open air, purely self-supporting structures, with no envelope or surface to bear roof or wind loads. To make the material and systems applicable and scalable in the industry, I believe a better-performing compressive material should be used in conjunction with carbon fibers in tension.

14 Menges, and Halbe "ICD/ITKE Research Pavilion 2014-15."

15 Imanova, "Expo 2020 Dubai Public Realm by Asif Khan | Identity.Ae."

An example of this is the research conducted by John Orr delving into wound Fiber Reinforced Polymer (FRP) filaments[16]. This work on structurally optimized concrete beams exhibits the use of tensile reinforcement made of carbon tow emersed in resin just before it is wound and set in place. The fibers are then cast in concrete-shaped elements.

Bearing in mind the public perception and promotion of this system, it is pertinent that a new visual language is conveyed. It makes a more convincing and compelling manifestation when a difference or unusual appearance can be identified. If carbon is embedded in the concrete like steel was, the advantages would exist; however, the performance would be out of sight. The combination of concrete with woven carbon affords a possibility to reveal the reinforcements rather than conceal them inside the concrete. Because carbon is not as corrosive as steel reinforcement would have been, it can come through beyond the surface that concrete would have otherwise concealed it. When the public can view the woven structural forms, it is easier to associate with and relate to the new constructive system rooted in the place. This marriage reintroduces the relations and ties between structure, material and ornament.

16 Spadea, Orr, and Ivanova, "Bend-Strength of Novel Filament Wound Shear Reinforcement."

The Crown Jewels

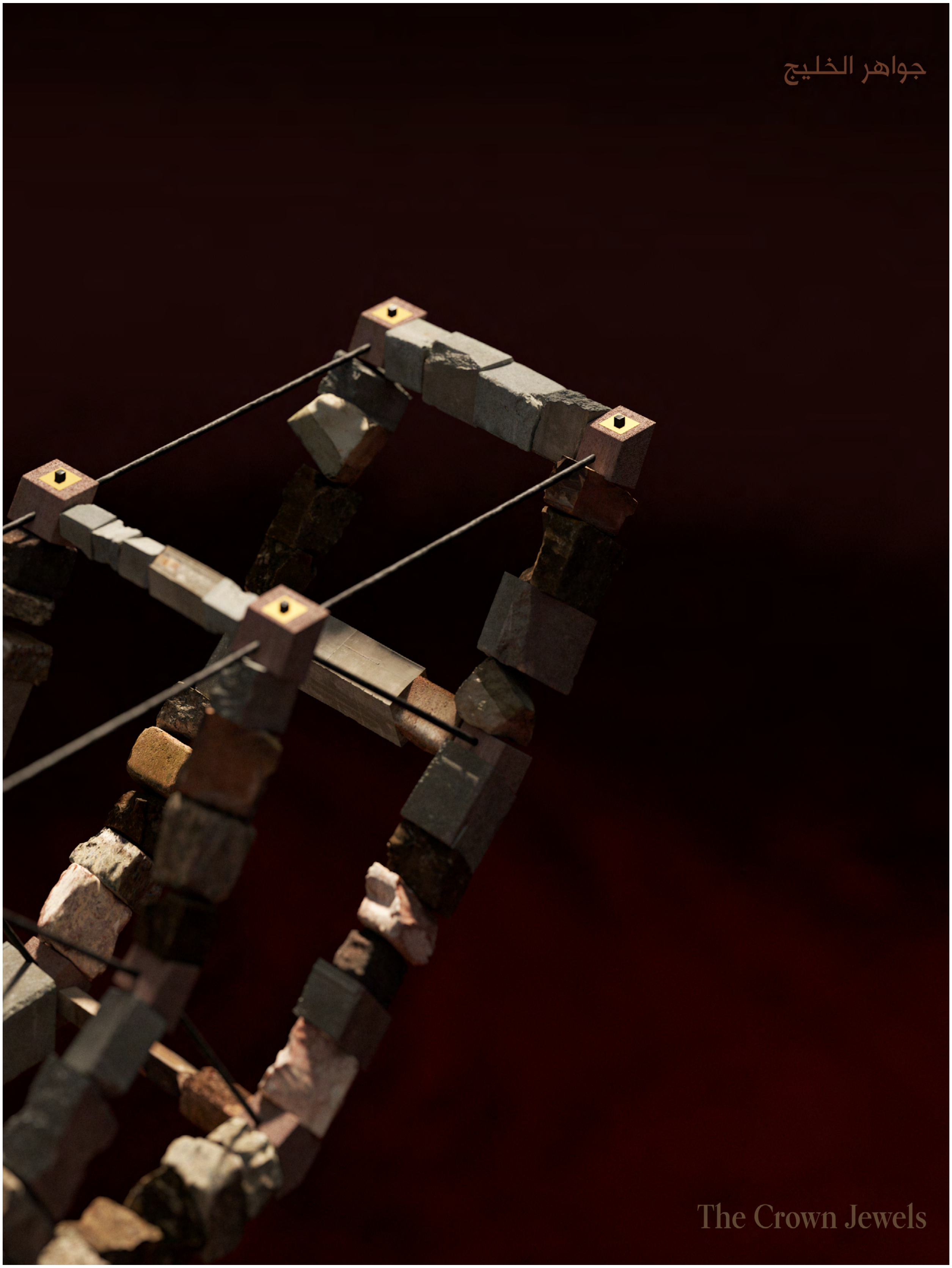


Fig 33. An advertisement promoting athe assembly system as a piece of fine jewelry.

The Crown Jewels are a series of projects that best exemplify this constructive system of fiber and fragment. They are monumental pieces of public infrastructure gifted to the countries of the Gulf Cooperation Council from their friendly neighbor and member, Saudi Arabia. As a series of colossal structures, they are erected to reinforce the investment in cultural initiatives. Grouped under one umbrella, they stress the regional ties that bind those countries but also afford them political and economic strength. The Crown Jewels respond to years of imported material, cultural, intellectual and technological consumption “following the discovery of oil”.

Seek to inflate the worth of an undervalued resource, rather than exemplifying the preciousness of a rare and opulent one.

Fig 34. Rubble as gems, exhibited and labelled with their source and date of aquisition.

The historic Crown Jewels have been the British Imperialist monarchy's precious jewelry collection. The nation's treasure includes a range of priceless objects, including presents to British monarchs as diplomatic gifts[17]. The Gulf's Arab leaders have participated in this generous protocol by gifting Queen Elizabeth II several pieces. Amongst those was a set of seven Bahraini pearls on her wedding in 1947 from Sheikh Salman bin Hamad Al Khalifa.

The proposed Crown Jewels differ from the British collection in a few ways. Their use is not accessible exclusively- instead, they are inclusive monuments open to all as a series of public spaces. They are gifted internally and seek to inflate the worth of an undervalued resource rather than exemplifying the preciousness of a rare and opulent one. The two are similar in how the gemstones are celebrated and framed with a material that arranges, frames, or ties them together. With the British jewels, the framing was made of precious metals like gold. In the constructive system, carbon fiber takes this role.

17 Cartwright, "British Crown Jewels."

Fig 35. Queen Elizabeth II receiving diplomatic gifts from the Bahrain's Emir and UAE leaders during the Gulf Tour in 1979.

Crown Jewels: Process

Fig 36. Concrete Piercing and Stringing.

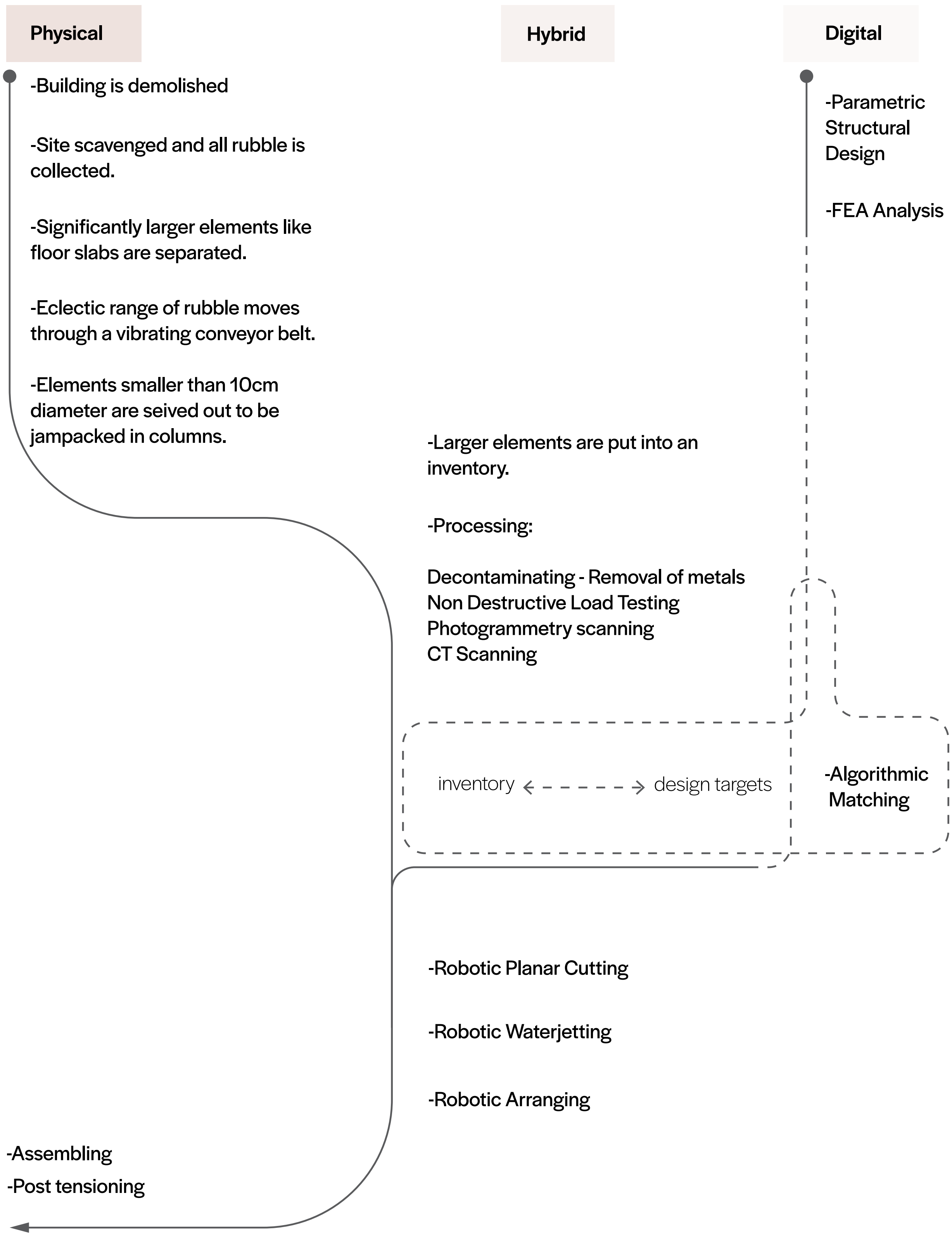


Fig 37. Diagram of Workflow

Fig 38. Comparison of pearl categorizing with concrete sorting

Fig 39. Comparison of pearl arrangement into pockets with jammed and packed concrete rubble

Fig 40. Comparison of pearl stringing with concrete post tensioning

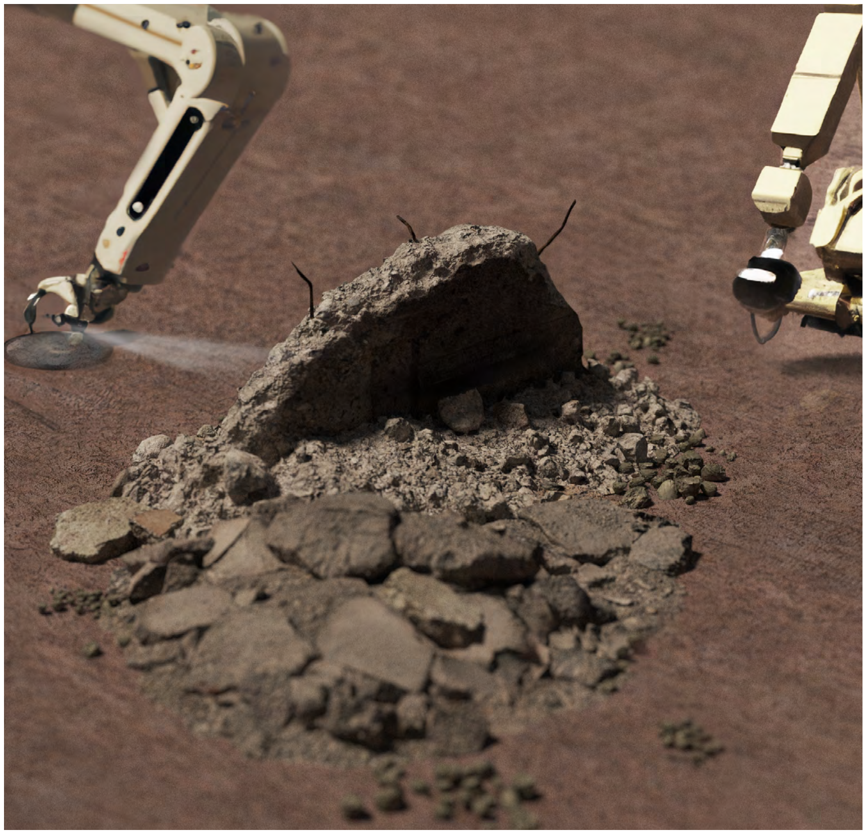


Fig 41. Summarized Concrete Processing a) Initial cutting b) Waterjetting c) Reordering d) Stringing

Fig 42. Depiction of the construction system as a totem, or recognizable piece of jewelry.

Fig 43. Jaques Cartier amongst Pearl Merchants in Bahrain

Fig 44. Cartier Jewelry Advertisements

Fig 45. Ibid.

Promotion of structure as jewelry

Campaign content advertising this gift-giving initiative portrays the structural system as finely crafted jewelry. It takes hints from Cartier's iconic posters, contrasting their jewelry against a red backdrop. This is also suggestive of the cloth that pearl merchants commonly used to display the pearls. The intention behind these representations is to shed light on the materials and structures that constitute people's dwellings and public spaces. Instead of merely industrial components that provide shelter, they are carefully handled and sourced assemblies that enter the realm of materially honest ornamentation.

Using Cartier's specific representational style also stems from the brand's regional success. Despite the popularity of the Gulf's pearls for centuries prior, Jacques Cartier's visit to Bahrain in 1912 significantly highlighted their luxury, excellence, and worth internationally[18]. Note that this is 20 years before the first oil well was discovered. Yet, the image of Cartier amongst the pearl merchants has stark similarities with photographs of geologists and engineers with leaders nearby oil wells. Both portrayed Western figures that visited the Gulf and benefitted from its natural resources while forming global ties. The difference lies in the expertise of the trade. The Gulf's economy had heavily relied on the pearling industry before oil was discovered. Thus, much like the palm experts, local specialists were well-established. On the other hand, petroleum was a new industry and the knowledge was passed on from American and British engineers.

18 Talass, "How a Trip to Bahrain Spelled Success for French Luxury Brand Cartier | Arab News."

Fig 46. Promotional content depicting details of structure as jewelry

The methods and assemblies strive to feed into a nationalist narrative through form and material, along with a future outlook of resourcefulness and care.

