Capturing Atmospheric Moisture:
Towards a Local Water Catchment at the Aral Sea

by
Miriam Ho

A Thesis
presented to the University Of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Architecture

Waterloo, Ontario, Canada, 2015

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public

Abstract

The desertification of the Aral Sea in Central Asia is an iconic example of the devastating local consequences of large-scale water diversion. Critical of the humanitarian consequences associated with trans-boundary water diversion, this thesis seeks local solutions that work directly with the water cycle. Through first-hand photographic documentation of the city of Aral'sk, Kazakhstan, on the North Aral Sea, the thesis identifies the urban fabric as a missed opportunity for local water harvesting. The building envelope of the home serves as the site for material investigation.

The thesis presents a strategy for designing a textile that passively collects moisture. It applies a promising new technology to the cultural context of Aral'sk. The textile is a projection for how building materials in the vernacular architecture of Kazakhstan might evolve to play a role in local water harvesting. Manipulating material properties to capture omnipresent but elusive water molecules from the atmosphere can temper the harsh and fragile environment of aridity, improving living conditions in the desert. The design investigations connect the performative and social functions of the building envelope.

New, emerging paradigms for decentralized water management emphasize the role of water-sensitive materials and design elements in improving the local urban watershed. Materials can strategically capture, retain, and redirect water flow, encouraging water to flow through the city rather than out of it. The thesis includes a theoretical discussion of the conception of building materials as zones of dynamic energy exchange to help shift the discourse towards a more nuanced relationship with water in our immediate environment.

Acknowledgements

To my committee members:

Dr. Elizabeth English, your enthusiasm for my thesis topic has meant much to me, and your own work in the Buoyant Foundation Project is an inspiring reminder that architects can make a difference working with local communities to address the impacts of climate change.

Dr. Tammy Gaber, thank you for your astute comments at critical stages throughout the thesis process. Your empathy and encouragement has been immensely helpful in allowing me to move forward despite my uncertainty.

To the external reader, Dr. Susan Elliott, thank you for participating in the defence with such enthusiasm. Your experience at the Aral Sea and your contributions to this interdisciplinary dialogue lends additional and valuable insight to the work.

Above all, to my supervisor, Philip Beesley: thank you for your friendship, readiness and unwavering support in the darkest hours (literally and metaphorically) of this thesis. Your tenacity and resilience have enabled me to feel grounded despite my paralyzing self-doubt, while the intricacy of your own work, along with the nuanced cultural connections it invokes, has motivated me for many years. I am extraordinarily lucky to be able to work with you.

Additionally,

To UWSA F_RMlab, thank you for driving my own research and allowing me to hone new skills through our collaborative projects.

To the Water Institute at the University of Waterloo, thank you for the many conversations with interdisciplinary water researchers from around the world.

To the 2013 ACSA Subtropical Cities Conference in Fort Lauderdale, USA and the 2013 Sigradi Conference in Valparaiso, Chile, thank you for the opportunity to present my ongoing work and gain feedback at a critical point from specialized researchers.

To the people of Aral'sk and Tastubek in Kazakhstan, thank you for welcoming me into your homes and sharing your stories with me.

Acknowledgements are also due to the Ontario Graduate Scholarship and the University of Waterloo President's Scholarship for funding this research.

Contents

declaration *ii*
abstract *iii*
acknowledgements *v*
list of figures *viii*

Preface **1**

1.0 Introduction **5**
    Note on the approach and scope of the thesis 6
    Structure of the Thesis 7

2.0 Rethinking the Flows of Matter **9**

Photo Essays *19*
    Water *21*
    Earth *37*
    Skin *47*

3.0 Designing Water-Sensitive Materials **57**
    Fabrics for Moisture Control 60
    How can architectural materials support a local water cycle? 61
    Precedents: The Mashrabiya & The Fog Collector 66
    Materials and Moisture 68
    Heterogeneous Materials 69
    Precedents for Performative Textiles 70
    Strategies for Differentiation 71
    Notes on Fabrication 72

4.0 Vernacular Architecture and Building Materials in Kazakhstan **87**
    Climate, Materials, and Seasonal Patterns of Use 90
    Aral'sk: The Evolving Vernacular 96
    Furnishings and Living Spaces 102
    Summary 102