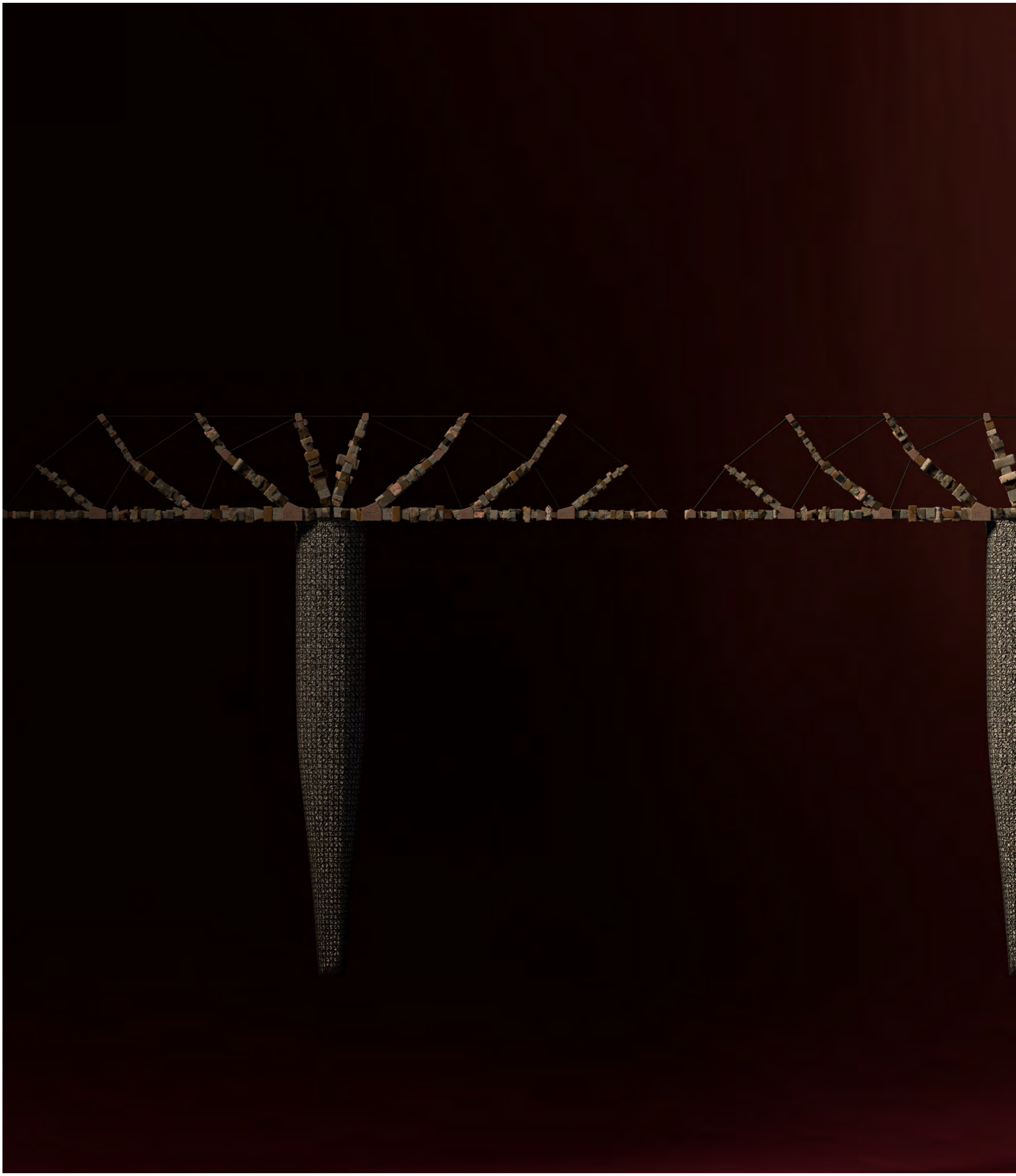


Fig 47.   Promotional content depicting details of structure as jewelry

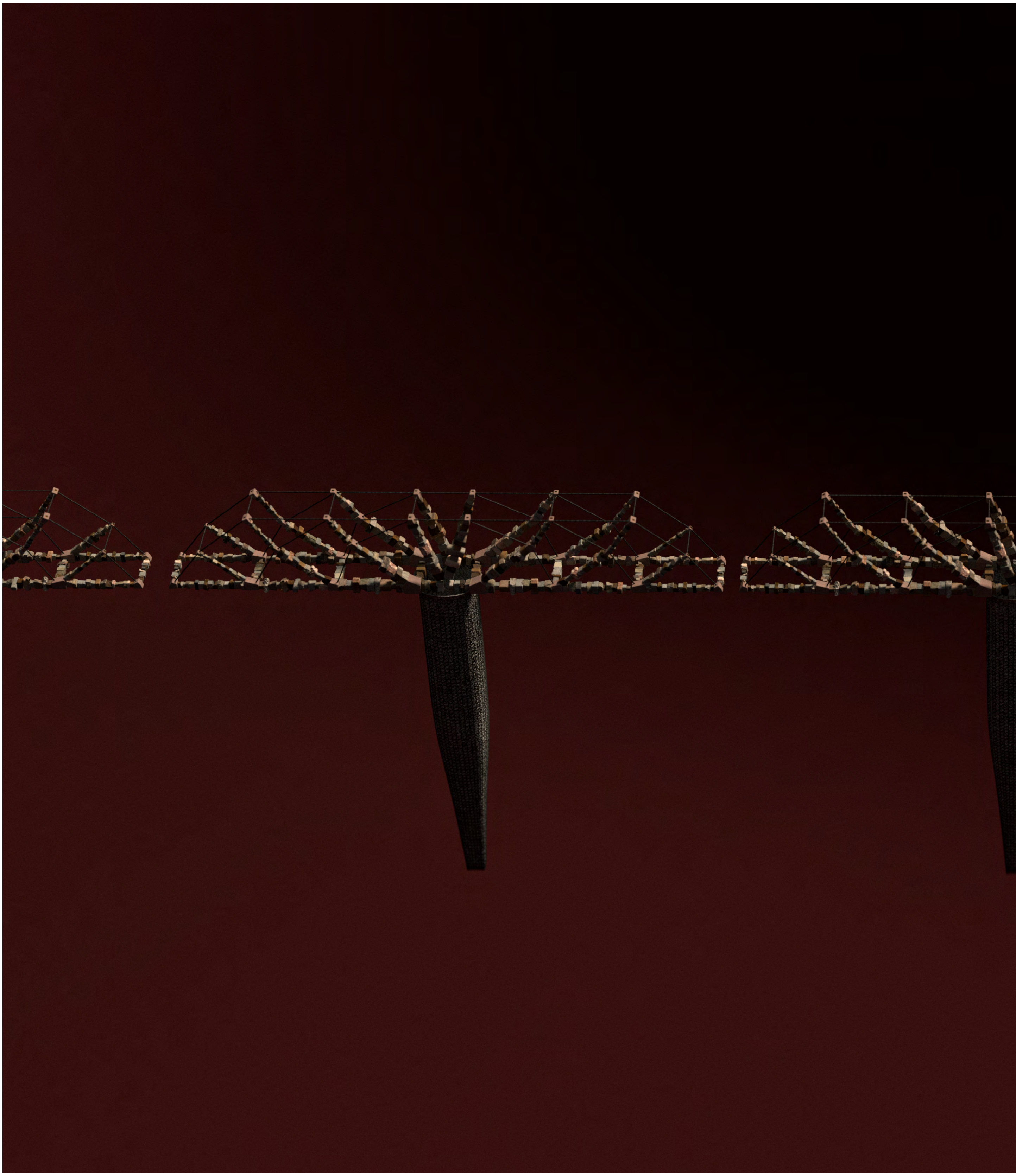


Fig 48. Promotional content depicting details of structure as jewelry

A Gift to the Neighbour: Muharraq Pier

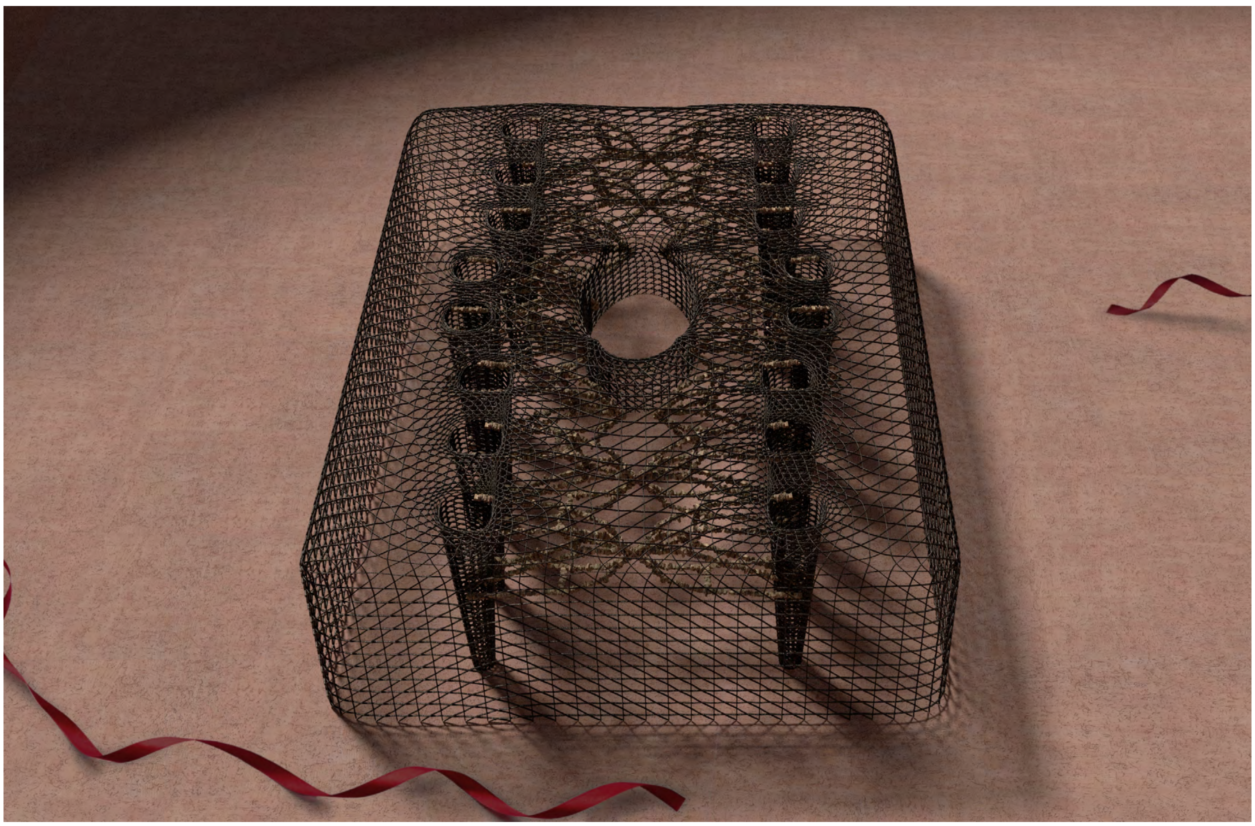


Fig 49. An architectural model of a diplomatic gift from the Kingdom of Saudi Arabia, to the Kingdom of Bahrain.

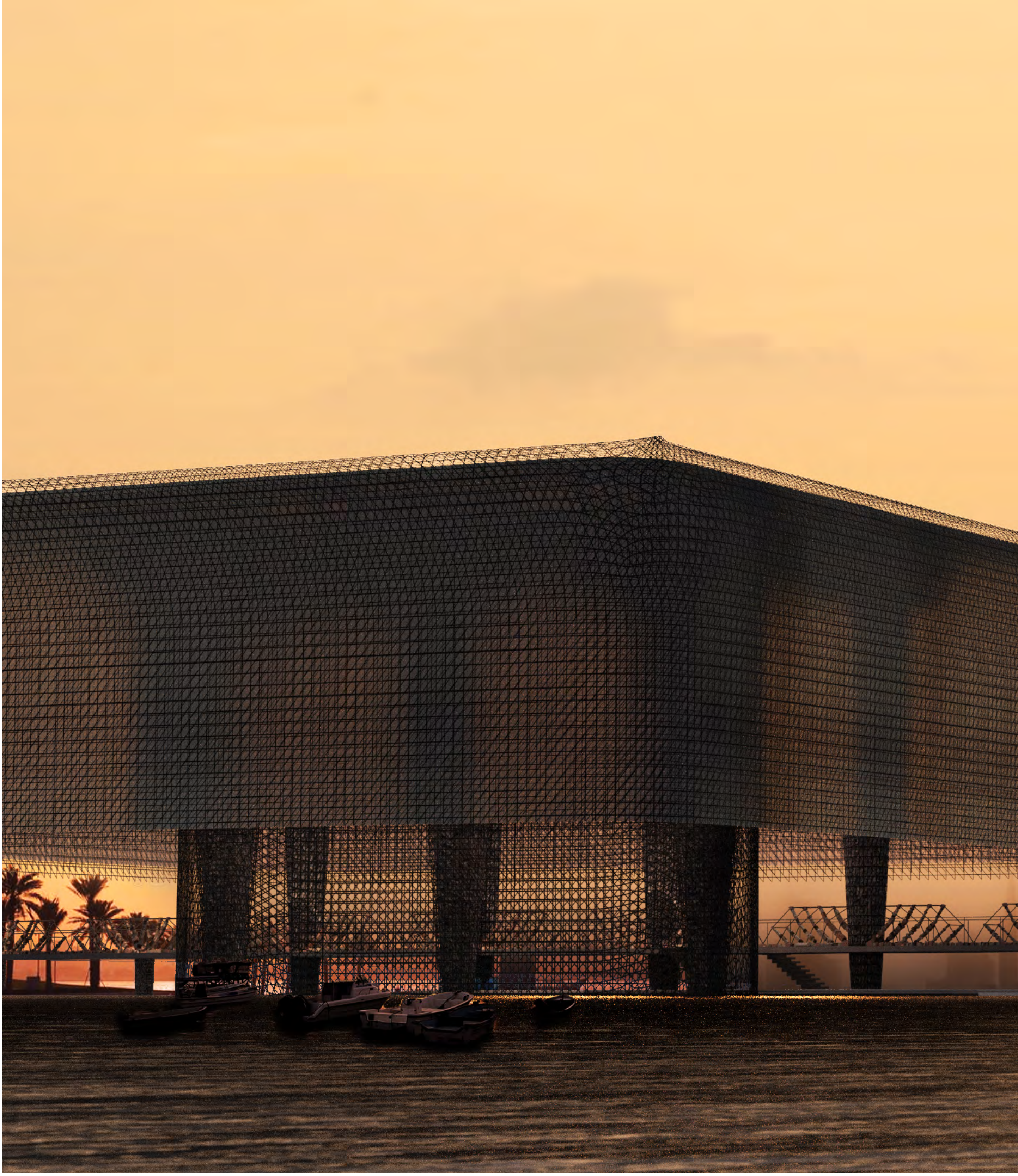


Fig 50. Fishermen take off from Muharraq's Public Pier at sunrise.

Fig 51. Multilayered Woven Carbon Fiber Enclosure

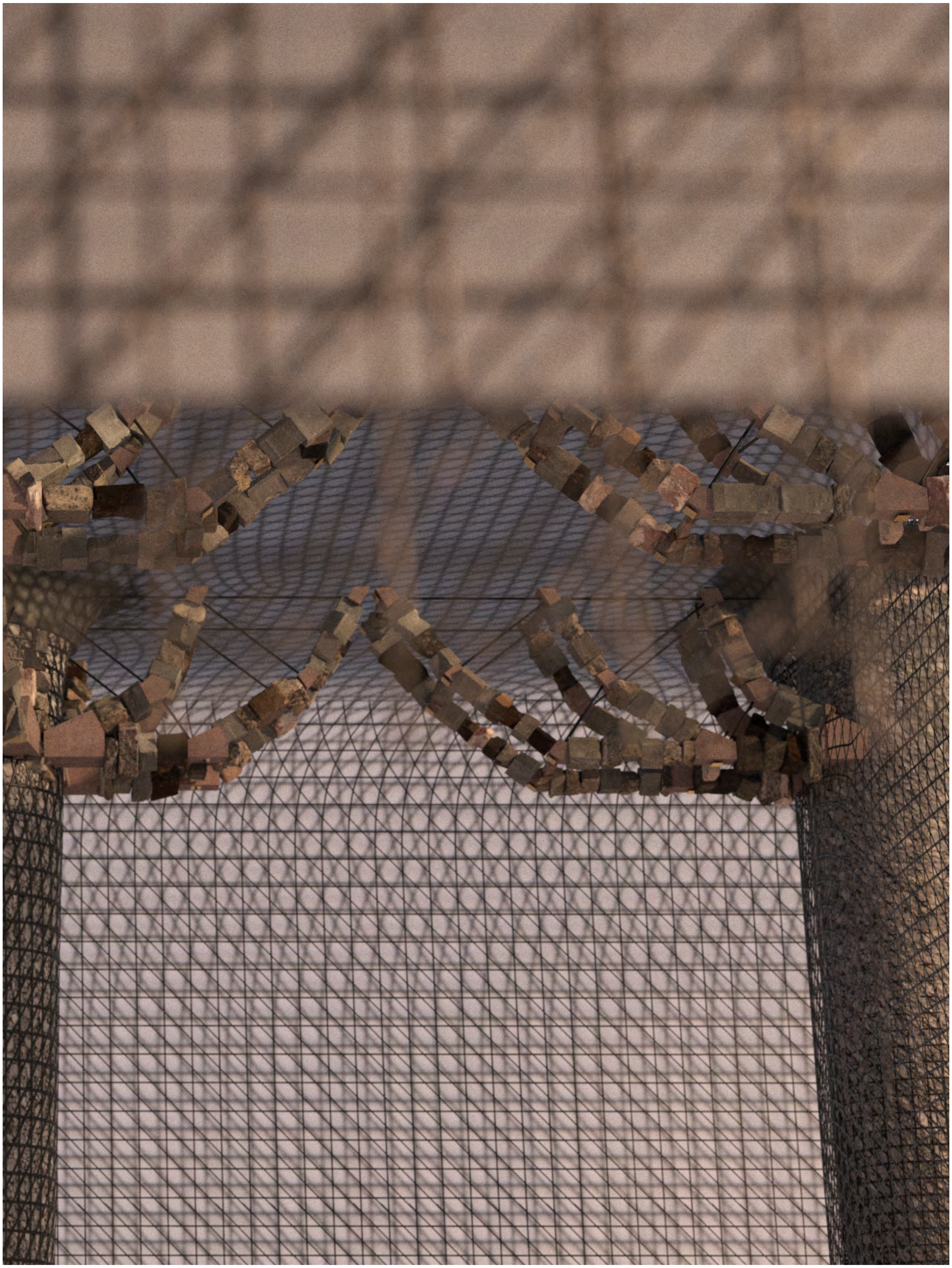


Fig 52. Rubble filled carbon fiber columns holding down the light roof hovering over the water.

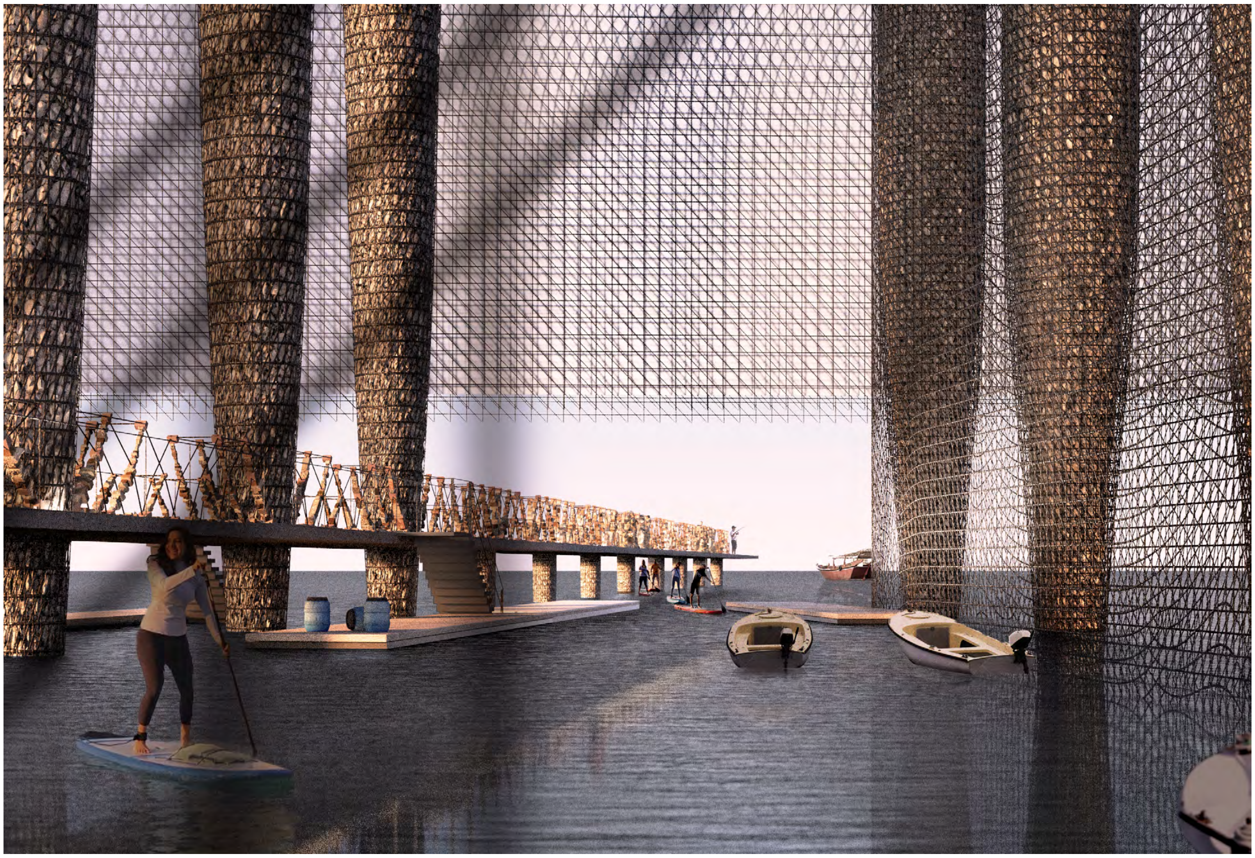
Gift to a neighbor: the Muharraq Pier

The Muharraq Pier is a piece of finely manufactured jewelry from the collection of Crown Jewels. Due to the abundance of demolition activity, it is designed to commemorate and elevate rubble, a devalued substance. Rather than treating it like waste, each chunk from structures likely associated with the region's protectorate past is regarded as a precious stone. Carefully sorted based on size and quality, the concrete fragments are strung together with carbon fibers like a necklace, forming elements of larger structures.

The methods and assemblies strive to feed into a nationalist narrative through form and material, along with a future outlook of resourcefulness and care.

The triaxial weave is used for its structural benefits, but it also carries symbolic meaning for some people. It is reminiscent of mashrabiya screens and the patterns within Islamic architecture commonly found in the region. Therefore, the triaxial weave may be a subtle reference to local heritage. As well as its structural value increasing stiffness, it also offers ornamental opportunities.

The role of the carbon fiber in this proposal is to hold up the fragments and create an illusion of lightness. The large spanning canopy hovers over the water, cantilevering. The concrete columns and post-tensioned truss support it, building a palace of rubble above the protected docking area.