5.0 Towards a Local Water Catchment **107**
    New Paradigms for Local Water 108
    The Pacific Institute's Soft Water Approach 108
    Water-Sensitive Urban Design 109
    Social Connection to Water 110

6.0 Conclusion **113**

bibliography *114*

Appendices **121**
    Appendix I: Grant Application for WaterWise 122
    Appendix II: Fibre Configurations for Moisture Control 128

List of Figures

Fig. 1 *Satellite Image of the Aral Sea 2005*
http://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=108

Fig. 2 *Satellite Image of the Aral Sea 2000 - 2013*
http://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=108

Fig. 3 *The Desertified Harbour of the Aral Sea*
Photography by Author

Fig. 4 *Locating the Aral Sea in Central Asia*
Illustration by Author

Fig. 5 *12th century map of the Aral Sea*
http://www.bibliomonde.com/pages/fiche-livre.php3?id_ouvrage=6554&texte_aff=table

Fig. 6 *United Nations Environment Program report on environment and security in the Ferghana Valley.*
http://na.unep.net/atlas/webatlas.php?id=11

Fig. 7 *Toktogul Reservoir*
http://overpoise.com/toktogul-hydroelectric-powerstation.html

Fig. 8 *The Aral Sea's transboundary water network*
Illustration by Author

Fig. 9 *Boundaries in Architecture*
Addington, D. M. 2005. Smart materials and new technologies : For the architecture and design professions, ed. Daniel L. Schodek. Amsterdam ; Boston: Amsterdam ; Boston : Architectural Press. p. 32

Fig. 10 *The traditional Kiiz Ui*
http://www.qaraqalpaq.com/yurts.html

Fig. 11 *Photograph by Author*

Fig. 12 *Photograph by Author*

Fig. 13 *Photograph by Author*

Fig. 14 *Photograph by Author*

Fig. 15 *Photograph by Author*

Fig. 16 *Photograph by Author*

Fig. 17 *Photograph by Author*

Fig. 18 *Photograph by Author*

Fig. 19 *Photograph by Author*

Fig. 20 *Photograph by Author*

Fig. 21 *Photograph by Author*

Fig. 22 *Photograph by Author*

Fig. 23 *Photograph by Author*

Fig. 24 *Photograph by Author*

Fig. 25 *Photograph by Author*

Fig. 26 *Photograph by Author*

Fig. 27 *Photograph by Author*

Fig. 28 *Photograph by Author*

Fig. 29 *Photograph by Author*

Fig. 30 *Photograph by Author*

Fig. 31 *Photograph by Author*

Fig. 32 *Photograph by Author*

Fig. 33 *Photograph by Author*

Fig. 34 *Photograph by Author*

Fig. 35 *Photograph by Author*

Fig. 36 *Projected Site Section*
Illustration by Author

Fig. 37 *Ways to Install Water-Harvesting Elements*
Illustration by Author

Fig. 38 *Ways to Install Water-Harvesting Elements*
Illustration by Author

Fig. 39 *The Mashrabiya*
http://upload.wikimedia.org/wikipedia/commons/thumb/d/d2/Mashrabiyya.jpg/640px-Mashrabiyya.jpg

Fig. 40 *The Mashrabiya*
https://totemscity.wordpress.com/2011/03/10/mashrabiya/

Fig. 41 *Density and Porosity of the Mashrabiya*
Illustration by Author

Fig. 42 *Fog-harvesting nets*
http://news.nationalgeographic.com/news/2009/07/photogalleries/fog-catchers-harvest-air-water-missions/index.html

Fig. 43 *The Raschel Mesh*
Illustration by Author

Fig. 44 *Elevation of a conventional fog harvester*
Illustration by Author

Fig. 45 *A Water Molecule*
Illustration by Author

Fig. 46 *Surface Tension*
http://nrich.maths.org/7273

Fig. 47 *Textile Sample*
Photograph by Author

Fig. 48 *Hydrophobic and Hydrophilic Materials*
Illustration by Author

Fig. 49 *Namib Desert Beetle*
http://www.rain-barrel.net/water-harvesting-through-biomimicry.html