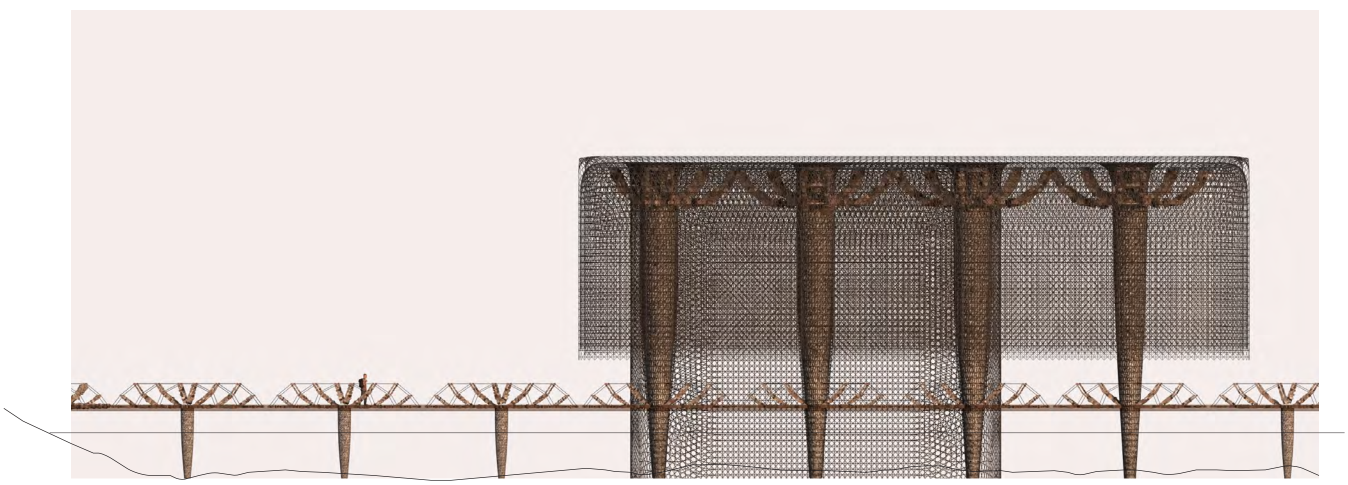


Fig 53. Within the semi enclosed space, boats are charged along PV powered stations. Whilst fisherman roam the docks early in the day, water sports discharge closer to sunset.

System

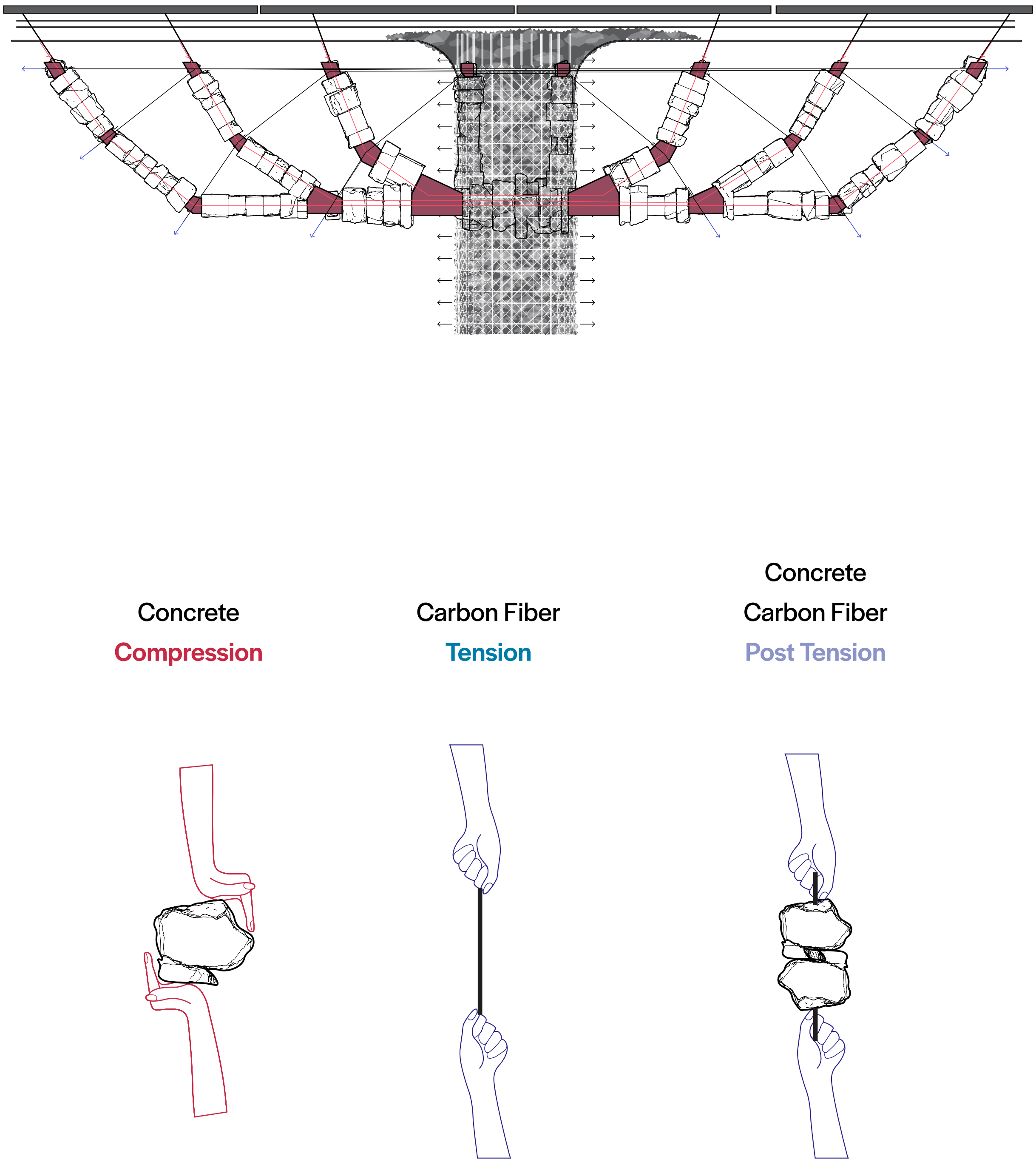


Fig 54. Core Structural Principles and Materials

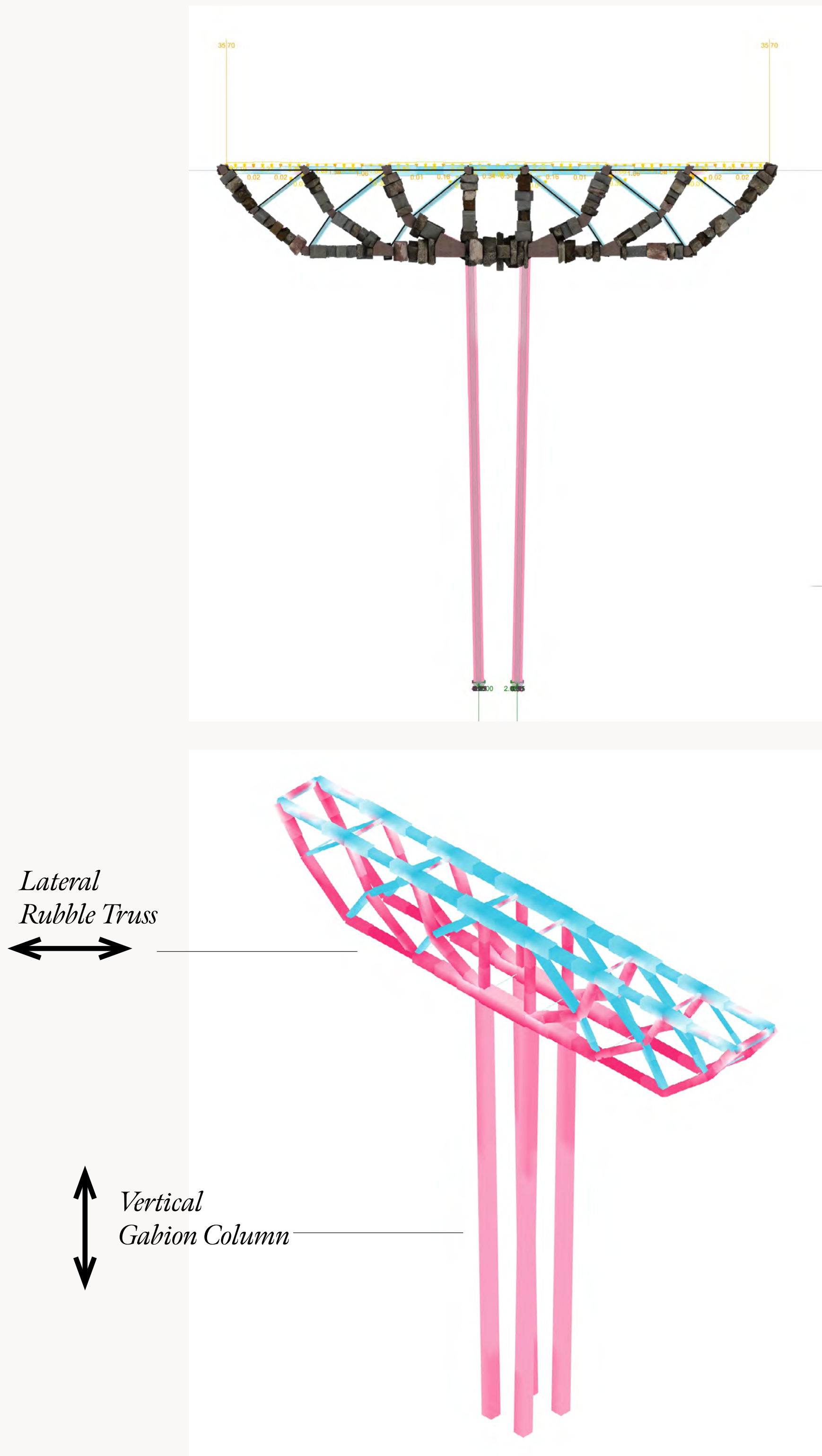


Fig 55. Digital Structural Analysis for cross sectional area information

Structural Design

The Truss topology mimics a Michell Truss. The Roof and Pier structures are both cantilevers, with the heaviest members closer to the supports. The truss chords get lighter as they move away from the vertical columns. Digital structural analysis on Karamba3D[19] was run to calculate the necessary cross-sectional areas for the truss chords. Each chord was subdivided, allowing for higher-resolution results. The discrete rubble assembly allows for variation; therefore, it matches the target chord cross-section. This way, the rubble material is utilized to its full capacity. For instance, a 40 x 40cm cross-section of concrete would be matched to a section demanding 38cm x 38cm rather than 20cm x20cm.

Some inefficiencies should be pointed out. Due to imperfect overlaps from one chunk to the next, sometimes, additional mass is added to the structure without full material utilization. These imperfections occur as processing the concrete chunks uses minimal cuts and retains the rough surfaces. Nevertheless, the system is not fully optimized for material efficiency in terms of utilization. This might have been the case if this was a freshly cast concrete structure. Instead, the benefits come through the amount of material saved had it been made of fresh concrete.

The images display elements in compression in red and those in tension in blue. As a demonstration of the strength, the tension members made of carbon fiber are left exposed. The impression of lightness this affords signifies the material's potential to the public.

The constructive system warps time with its use of rubble in a newly built structure. The notions of novelty, smoothness, cleanliness, clarity, immortality, permanence, and durability are highly regarded in the current culture. It can be speculated that these are still reactions to a long-lost generation of clay and stone or fiber dwellings. The constant search for renewal, or the tabula rasa approach many admire, eases demolition. It also justifies how halted development projects like Mina Plaza get demolished rather than picked up from where previous developers or investors had left off.

This outlook contradicts the appreciation of European cities and towns that the same people have. Those cities are admired and highly regarded for their historical nature. Their structures withstood the test of time and "beautifully" showcase aging on the surface. Weathering in eroded brick, chipped-off stucco or paint, and broken cobbles is "charmful." It creates textural qualities that exemplify the contrast between light and shadow.

The constant demolition makes it difficult for the Gulf cities to preserve and similarly develop into historical sites. Apart from earthen structures, not much is considered worthy of retaining. It is always too soon or too recent for structures to be 'historical' or significant enough, meaning not many make it through to the years where they are historically worthwhile. Though there are anomalies, individuals, and institutions advocating for preserving modernist structures as they play a role in forming the existing nation-states, the impact is not at an urban scale.

Accepting that demolition, as undesirable as it may be, will persist, its outcomes are used to build timeless structures. The rubble forming the trusses is only processed to the necessary degree, with planar cuts transferring load across chunks. They retain the roughness to celebrate their circularity.