Fig. 50 *Dew-Harvesting Bottle*
http://inhabitat.com/beetle-inspired-bottle-harvests-drinking-water-from-thin-air/

Fig. 51 *Textile Research for Sportswear*
Chen, Q., Fan, J., Sarkar, M., & Bal, K. (2011). Plant-Based Biomimetic Branching Structures in Knitted Fabrics for Improved Comfort-Related Properties. Textile Research Journal. Retrieved from http://trj.sagepub.com/content/early/2011/03/25/0040517510397579

Fig. 52 *Heirarchy in Knitted Forms*
Heirarchy in Knitted Forms. In Proceedings from ACADIA Conference 2013. Toronto: Riverside Architectural Press.

Fig. 53 *Flexible Geometries for Knitting using Processing*
Illustration by Author

Fig. 54 *Plan of a typical residence in Aral'sk*
Illustration by Author

Fig. 55 *Plan of a typical neighbourhood in Aral'sk*
Illustration by Author

Fig. 56 *Axonometric of a typical house in Aral'sk*
Illustration by Author

Fig. 57 *Elevation of Diffusive Textile*
Illustration by Author

Fig. 58 *Section through Diffusive Textile*
Illustration by Author

Fig. 59 *Installation details for a precrimped wire mesh*
http://www.architecturalwiremesh.com/installation-techniques/precrimped-vert-cables.asp

Fig. 60 *Mesh cladding on Cork County City Hall, Eire*
http://www.architecturalwiremesh.com/installation-techniques/precrimped-vert-cables.asp

Fig. 61 *Rendering of Diffusive Textile*
Illustration by Author

Fig. 62 *Section through Water Harvesting textile*
Illustration by Author

Fig. 63 *Elevation through Water Harvesting textile*
Illustration by Author

Fig. 64 *Rendering of Water Harvesting textile*
Illustration by Author

Fig. 65 *Passap e6000 Flatbed Knitting Machine*
Photographs by Author, Illustrations from http://machineknittingetc.com/passap-e6000-instruction-manual.html, Compiled by Author

Fig. 66 *Attractor Points/Curves*
Illustration by Author

Fig. 67 *Density/Porosity Knit Sample*
Photography by Author

Fig. 68 *Pattern Saturation Knit Sample*
Photography by Author

Fig. 69 *A Composite Fabric*
Illustration by Author

Fig. 70 *Reticulated Surface Knit Sample*
Photography by Author

Fig. 71 *Hydrophobic Knit Sample*
Photography by Author

Fig. 72 *Photograph by Author*

Fig. 73 *Photograph by Author*

Fig. 74 *Photograph by Author*

Fig. 75 *Kiiz Ui Layers*
http://www.qaraqalpaq.com/yurts.html

Fig. 76 *Kiiz Ui*
http://www.qaraqalpaq.com/yurts.html

Fig. 77 *Kiiz Ui*
http://www.qaraqalpaq.com/yurts.html

Fig. 78 *Photograph by Author*

Fig. 79 *Photograph by Author*

Fig. 80 *Photograph by Author*

Fig. 81 *Photograph by Author*

Fig. 82 *Photograph by Author*

Fig. 83 *Photograph by Author*

Fig. 84 *Illustration by Author*

Fig. 85 *Illustration by Author*

Fig. 86 *Photograph by Author*

Fig. 87 *Photograph by Author*

Fig. 88 *Photograph by Author*

Fig. 89 *Tapchan*
https://www.flickr.com/photos/marissa8/3768453450/ , http://camel76.files.wordpress.com/2012/04/tapchan-were-we-sat-to-eat-khiva.jpg?w=848

Fig. 90 *Illustration by Author*

Fig. 91 *Photograph by Author*

Fig. 92 *Vernacular Technologies*
Laureano, P. (2011). The water atlas- traditional knowledge to combact desertification (A. W. Anna Cirella Trans.). Turin, Italy: Bollati Boringhier.

Fig. 93 *The Water Cycle*
Hoyer, J. (2011). Water sensitive urban design : Principles and inspiration for sustainable stormwater management in the city of the future. Berlin: Berlin : Jovis. p.9

Fig. 94 *The Water Harvest*
F_RMlab Presentation for Roxton Road Parks

Fig. 95 *The Water Harvest*
F_RMlab Presentation for Roxton Road Parks

Fig. 96 *The Water Harvest*
F_RMlab Presentation for Roxton Road Parks

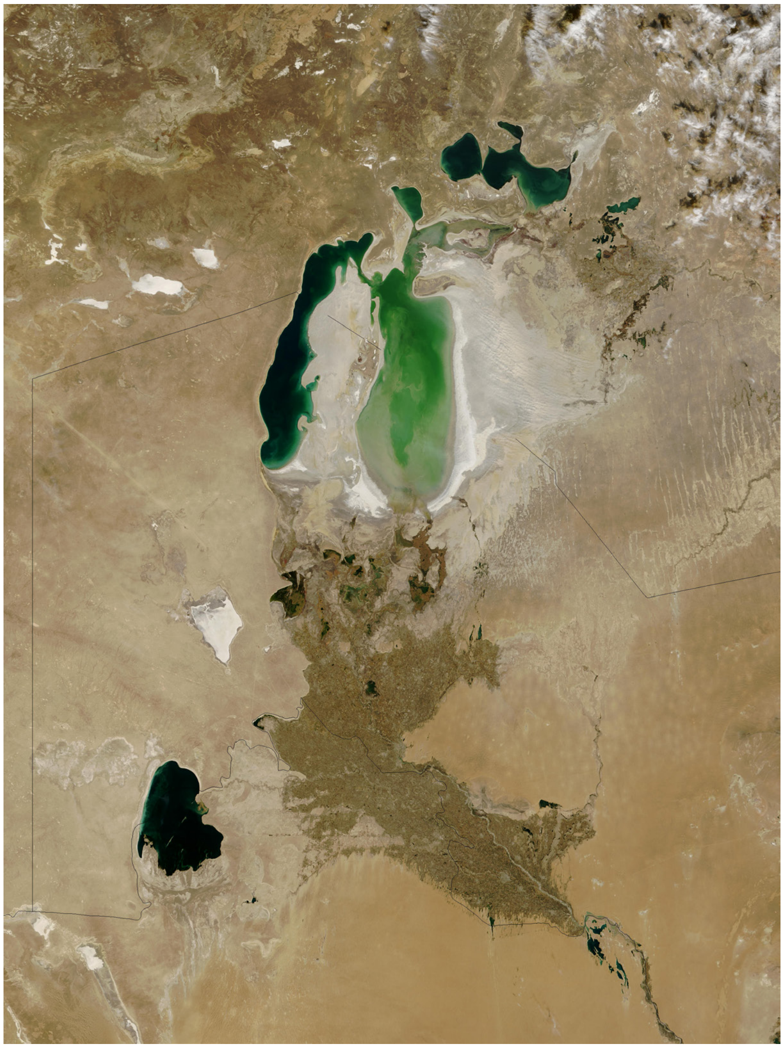
Fig. 97 *The Water Harvest*
F_RMlab Presentation for Roxton Road Parks