19 Preisinger, "Linking Structure and Parametric Geometry."

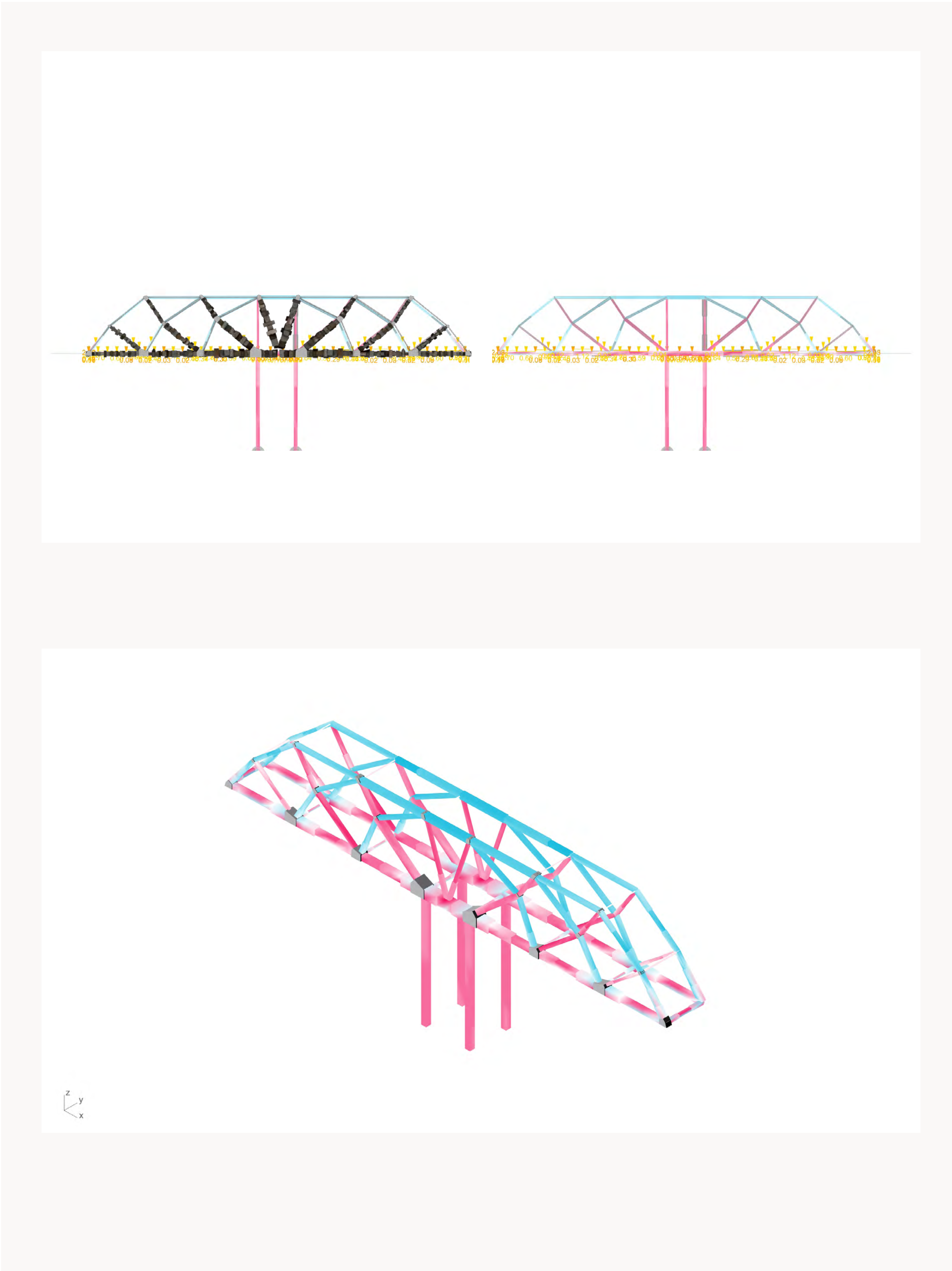


Fig 56.   Digital Structural Analysis for cross sectional area information

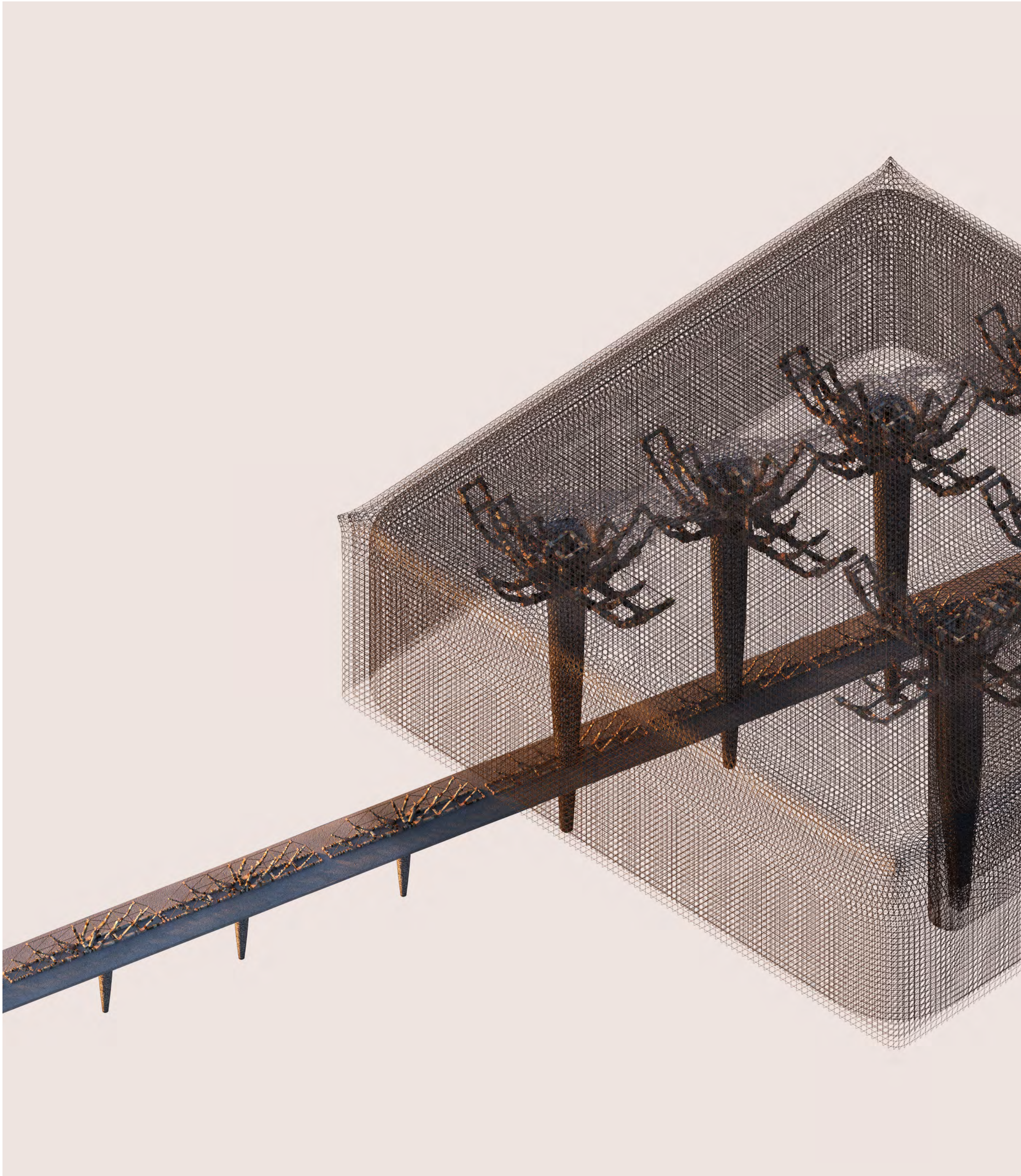
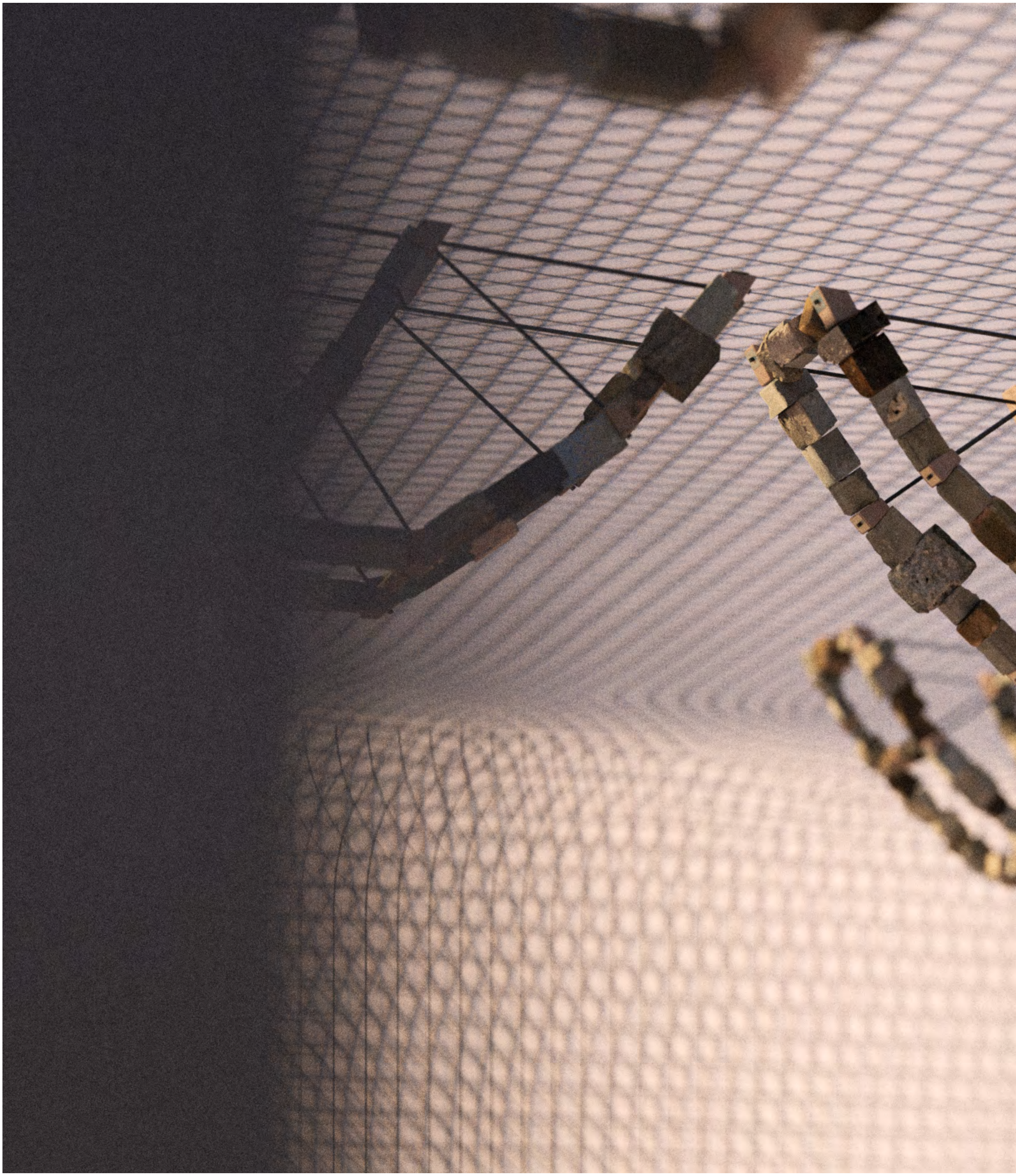


Fig 57. Muharraq Pier Structural elements including the Roof Trusses, Pier Trusses and Carbon Fiber Veil