Fig. 98 *Photograph by Author*

Fig. 99 *Photograph by Author*

Fig. 100 *Photograph by Author*

Fig. 101 *Photograph by Author*



Fɪɢ. 1 Satellite Image of the Aral Sea

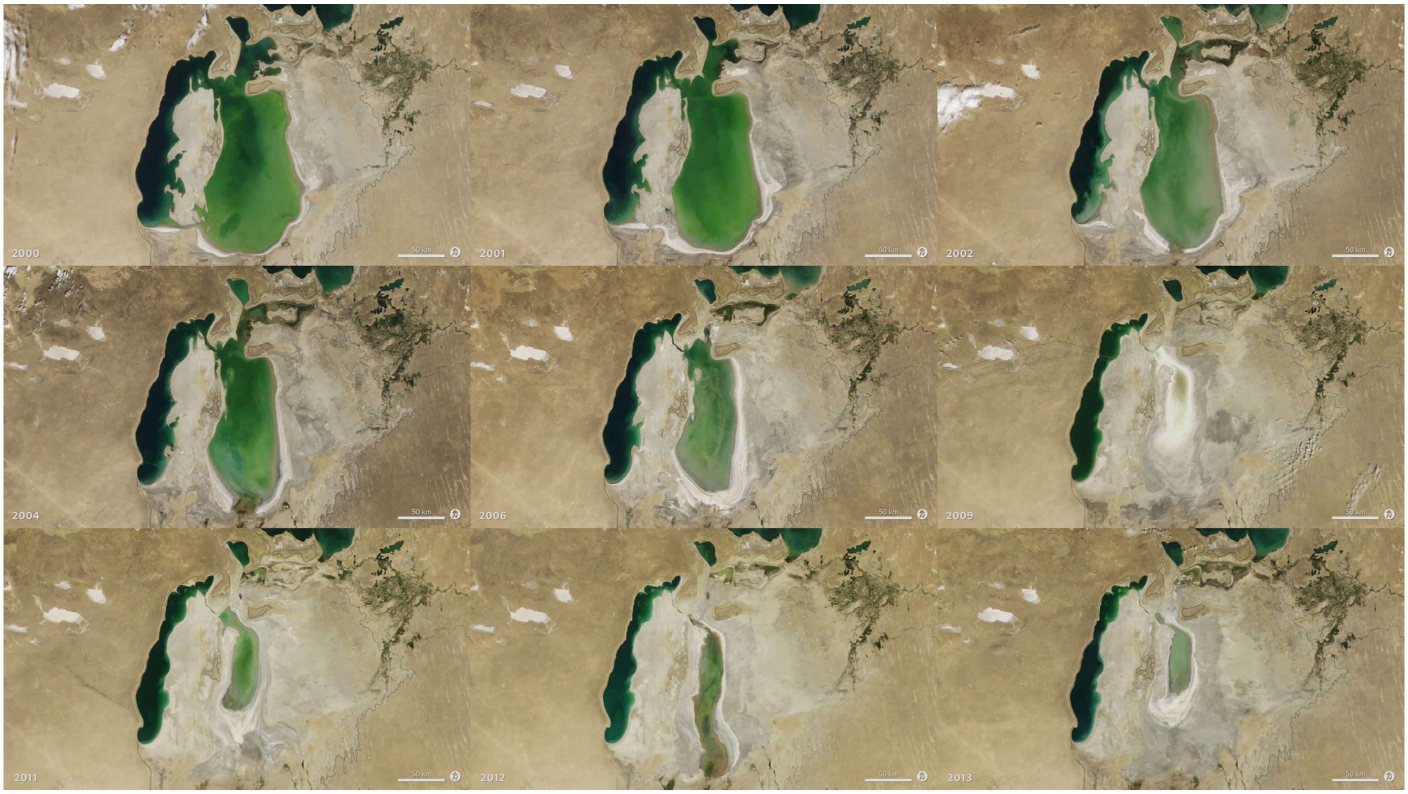


FIG. 2 Satellite images of the Aral Sea shows the rapidity with which the Aral Sea declined between 2000 and 2013. The dramatic desertification of this major geographical feature due to anthropogenic use has made it infamous as "one of the planet's worst environmental disasters," according UN Secretary Ban-Ki Moon in 2010. [i]

---

i. "Shrinking Aral Sea underscores need for urgent action on environment,"

Fig. 3
The desertified harbour of Aral'sk, Kazakhstan, from my visit in July 2011. Fishing boats decay on the intermittent pools and the lake-bed sediments.

Preface

I first visited the shores of the North Aral Sea in the summer of 2011, as part of the production team for an independent documentary on the Aral Sea crisis.[1] We worked with *Aral Tenizi*, a Danish-Kazakh non-governmental organization, to document the daily life of local Kazakh families, interviewing fishermen, construction workers, women, students, and religious community leaders on their memories of the sea and their aspirations for the future. *Aral Tenizi* is acclaimed for attracting World Bank funding to construct the Kok-Aral dam, which has allowed gradual ecosystem recovery in the North Aral Sea, and for creating a grassroots fishing industry in the Aral'sk region. The employees of *Aral Tenizi*, including our Kazakh translator, come from large families that have fished on the Aral for five generations, since their settlement here on Soviet collective farms in the early 20th century.[2] During the month that I spent in Aral'sk in 2011, and during a subsequent visit in May 2013, I witnessed the ongoing transformation of a community that has adapted resourcefully to rapid climate change and its accompanying economic shifts.

At first, as filmmakers and storytellers, we were moved by the pathos of the Kazakh people and the poetry of the salt-encrusted sea bed; we felt, viscerally, the turbulent dust storms that swept through a city that was once a man-made oasis. We were drawn to how the vanishing Aral Sea resonates with a widespread sense of peril over dwindling resources and climate instability in current events. When I returned to Canada to begin this thesis, I read countless papers on the desertification of Aral Sea from the perspective of water scientists, water policy makers, ecologists and cultural anthropologists. What can an architect add to the conversation?

Water resource insecurity is a pressing issue across many disciplines. At the University of Waterloo, I spoke to researchers in hydrology and water policy management through the Water Institute, who increasingly recognized the limitations of linear thinking in solving increasingly complex global problems. I also spoke to water activists in Canada who advocated passionately for the importance of local knowledge and decentralized water management. An architect is trained to consider people's relationship to the immediate environment that they inhabit.

1. Ghosts of the Aral Sea. Directed by Lucas P. Smith. 2012. New York City, NY.

2. Myrzagazieva, Mira (local resident), Interview, Ghosts of the Aral Sea, Tastubek, Kazakhstan, July 28th, 2011

In this architectural reading of Aral'sk, I weave together what I have learned from many interdisciplinary conversations, from the empathy of the filmmaker, the strategic thinking of scientists, to the drive of local communities.

1.0

INTRODUCTION


Aral'sk
Kok'aral Dam
The Aral Sea
syr darya
KAZAKHSTAN
1960 shoreline
amu darya
UZBEKISTAN
KYRGYZSTAN
CHINA
TAJIKSTAN
TURKMENISTAN
IRAN
AFGHANISTAN
Aral Sea Drainage Basin

The rapid desertification of the Aral Sea in Central Asia is a well-known example of the devastating, localized consequences of large-scale water diversion. Precipitated by the construction of an extensive irrigation infrastructure for cotton farming under Stalin's regime, the inland sea shrank from 68,000km^2 to 6,800km^2 in forty-five years,[1] with severe impacts on its ecology, climate, and local livelihoods. Water levels in the Aral Sea's watershed continue to be threatened by the conflicting water needs of the post-Soviet states, such that downstream communities rely on a distant water source and its uncertain flows through geopolitically contested territories for their water supply. In lieu of a dependence on the linear distribution of water in modern infrastructure, this thesis is interested in local solutions that work directly with the water cycle. The surfaces of the built environment, typically designed to repel rather than retain moisture, are recognized as a missed opportunity for cultivating a local water catchment.

This thesis investigates the design of a textile that passively collects airborne moisture. The textile is a projection for how building materials in the vernacular architecture of Kazakhstan might evolve to include functions of water collection and temperature modulation. The design is inspired by a site visit to Aral'sk, Kazakhstan on the North Aral Sea, where I witnessed first-hand the resourcefulness of the local community in adapting to rapid climate change through their building materials and methods. It shows how the promising new technology of fog-harvesting fabrics can be applied to the urban cultural context of Aral'sk.

As an element, water is omnipresent, and materials in the built environment constantly exchange heat and moisture economies with their surrounding environment. New, emerging paradigms for decentralized water management emphasize the role of water-sensitive materials and design elements in improving the local urban watershed. Materials can strategically capture, retain, and redirect water flow, encouraging water to flow through the city rather than out of it. This can in turn promote ways to become more connected to the vital resource of water, and to draw on local knowledge for better water stewardship.

Fig. 4
Locating the Aral Sea in Central Asia:

The Aral Sea is a shallow, saline, terminal lake in the deserts of Central Asia. It is fed by the inflow of two rivers, the Amu Darya and the Syr Darya, as well as by precipitation and groundwater inflow. It was the world's fourth largest lake by area, but water diversion from the Syr Darya and Amu Darya for irrigation and later for hydroelectricity curtailed water flow into the sea and lead to its rapid desertification.