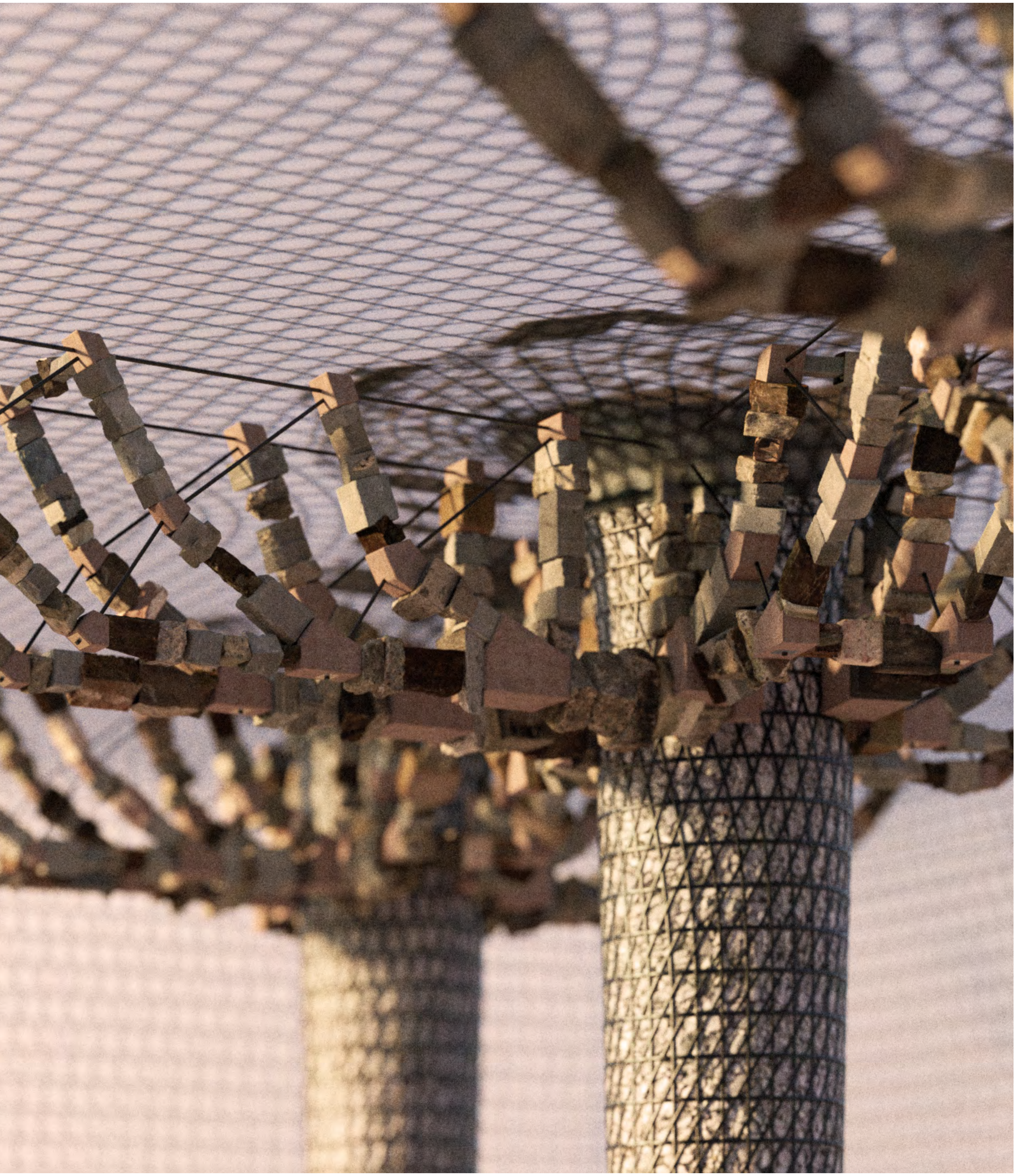


Fig 58. Rubble Truss

Roof Structure

Fig 59. Prototype of Post tensioned truss

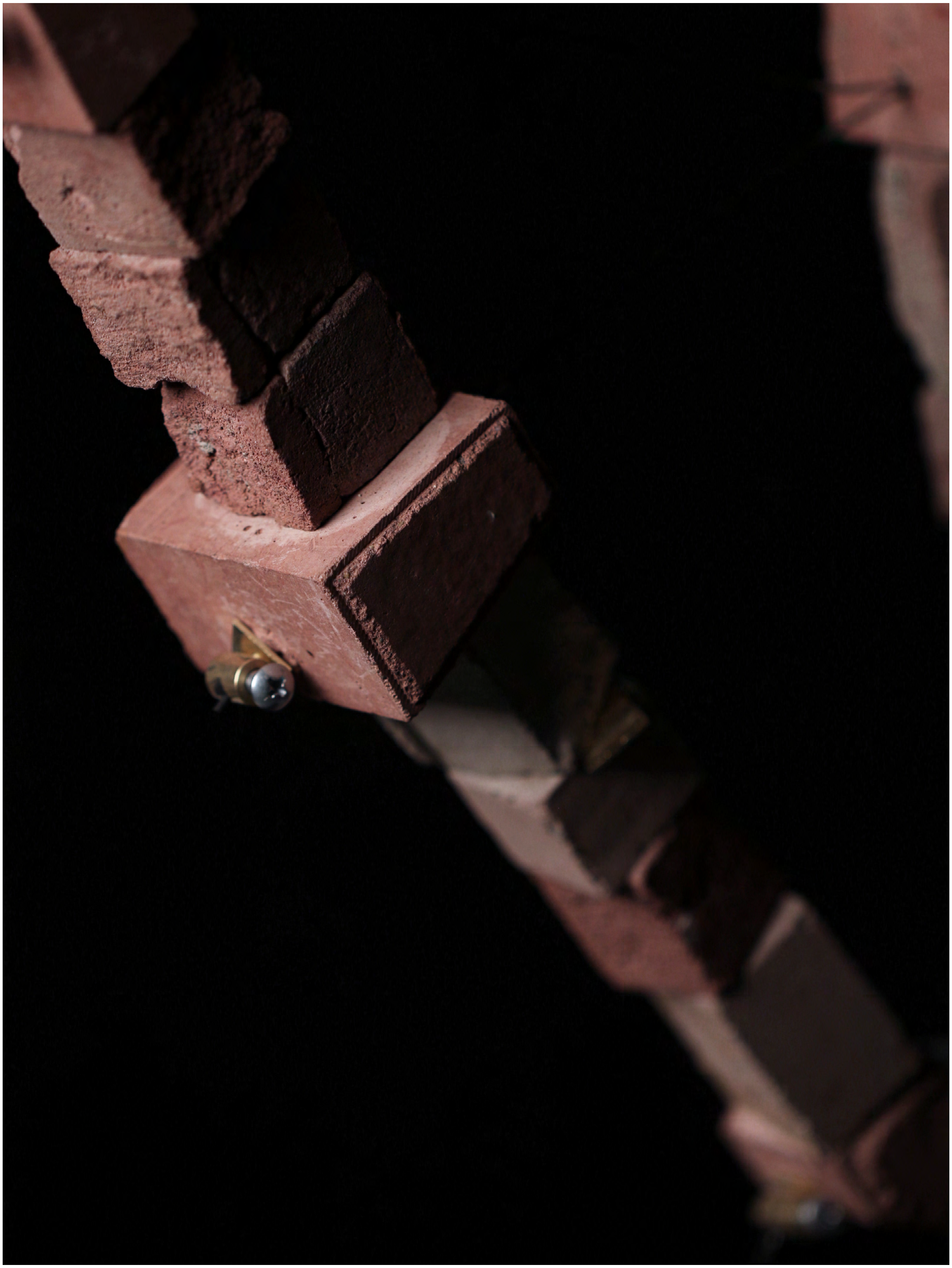


Fig 60. Detail of one of the angled 'orienting' pieces

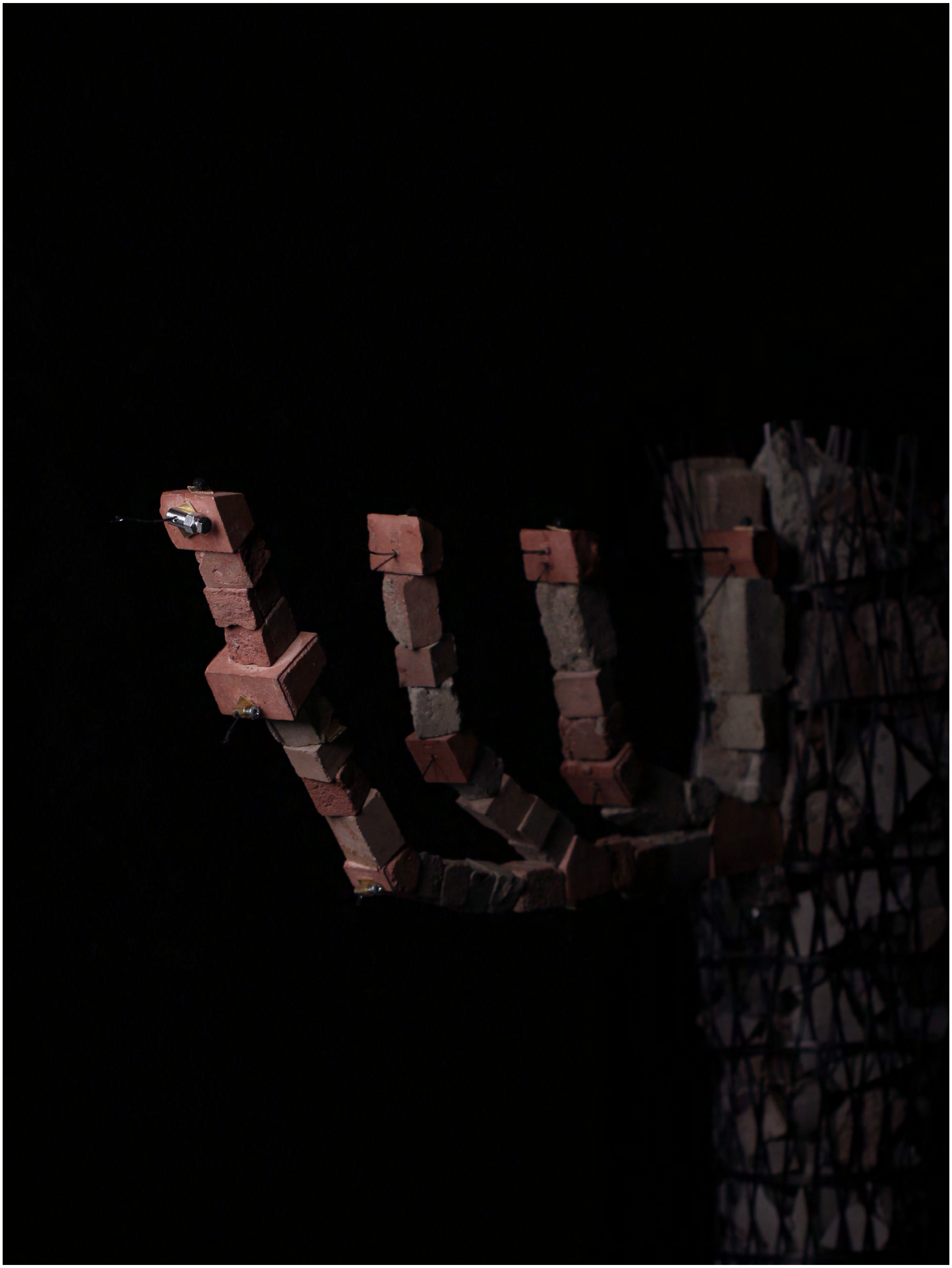


Fig 61. Branching combression members

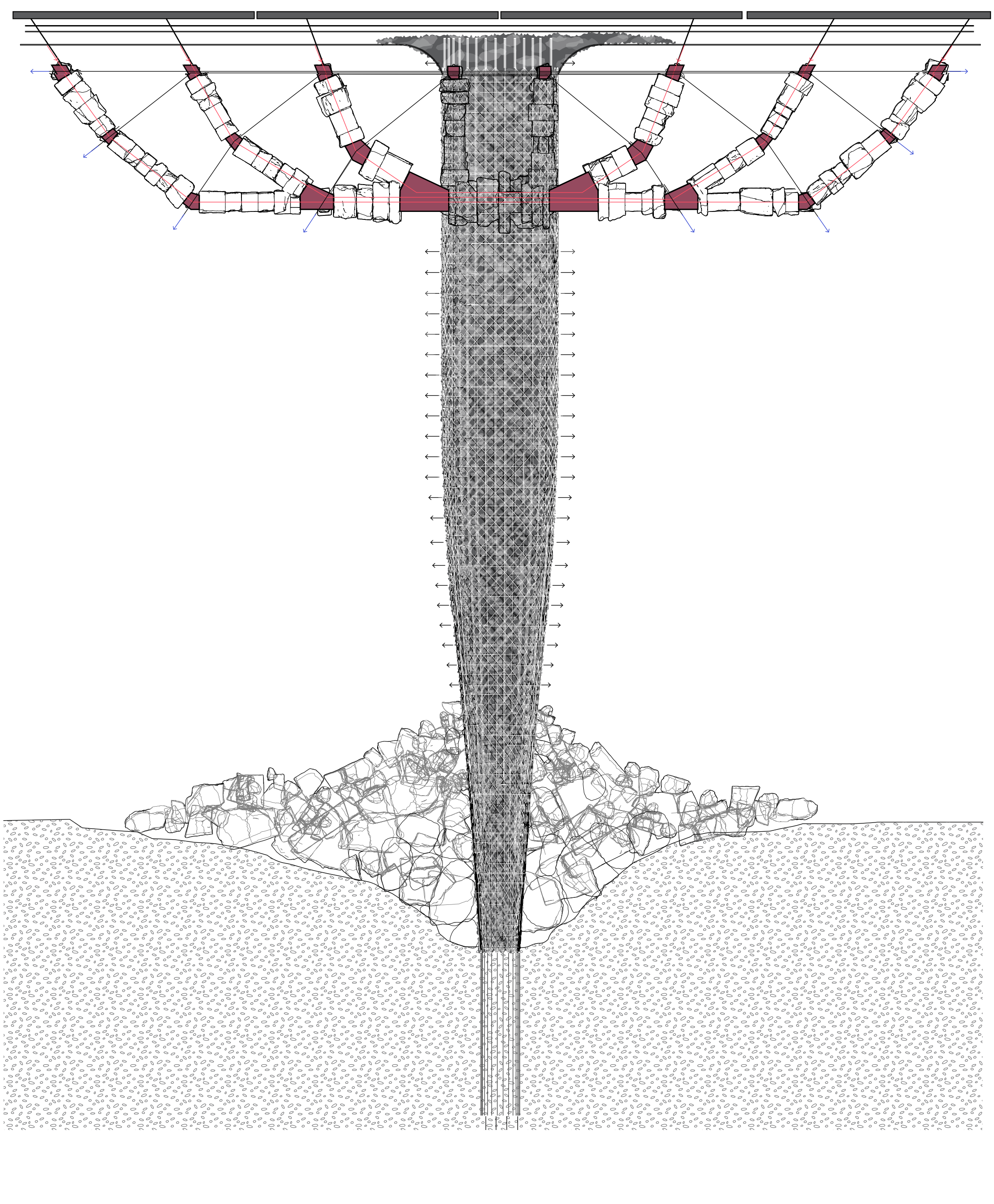


Fig 62. Section drawing through the system from roof

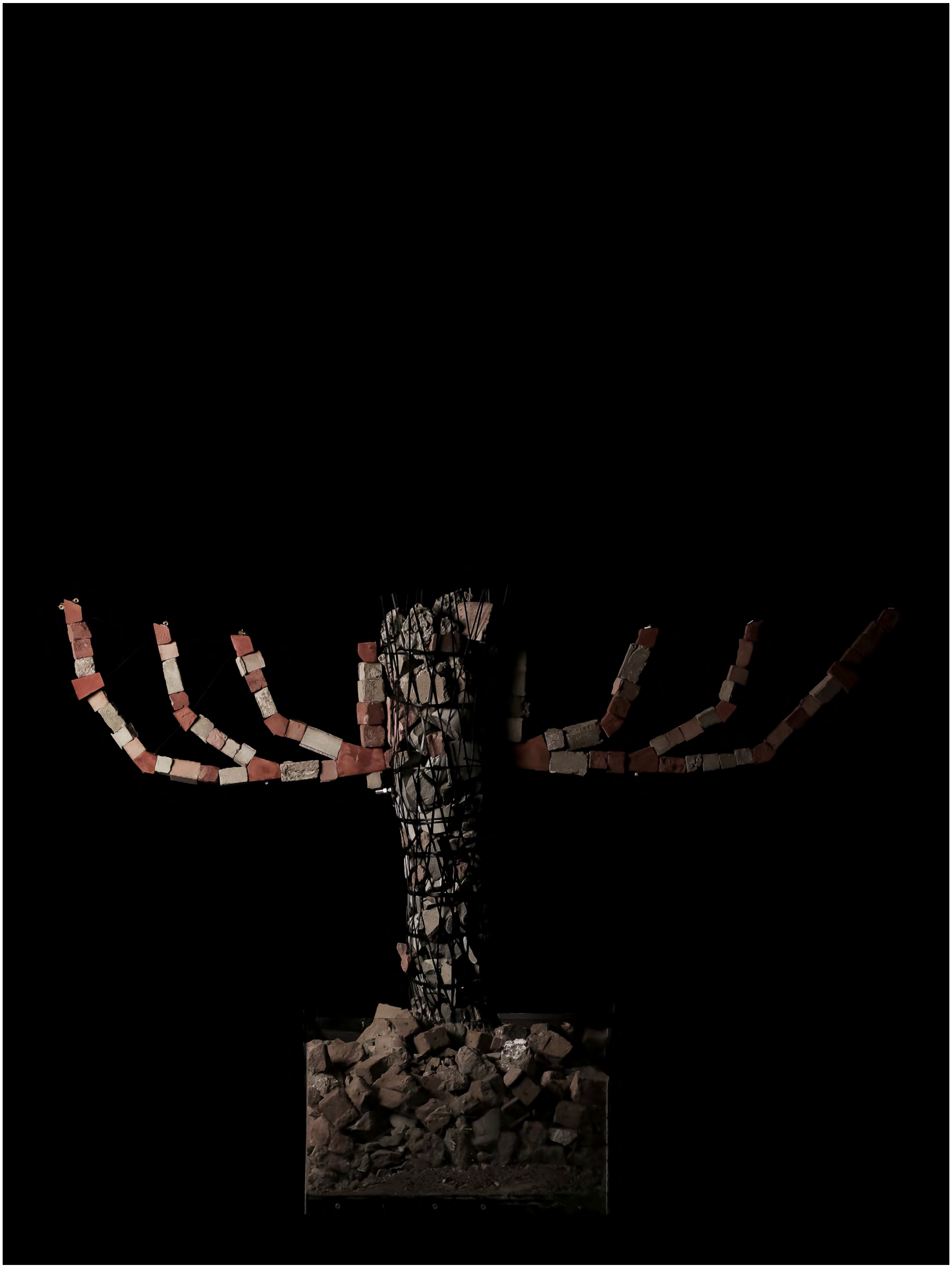


Fig 63. Sculptural protoype with 'floating' elements.

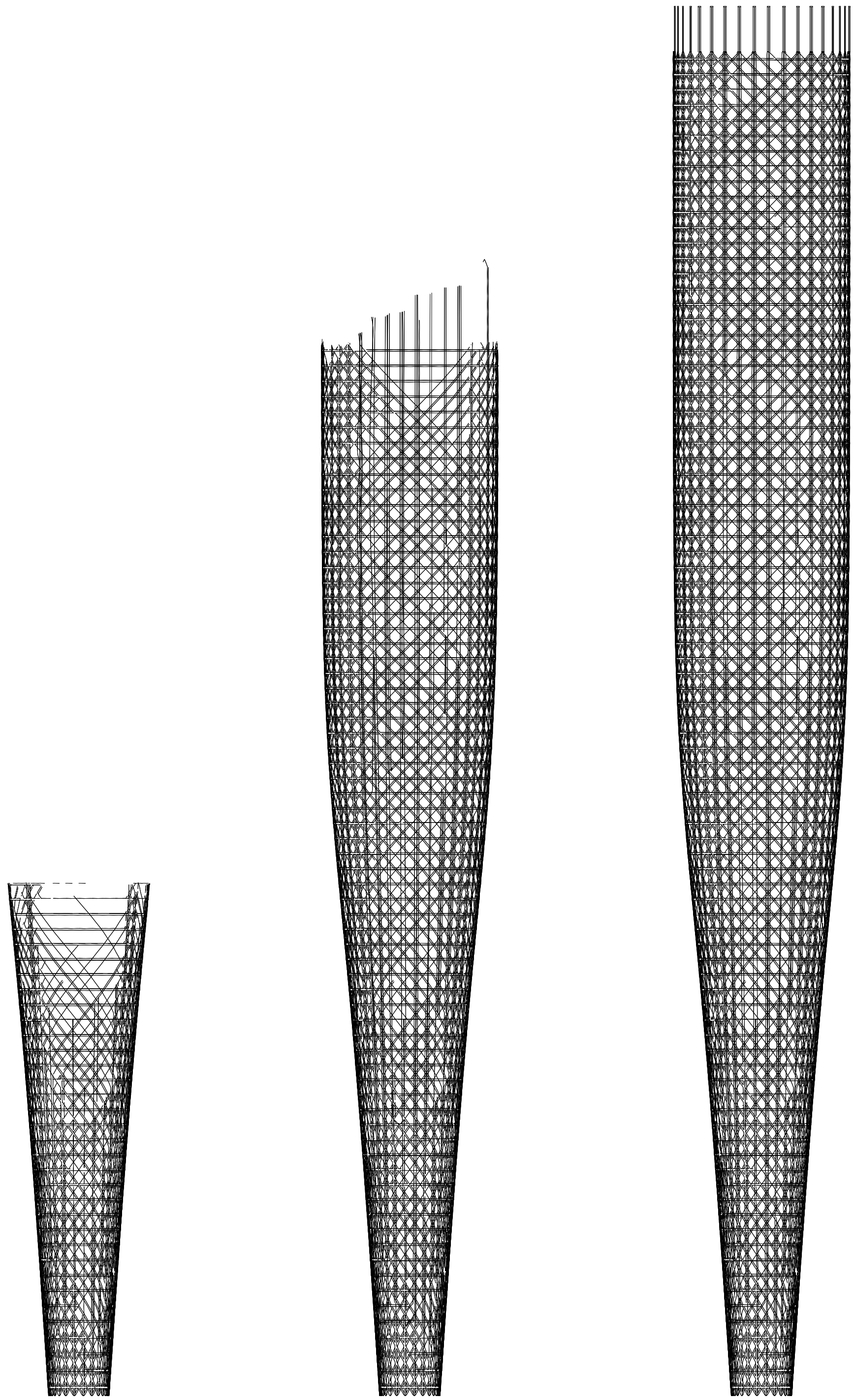


Fig 64. Assembly Sequence of Carbon Fiber Woven elements. Splicing is used, wherby ends are overlapped to join the parts as they rise.

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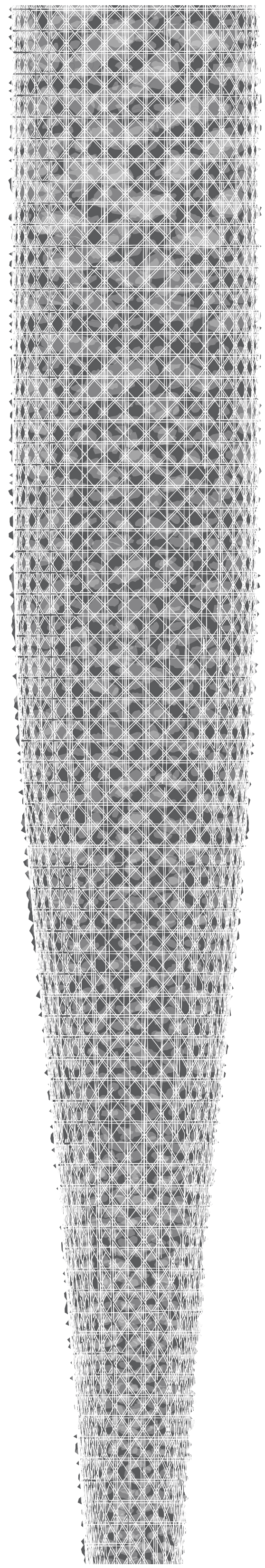

Fig 66. Triaxially Woven Carbon Fiber Column. Jam packed with concrete rubble from previous projects.

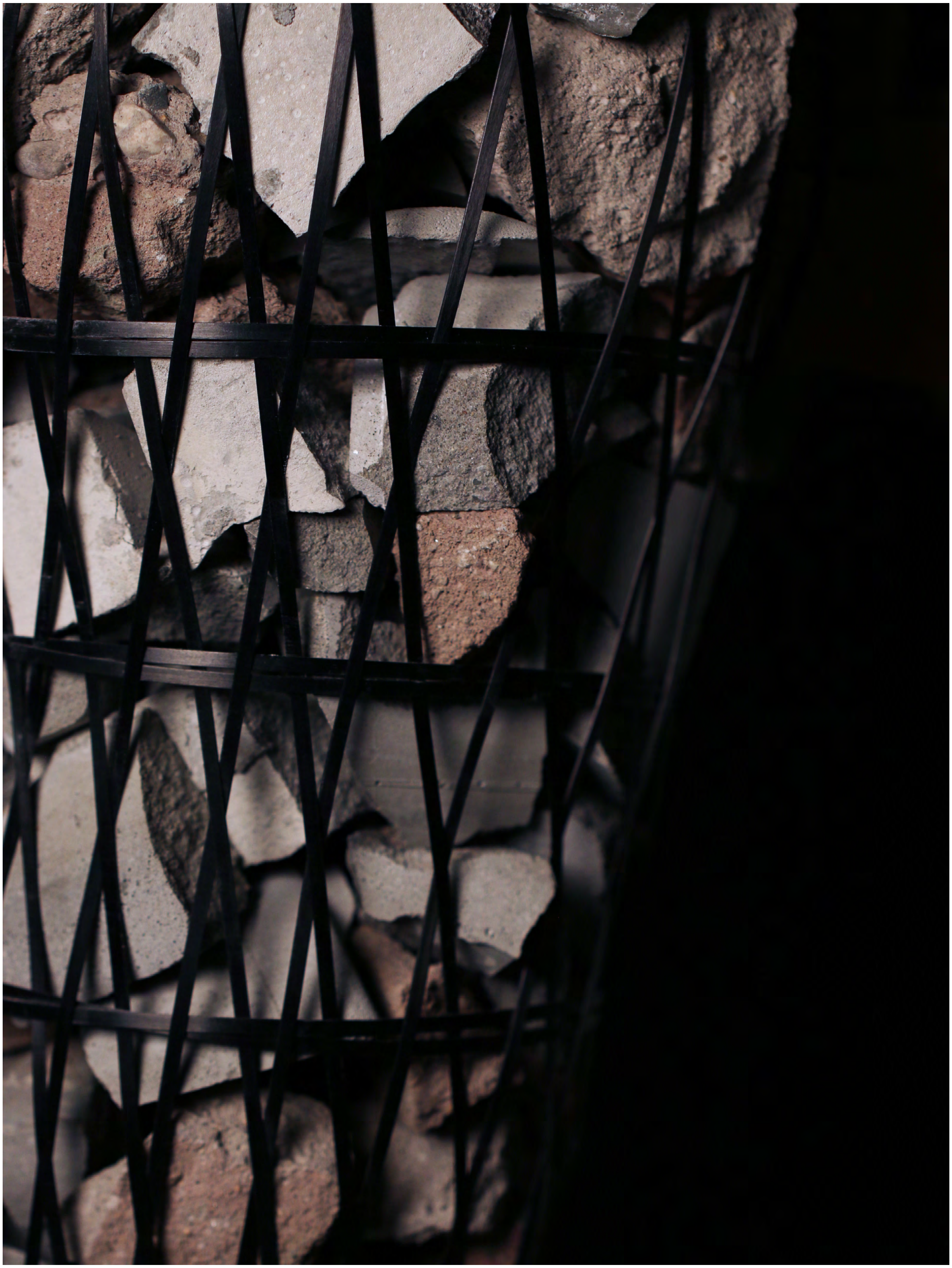

Fig 67. Close Up of Woven Cured Carbon Fiber strips and Concrete Rubble .

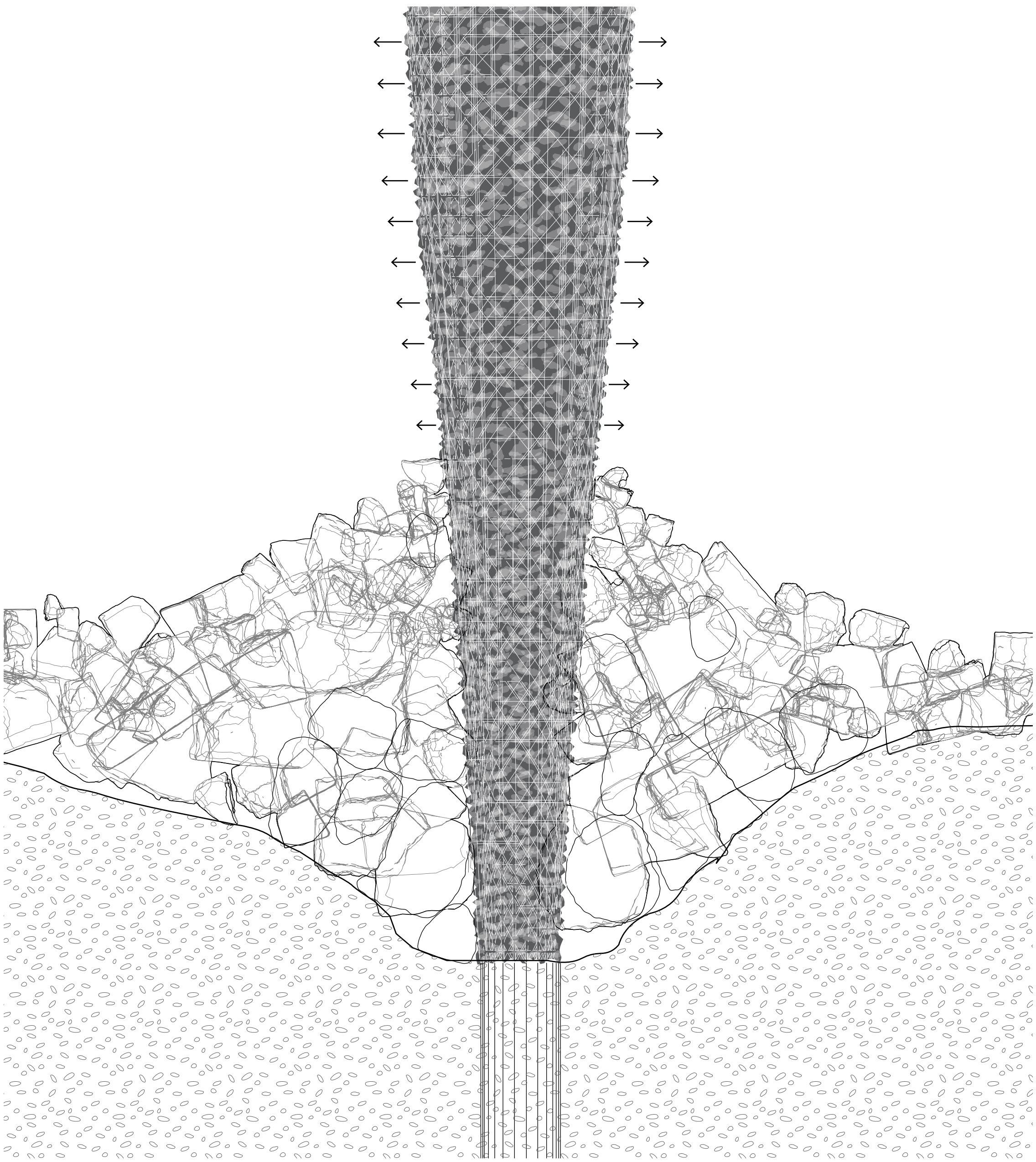

Fig 68. Conceptual Foundation Drawing

Fig 69. Close Up of Conceptual Sculpture Foundation.

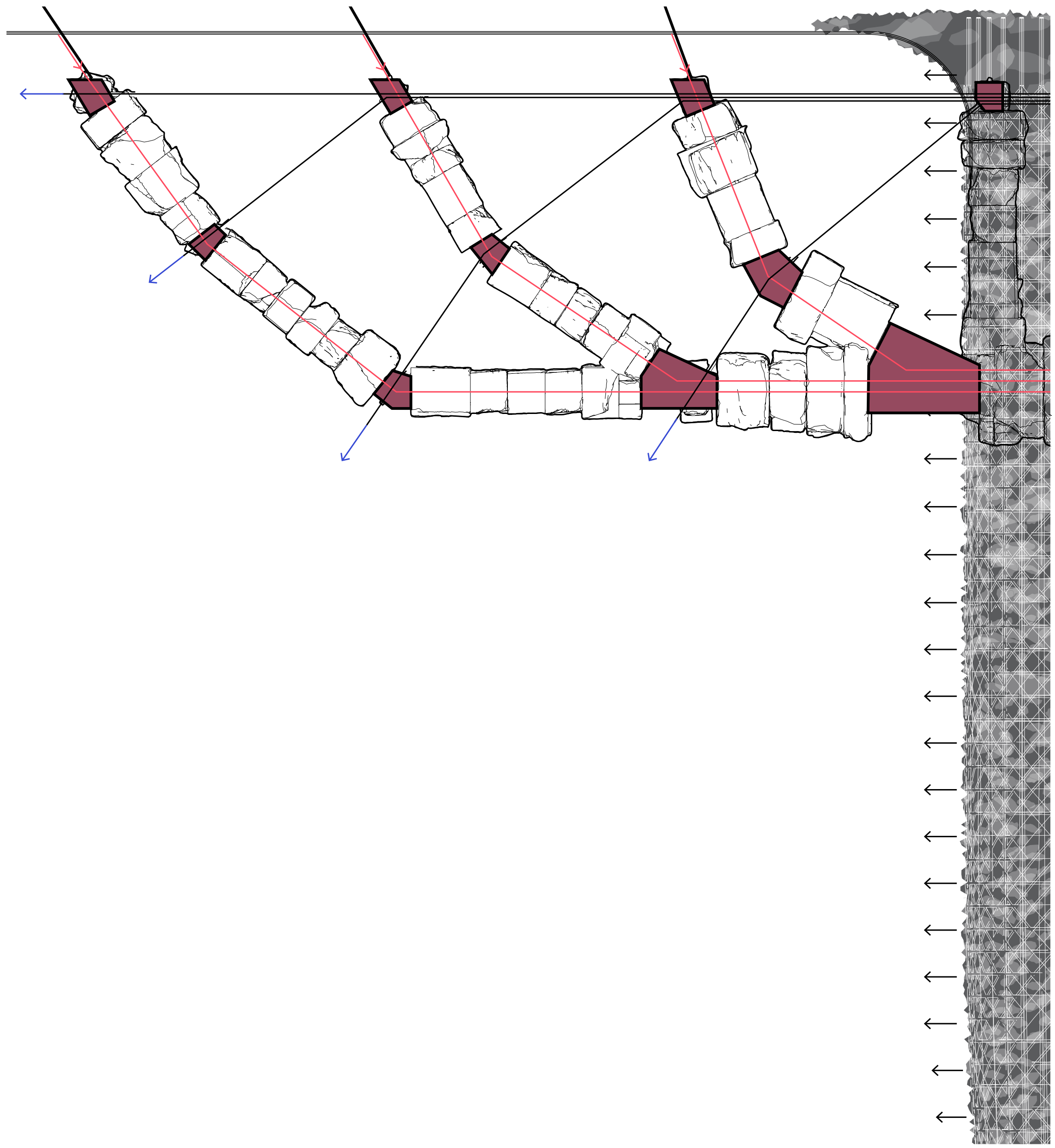

Fig 70. Drawing revealing the cables within the truss. In Red, the Post Tensioning Cables tying the rubble together, In Blue, the Tension Carbon Fiber Members.