From 1960 to 2005, the Aral Sea has shrank from 68,000km^2 to 6,800km^2. The construction of the Kok-Aral dam in 2005 has stabilized water levels at the North Aral Sea, where a recovery is anticipated by 2025. The eastern basin of the South Aral Sea dried up entirely in August 2014. Water levels fluctuate each year depending on annual precipitation.

---

[1] By 2005, the Aral Sea had divided into the North Aral Sea (3,300 km^2) and South Aral Sea (3,500 km^2).

A Note on the Approach and Scope of the Thesis

The thesis focuses on the socio-cultural dimensions of water insecurity at the Aral Sea. It is derived from personal, empirical observations, supplemented by secondary research. The role of the architect here is someone trained to read space, to consider people's relationship to the immediate environment that they inhabit. Design is offered as a way of articulating, and improving this relationship.

Although the thesis research demonstrates interest in developing the performance of advanced technical materials, technical testing is beyond the scope of this thesis. The thesis simply outlines strategies for material design that can move towards technical testing. The viability of collecting atmospheric moisture in Aral'sk remain to be assessed.

Structure of the Thesis

The thesis does not present a cohesive design solution to the problems caused by the desertification of the Aral Sea. Rather, it seeks a way of thinking through these issues that is valuable to the architect. In the body of the thesis (Chapter Two - Chapter Five), each chapter learns from the specialized knowledge of another discipline or culture and applies this to architecture. Chapter two identifies a new way of thinking about the dynamic flows of water through philosophy, sociology and architectural theory. Chapter three presents strategies for designing a passive, heterogenous material system using the principles of materials and moisture. Chapter four learns from the past and present building traditions of Kazakhstan, showing how these technologies continue to be relevant. Chapter Five discusses new paradigms for local water management, in which building materials play an important role.

The thesis is organized such that we trace the "performative agency,"[2] of water across various scales from particulate matter to urban implications. Based on the conceptual reading of matter introduced in Chapter Two, the thesis asks the reader to scrutinize water as a substance in photographs of Aral'sk; it uses the physics of moisture to develop material systems that interact with moisture; it discusses how these material systems in the context of the vernacular of the house, and how they contribute to the water-sensitive urban design.

---

[2] Goodbun, J. and Jaschke, K. (2012), Architecture and Relational Resources: Towards a New Materialist Practice. Archit Design, 82: 28–33. doi: 10.1002/ad.1424
11. Ibid.

Here is an expanded description of the contents of this thesis:

Chapter Two, *Re-thinking the Flows of Matter,* articulates the cultural and theoretical impetus for the thesis. Sociological research[3] shows a disconnect between traditional values related to water and modern water distribution infrastructure. A review of relevant literature on themes of scarcity, new materialist philosophy, and the conception of building materials as zones of dynamic energy exchange helps shift the discourse towards a more nuanced relationship with water in our immediate environment.

Three photo essays containing personal observations on the presence of *Water*, the particulate matter of the *Earth*, and the way building *Skins* interact with moisture, orient us in the rich material environment of Aral'sk. The photos seek to depict the vibrancy of matter at the Aral Sea, and identify opportunities for local water harvesting.

Chapter Three, *Designing Water Sensitive Materials*, presents a strategy for designing a material system that subtly controls atmospheric moisture. The building envelope of the home serves as the site for material investigation. The design applies the mechanisms of passive fog harvesting technologies to the cultural context of Aral'sk, connecting the performative and social aspects of building envelope design using examples from vernacular architecture. Strategies for material manipulation are suggested for two possible functions for capturing atmospheric moisture: groundwater infiltration, and thermal modulation. Variegated material prototypes using machine knitting are documented, showing how differentiating material properties can create hydrophilic and hydrophobic zones for water transport and retention. Manipulating material properties to capture omnipresent but elusive water molecules from the atmosphere can temper the harsh and fragile environment of aridity, improving living conditions in the desert. Building materials are capable of contributing to a local water catchment.