Fig 71. Close up of Joints Orienting the Rubble in the Planned Directions to Form the Overall Truss Topology.

Pier Structure

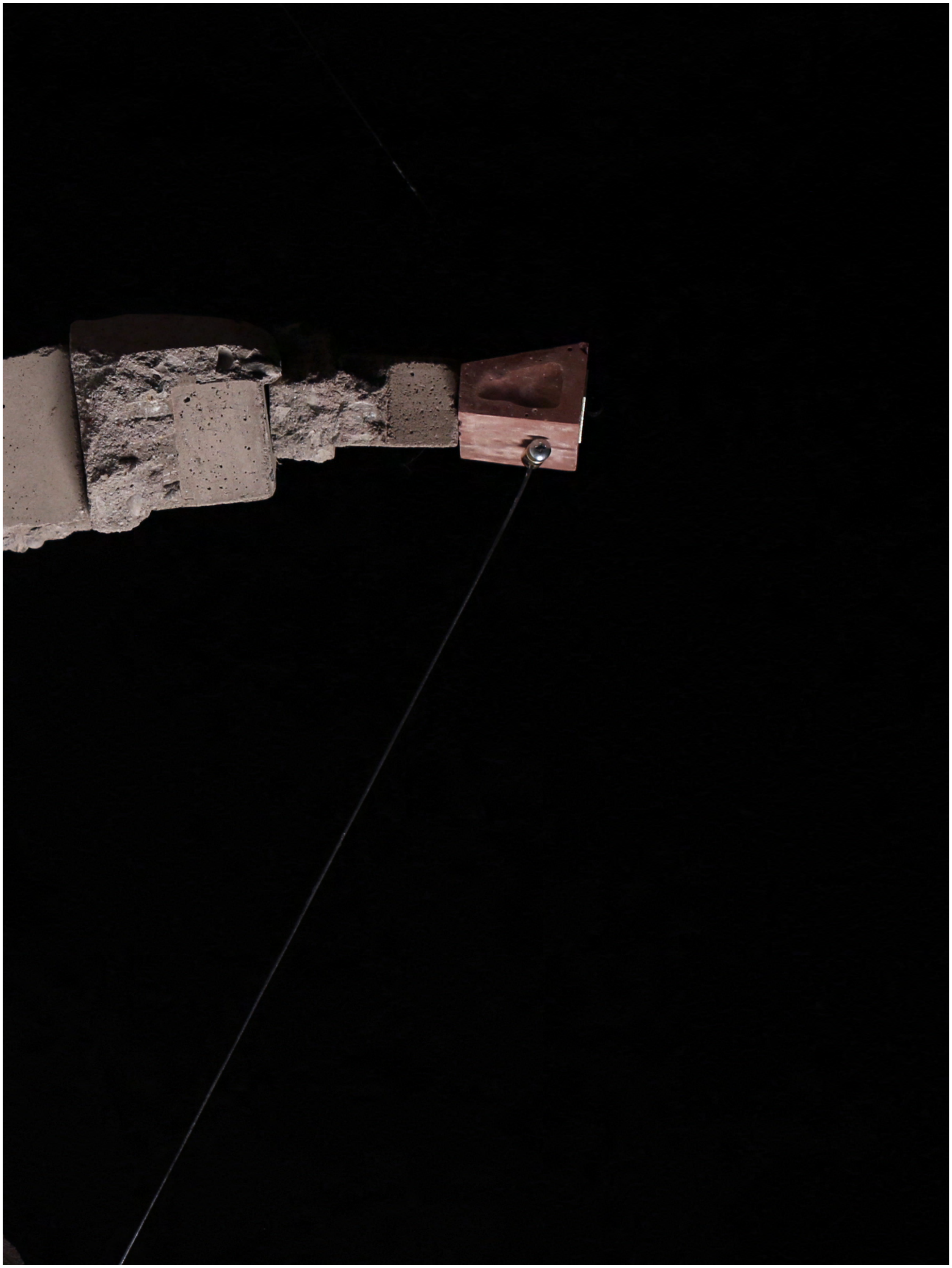

Fig 72. Detail of custom cast end piece.

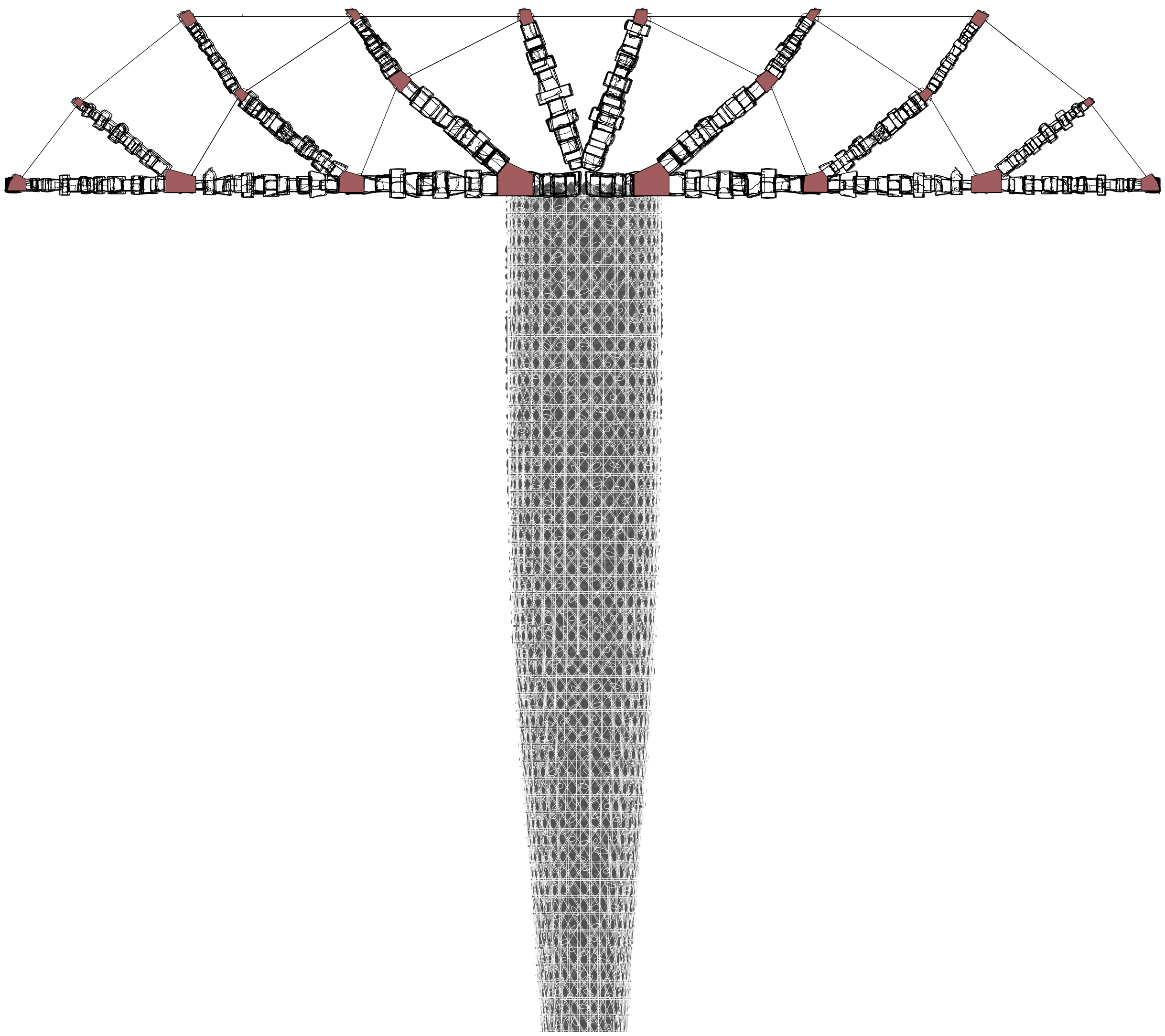

Fig 73. Drawing of Cantilvering Pier Assembly

Fig 74. 1:5 Scale Model of Pier section.

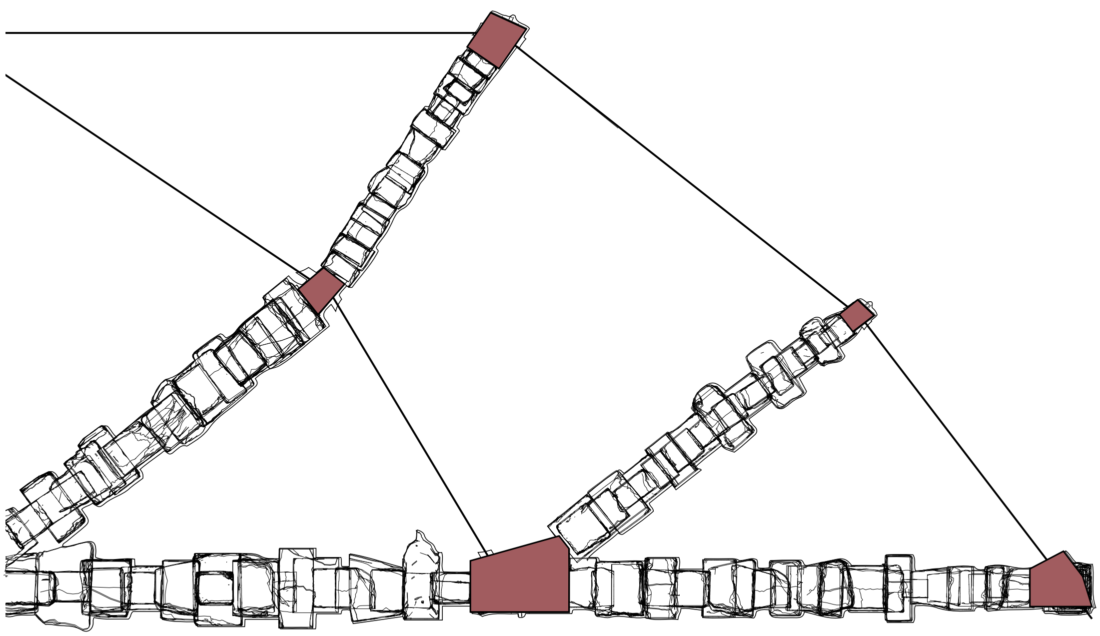

Fig 75. Drawing of intended Pier Structure Topology with ‘Orienting Joints’

Fig 76. Prestressed Concrete rubble acting in compression, cable in tension.

Conclusion

This thesis presents a method and approach for the Gulf's construction industry. The method is a designed process and innovative means of combining concrete and carbon. The approach, a resourceful attitude on working with strictly local materials and existing industry infrastructure, finding opportunities to develop expertise from within, and leveraging materials not only for their structural value but also the autonomy they entail. The proposed constructive system operates in tandem with exemplary craft practices where technique may be transferable.

By viewing concrete rubble fragments as gems that are valuable fruits of labor, a deeper appreciation for the embodied hard work within the structures we inhabit is called for. Incorporating robotic and digital fabrication methods, which alleviate physical efforts, prompts a conversation on labor issues.

Moreover, it investigates how carbon fiber may enter the mainstream regional construction industry. The material has immense potential to achieve technical feats for its resilience in such a climate. Here, it complements an undervalued resource, feeding into many hybrid solutions to the industry's issues.

Considering the context and history, the approach taken is not nostalgic for pre-industrial methods. It accepts the modern history of the place and its people's desires but seeks to reassess the industry with a nationalist take.

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Fig 11. Image from Arabian Gulf Archive.

Fig 12. Image by Latifa Alkhayat.

Fig 13. Image by Latifa Alkhayat based on resourcetrade.earth.

Fig 14. Image by Gulf Institute.

Fig 15. Image by Latifa Alkhayat

Fig 16. Image by Latifa Alkhayat based on Google Maps.

Fig 17. Image by The National.

Fig 18. Image by The National.

Fig 19. Image by Latifa Alkhayat.

Fig 20. Image by Latifa Alkhayat.

Fig 21. Image by Latifa Alkhayat.

Fig 22. Image from Aramco World Archive.

Fig 23. Image from Aramco World Archive.

Fig 24. Image by Latifa Alkhayat.

Fig 25. Image by Latifa Alkhayat.

Fig 26. Triaxially woven sliced palm tree fronds and rattan

Fig 27. Image by Latifa Alkhayat based on the General Classification of Fibers by Jawaid and Abu Khalil 2011)

Fig 28. Image by Latifa Alkhayat.

Fig 29. Image by Latifa Alkhayat.

Fig 30. Image by Latifa Alkhayat.

Fig 31. Image by Latifa Alkhayat.

Fig 32. Images by Helene Binet

Image by Roland Halbe

Image by John Orr.

Image by Clement Guillaume.

Image by Structural Xploration Lab.

Image by Gramazio Kohler Research.

Fig 33. Image by Latifa Alkhayat.

Fig 34. Image by Latifa Alkhayat.

Fig 35. a- Image by Anwar Hussein, Getty Images.
b-Image by Tim Graham, Getty Images.

Fig 36. Image by Latifa Alkhayat

Fig 37. Image by Latifa Alkhayat.

Fig 38. Image by Latifa Alkhayat and image from Keystone/Hulton Archive recoloured.

Fig 39. Image by Adam Woolfit.

Fig 40. Image by Mattarjewelers.com.

Fig 41. Image by Latifa Alkhayat.

Fig 42. Image by Latifa Alkhayat.

Fig 43. Image fromBahrain Authority for Culture and Antiquities Archive.

Fig 44. Image by Cartier.com

Fig 45. Image by Cartier.com

Fig 46. Image by Latifa Alkhayat.

Fig 47. Image by Latifa Alkhayat.

Fig 48. Image by Latifa Alkhayat.

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Fig 72. Image by Latifa Alkhayat.

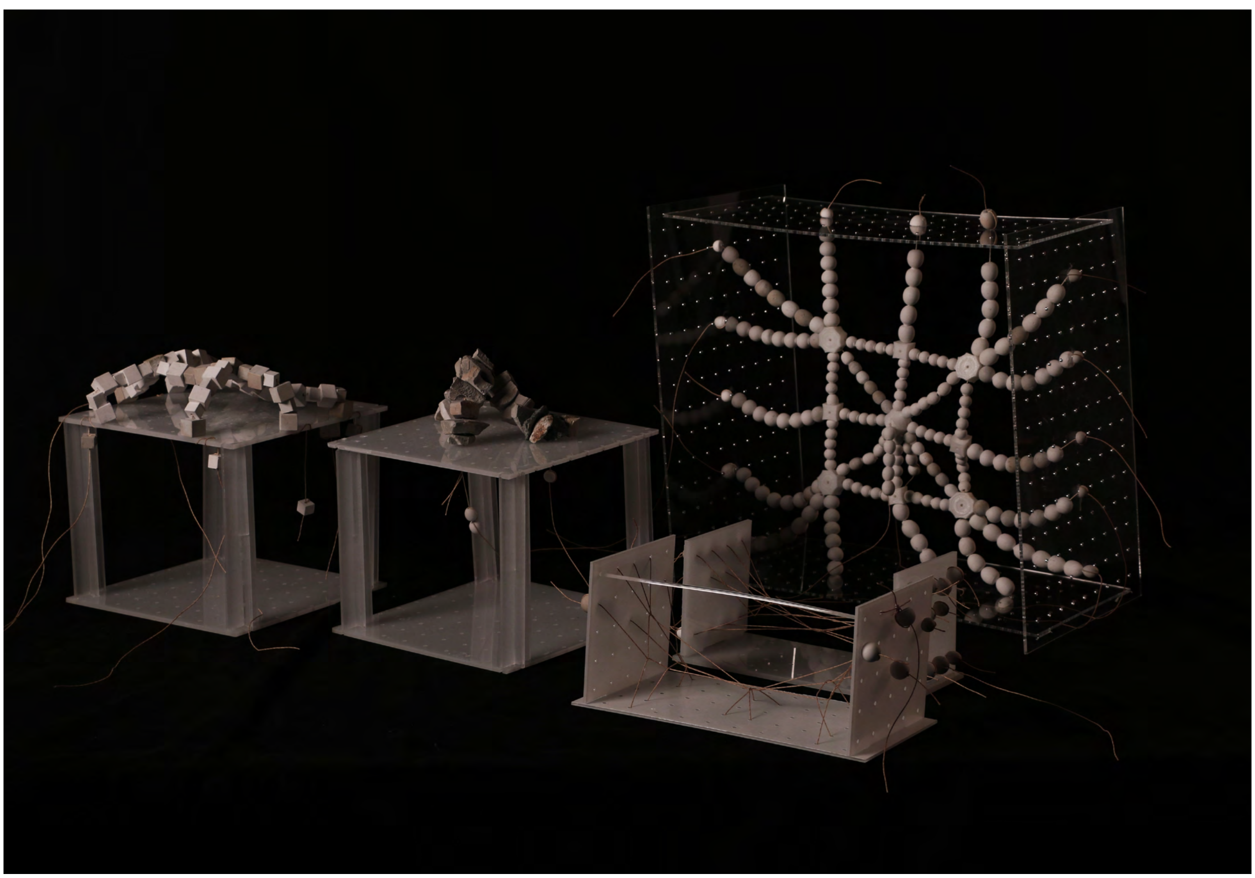
Fig 73. Image by Latifa Alkhayat.

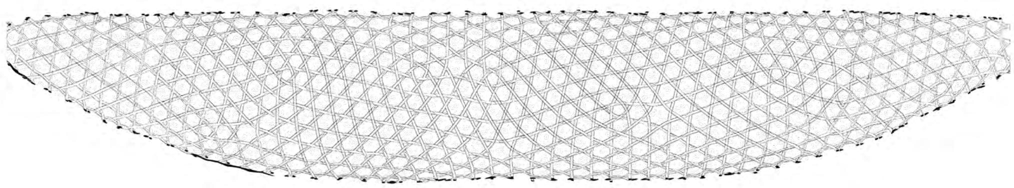
Fig 74. Image by Latifa Alkhayat.

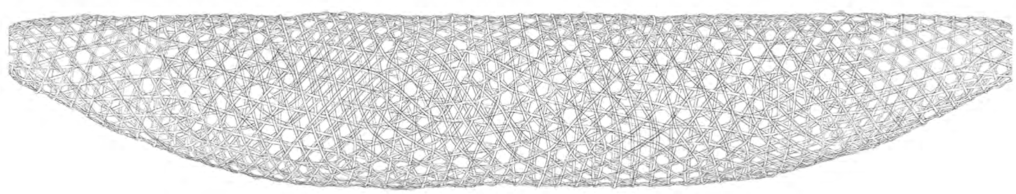
Fig 75. Image by Latifa Alkhayat.

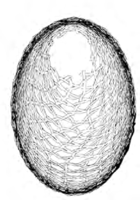
Fig 76. Image by Latifa Alkhayat.

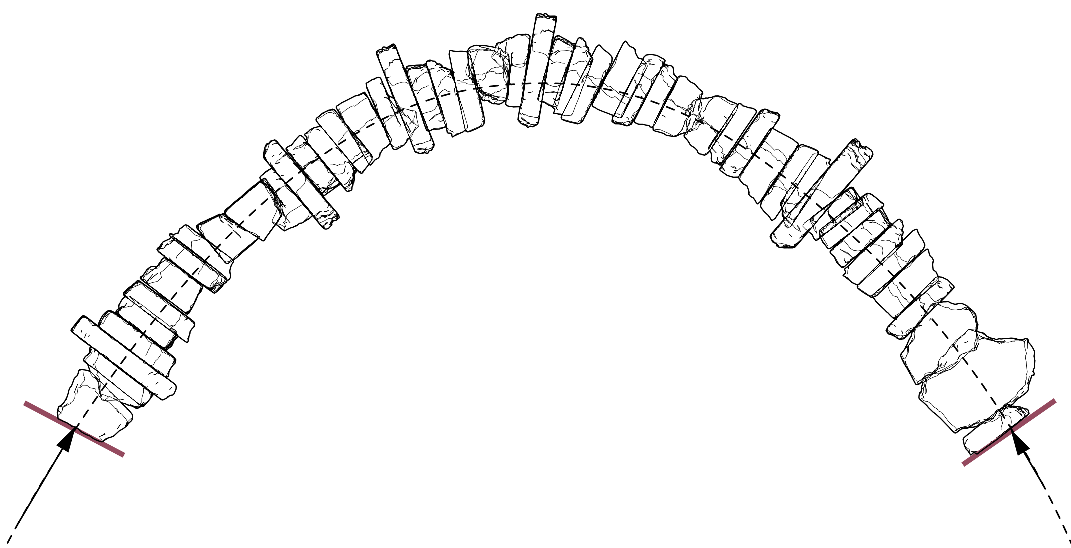
Appendix A - Physical Prototypes

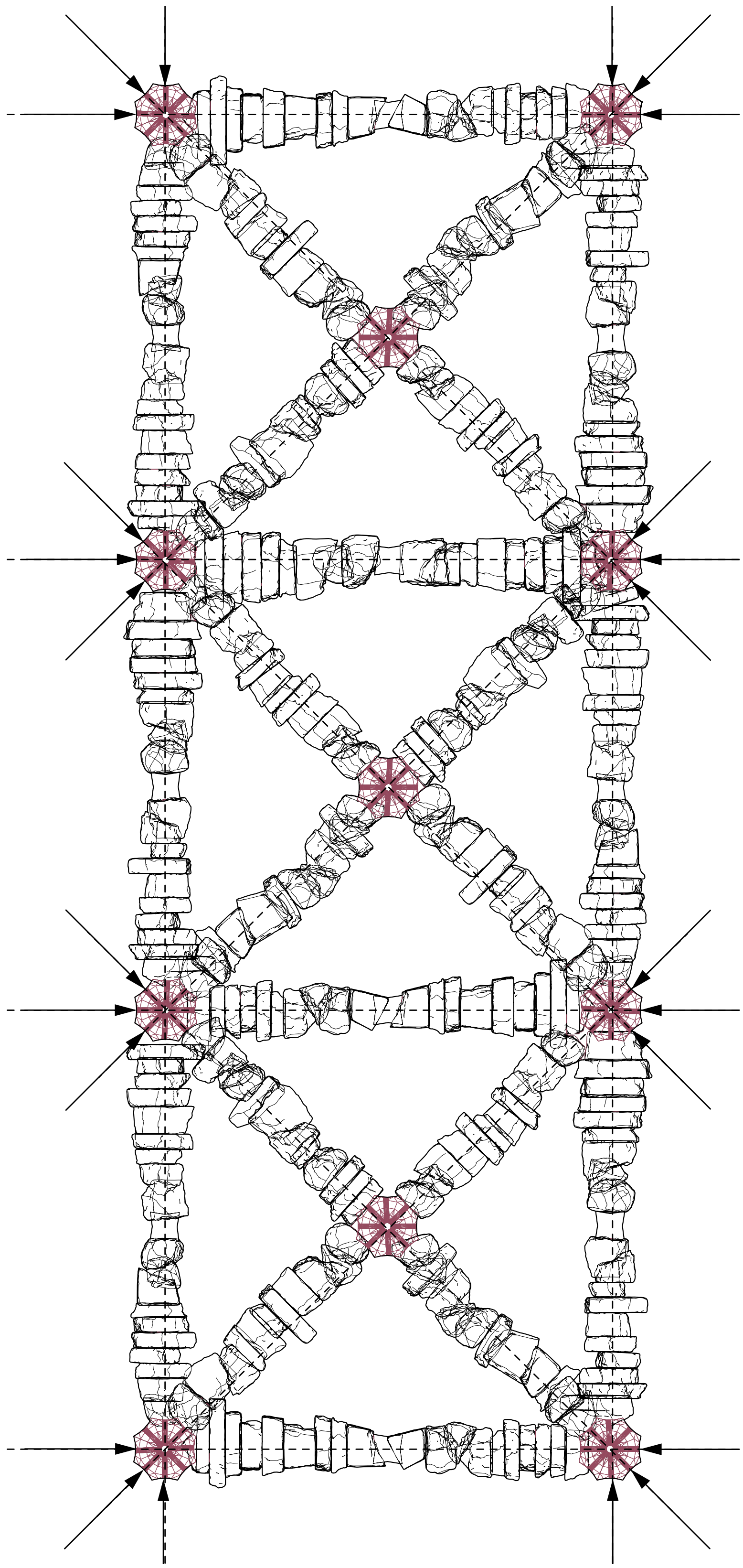


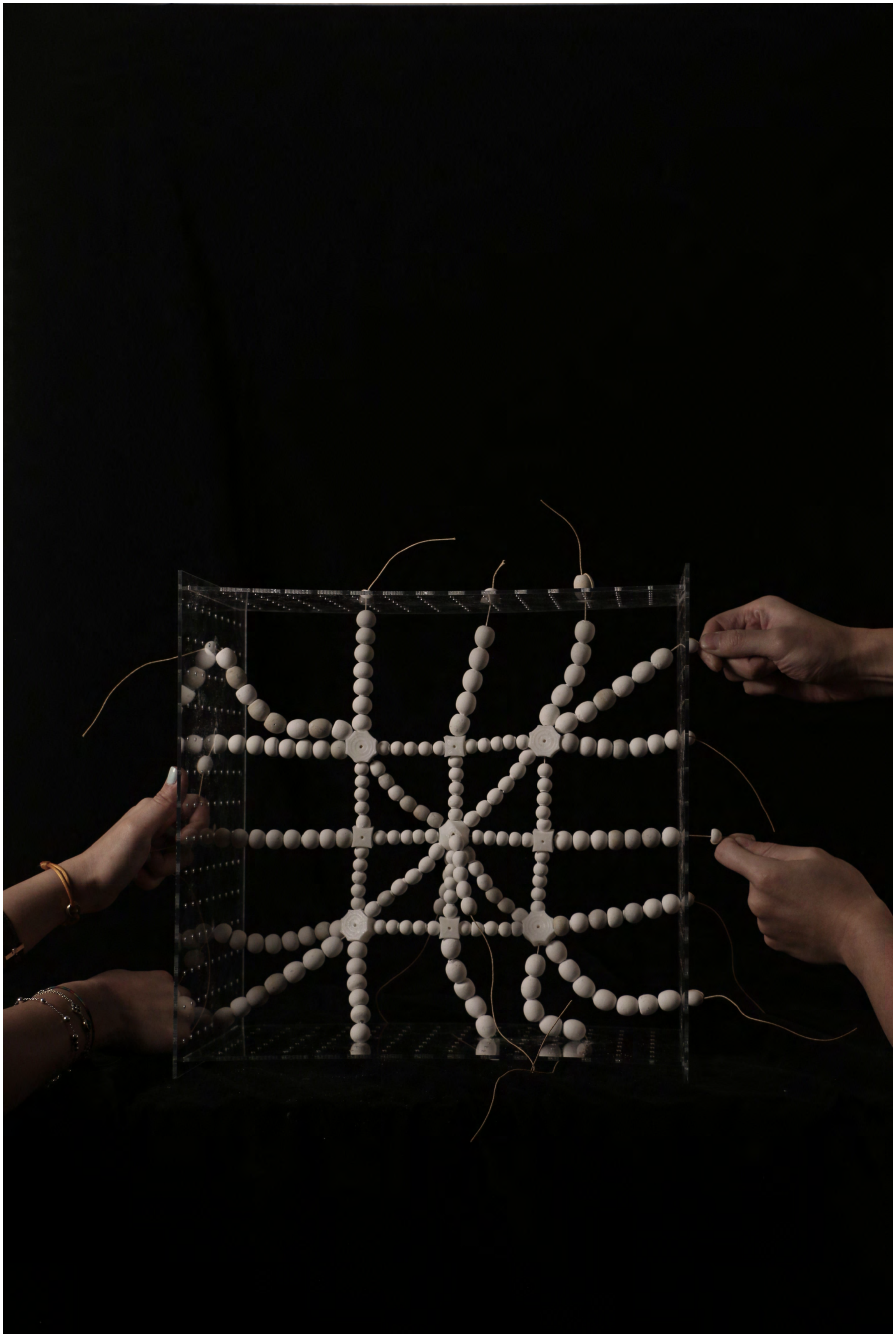




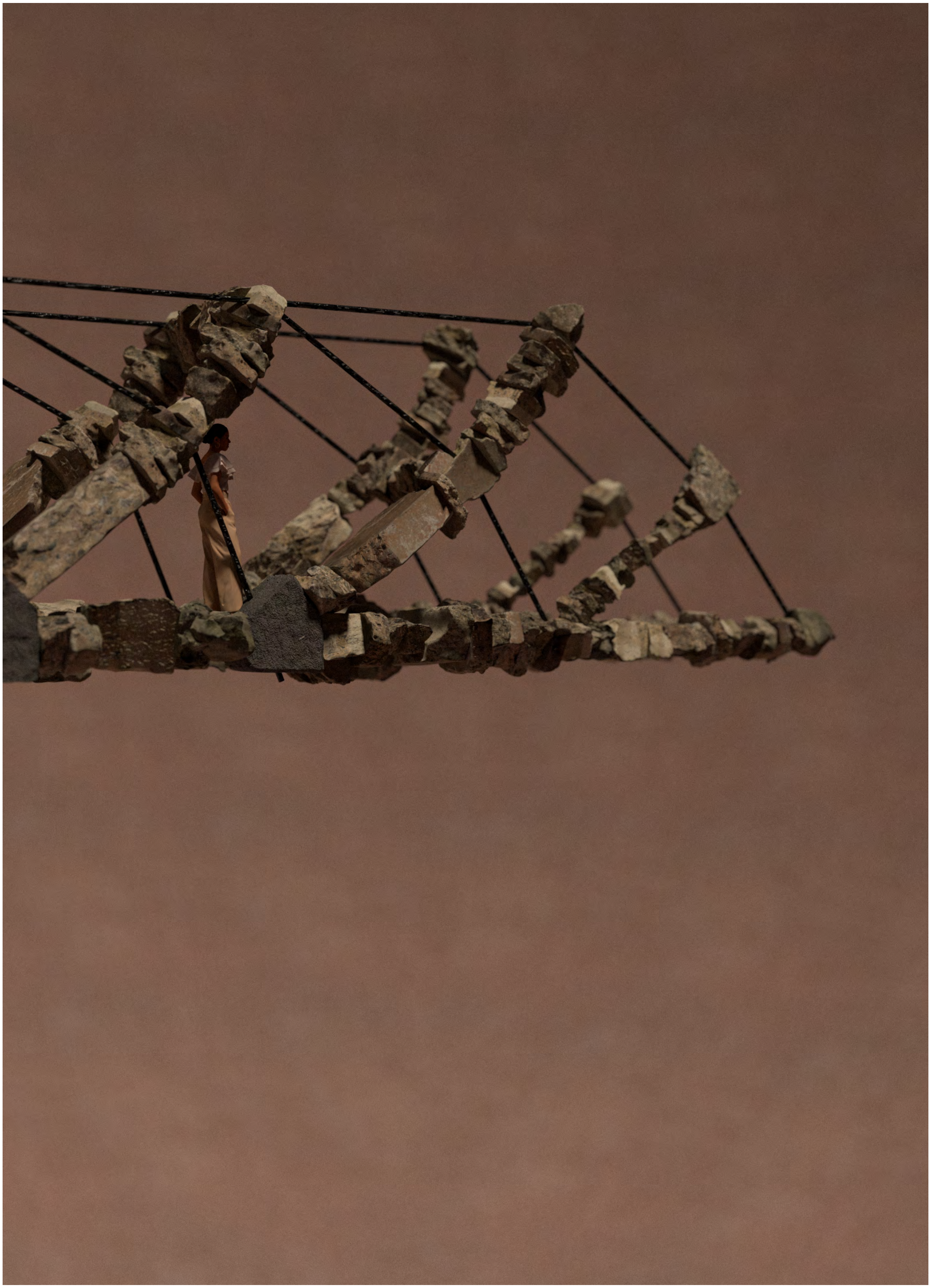


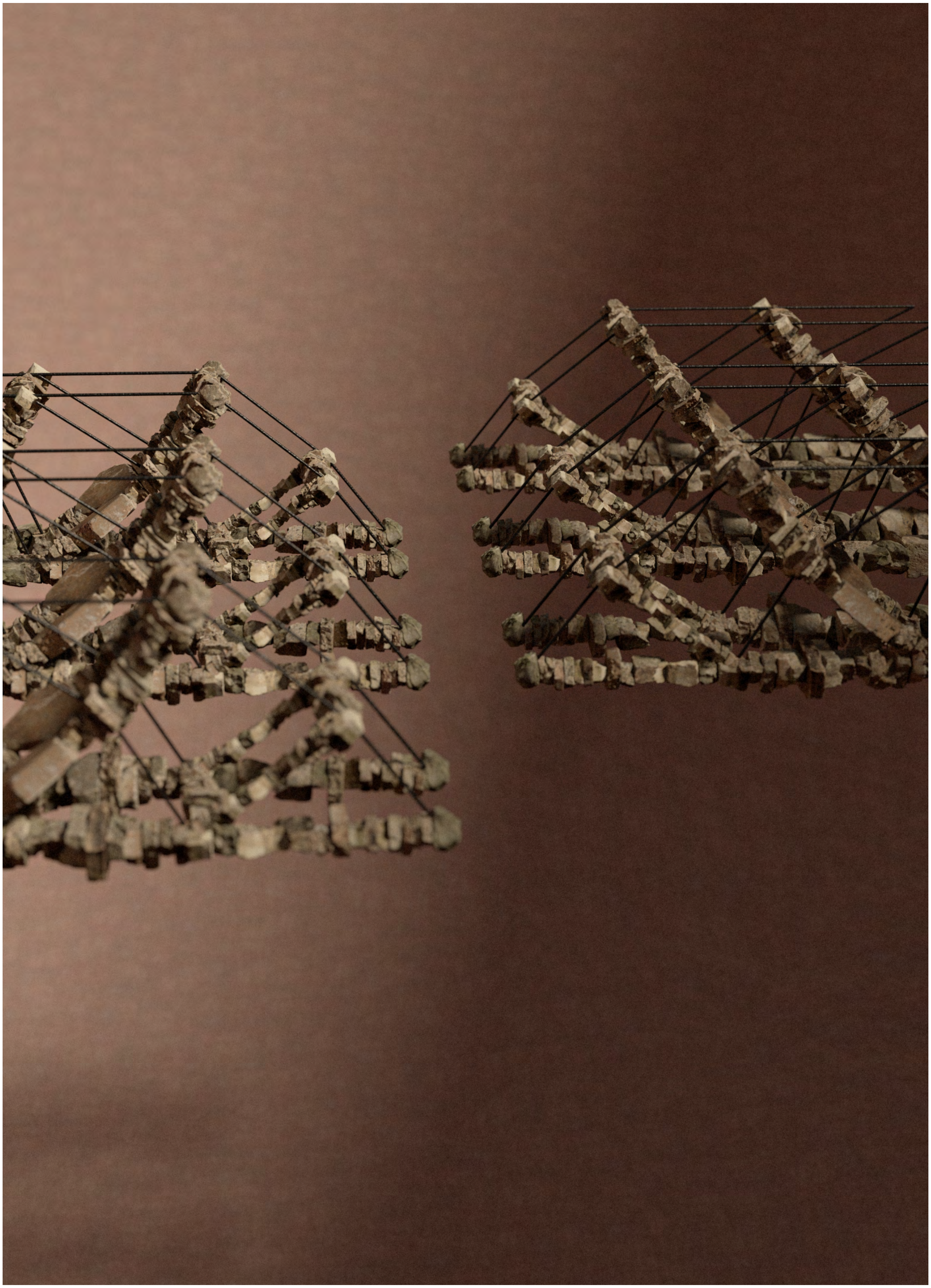


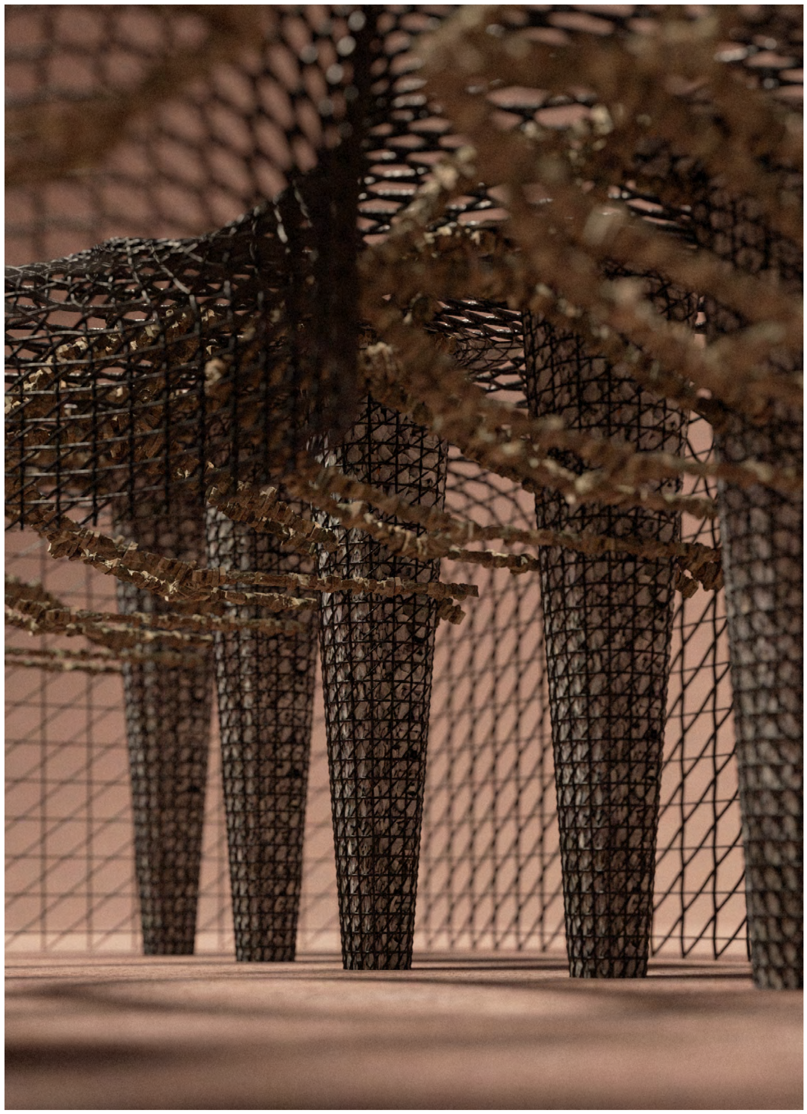


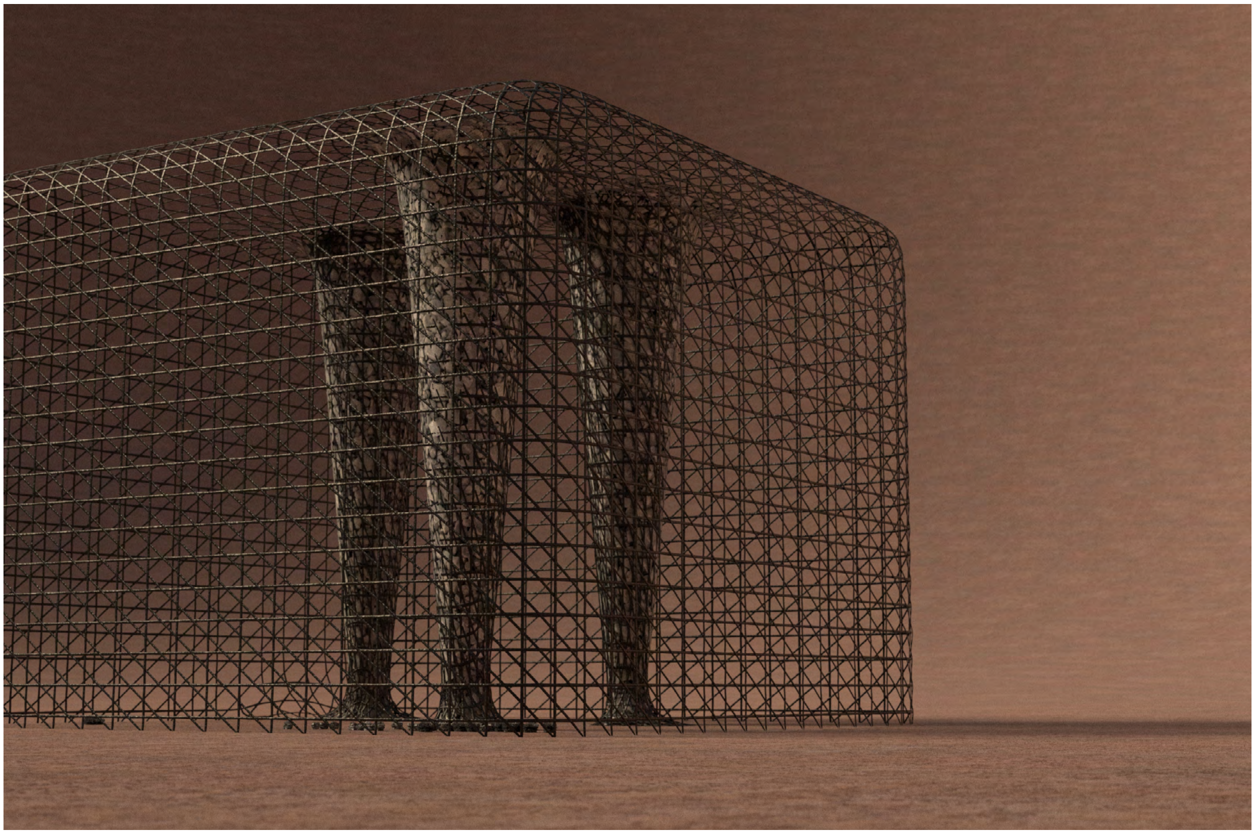


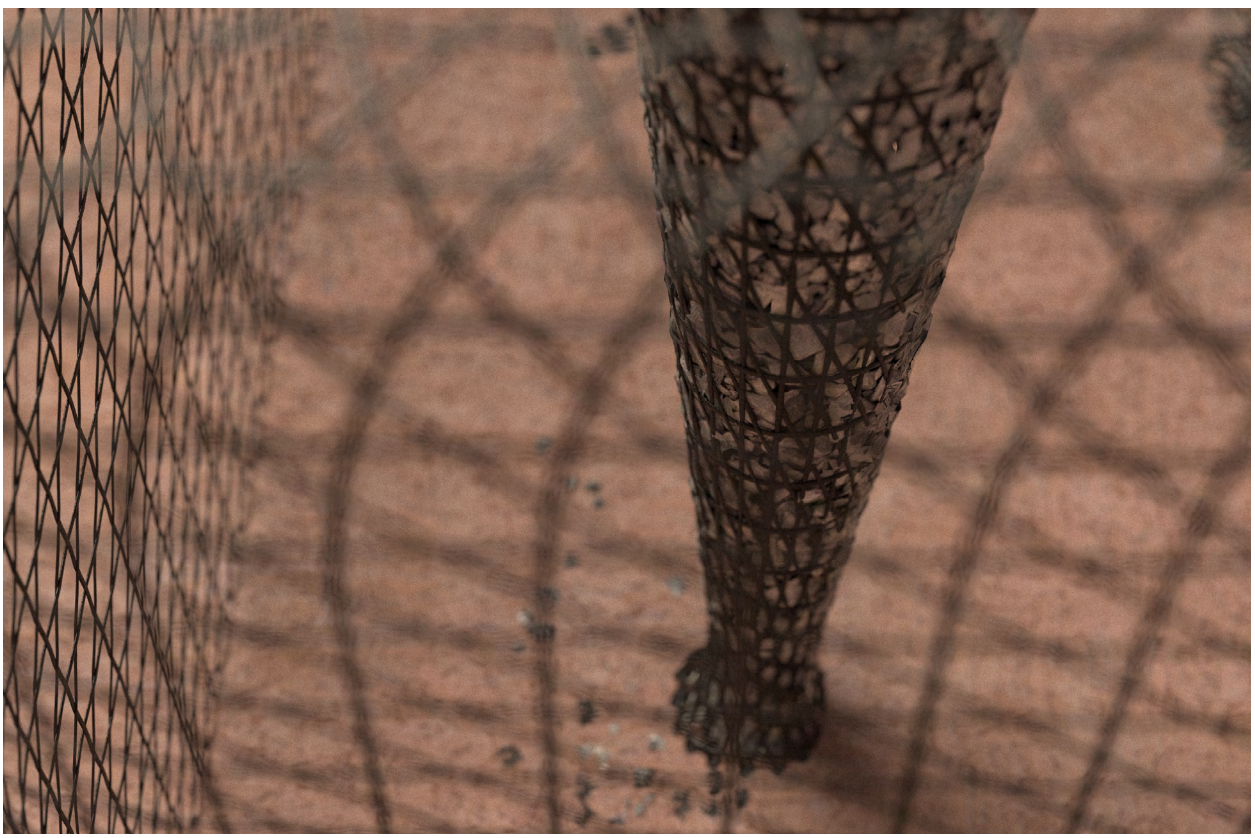
Appendix B Digital Prototypes

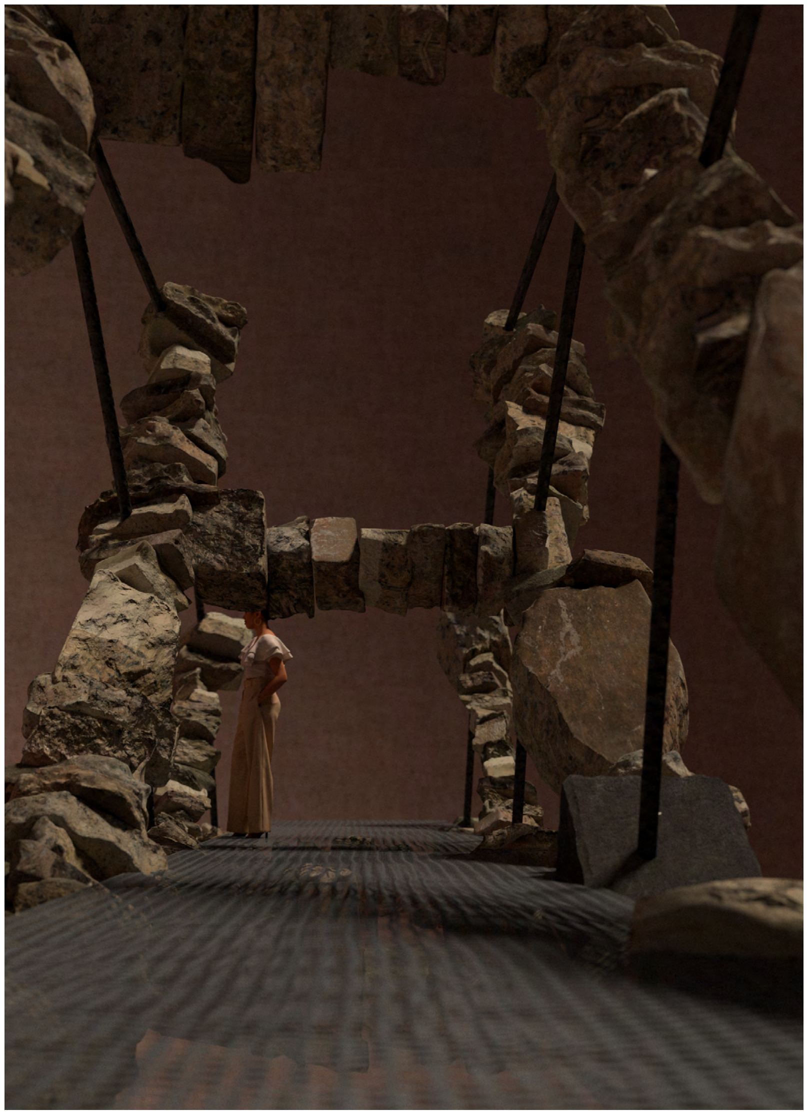


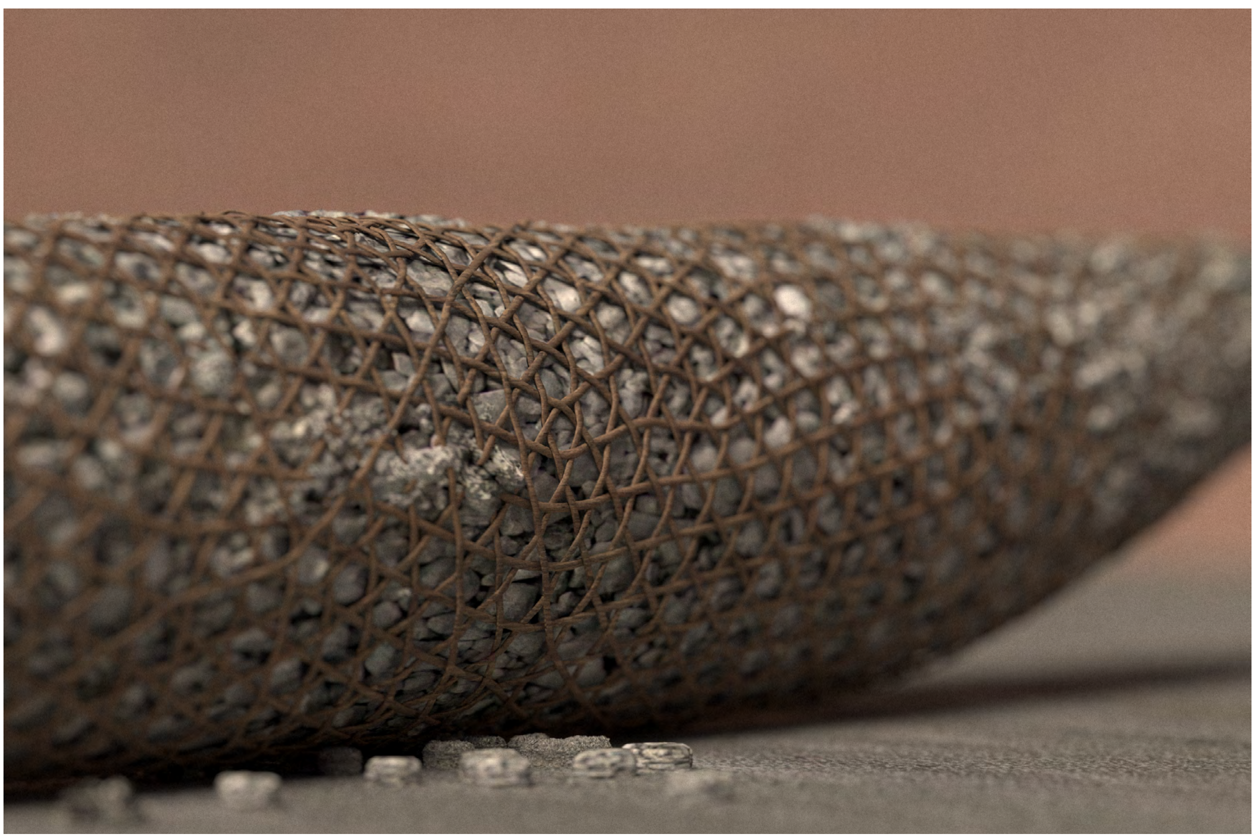


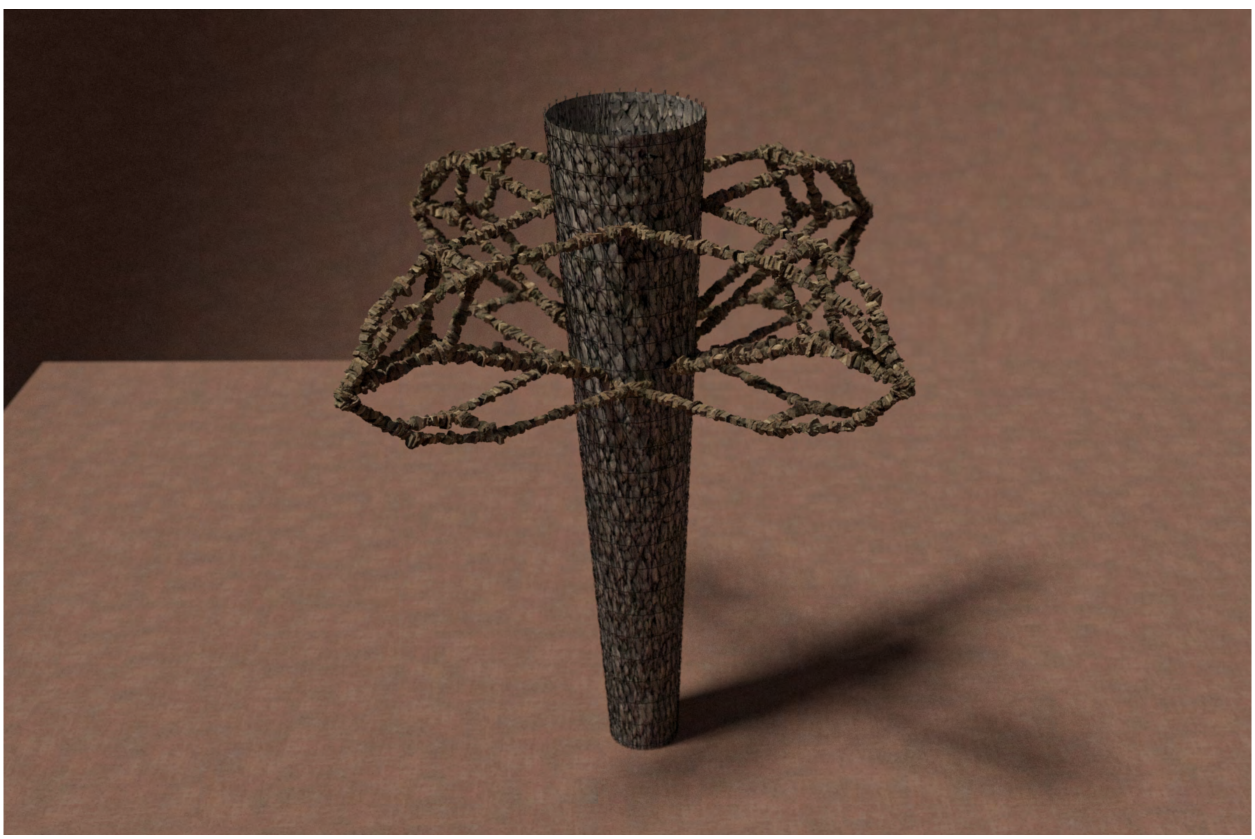












Appendix C - MArch Thesis Review

December 22nd 2022

Image by Olivier Faber

Image by MIT Communications Team

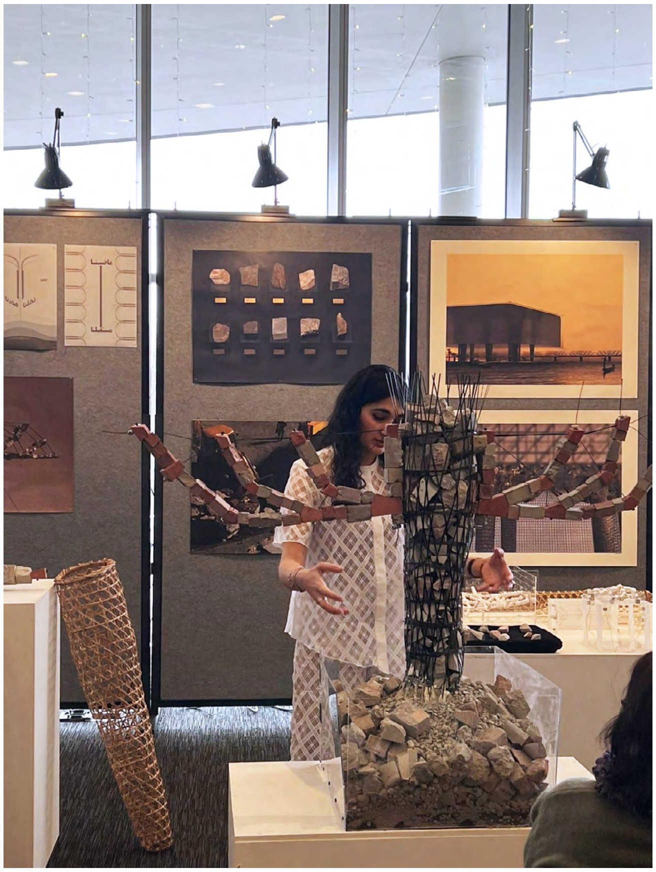


Image by Maryam Al Jomairi