Chapter Four, *Evolving Vernacular Architecture of Kazakhstan,* traces the transformation of the vernacular architecture in Aral'sk, learning from local knowledge and creative solutions for limited resources. Aral'sk has experienced rapid climate change and its accompanying economic shifts with the desertification of the Aral Sea, and now faces new growth

[3] Oberkircher, Lisa, and Anna-Katharina Hornidge. 2011. "Water Is Life"--Farmer Rationales and Water Saving in Khorezm, Uzbekistan: A Lifeworld Analysis. Rural Sociology 76 (3): 394-421. See Chapter Two for more detail.

through regional oil and gas extraction. The building materials of the city catalogue these social changes. In the history of Kazakhstan's vernacular architecture, the building envelope acts as an environmental filter, modulating heat and humidity to provide comfortable living spaces in a hostile climate. This continues to be relevant despite social transformation. The material investigations in Chapter Three are positioned as part of a lineage of differentiated building envelopes that subtly control moisture.

Chapter Five, *Towards a Local Water Catchment,* discusses an emerging paradigm shift towards "soft" water management strategies that support local, decentralized water systems. Various cities across the world have responded to increasingly volatile weather events and rapid environmental change by emphasizing the importance of local knowledge and connection to natural resources. As demonstrated in Chapter Two, in the Aral Sea basin, the disconnect between local water values, practices, and the spaces of contemporary water delivery supports the need for a local water catchment. The importance of establishing a local connection to water resources is discussed. Architecture and its materials offer a way to imagine this connection.

Chapter Six, the conclusion, summarizes the material covered in the body of the thesis and identifies next steps for development.

The appendix contains two projects on water and material systems undertaken during this thesis, which probe possible directions for the application of this thesis research in the design of sustainable cities, or in the further development of the technical textile.

2.0

RE-THINKING THE FLOWS OF MATTER

This section articulates the social and theoretical impetus for the thesis. Literature referenced from sociological research, philosophy and architectural theory help construct an argument for rethinking our time-space relationships to matter such as water. Field research by Lisa Oberkircher and Anna-Katharina Hornidge identify a disconnect between traditional values related to water and how water is allocated and used under the modern water distribution infrastructure. The philosophy of vital materialism argues that matter has a performative agency of its own which defies human control, and has deeply embedded social and mental configurations, which is reflected in Oberkircher and Hornidge's discussion of how water is locally perceived. In architectural terms, a re-conception of the built environment in terms of thermodynamics, transience, and heterogeneity as suggested in the writings of Michelle Addington[1] and Hasan Fathy,[2] pointing to how architects can strategically use building materials to modify thermodynamic flows for human habitation, might support a new materialist reading of matter, time and space.

In their survey of local farmers' own perspectives on water scarcity in the lower deltas of the Aral Sea in Uzbekistan, researchers Lisa Oberkircher and Anna-Katharina Hornidge[3] reveal that linear systems of water delivery through modern infrastructure conflict with traditional beliefs of water as a God-given gift and a shared responsibility. This disconnect can be described in terms of the farmers' spatial and temporal understanding.

Traditionally, water is understood as a God-given gift with intrinsic value, and since it comes from God, when it is available everyone has an equal right to it and it is seen as a communal responsibility. Availability refers to the ability to see and access water in immediate environment. However, modern water delivery infrastructure is a linear system of source to sink flows, such that water comes from a source external to the immediate environment, subject to uncertain flows through vast, geopolitically contested territories. The existing water delivery network enables uneven distribution. Those surveyed by Oberkircher and Hornidge spoke of the trans-boundary nature of the drainage basin, indicating that "there will be water as long as the heads of the countries [...] get along."[2] They expressed uncertainty about their water supply, which can be caused by both climate change and political tension "It [the

---

1. Addington, D. M. 2005. Smart Materials and New Technologies : For the architecture and design professions, ed. Daniel L. Schodek. Amsterdam ; Boston : Architectural Press.

2. Fathy, H. (1986). Natural Energy and Vernacular Architecture. Tokyo: United Nations Press.

3. Oberkircher and Hornidge, p. 394-421.

4 Oberkircher and Hornidge, p. 401

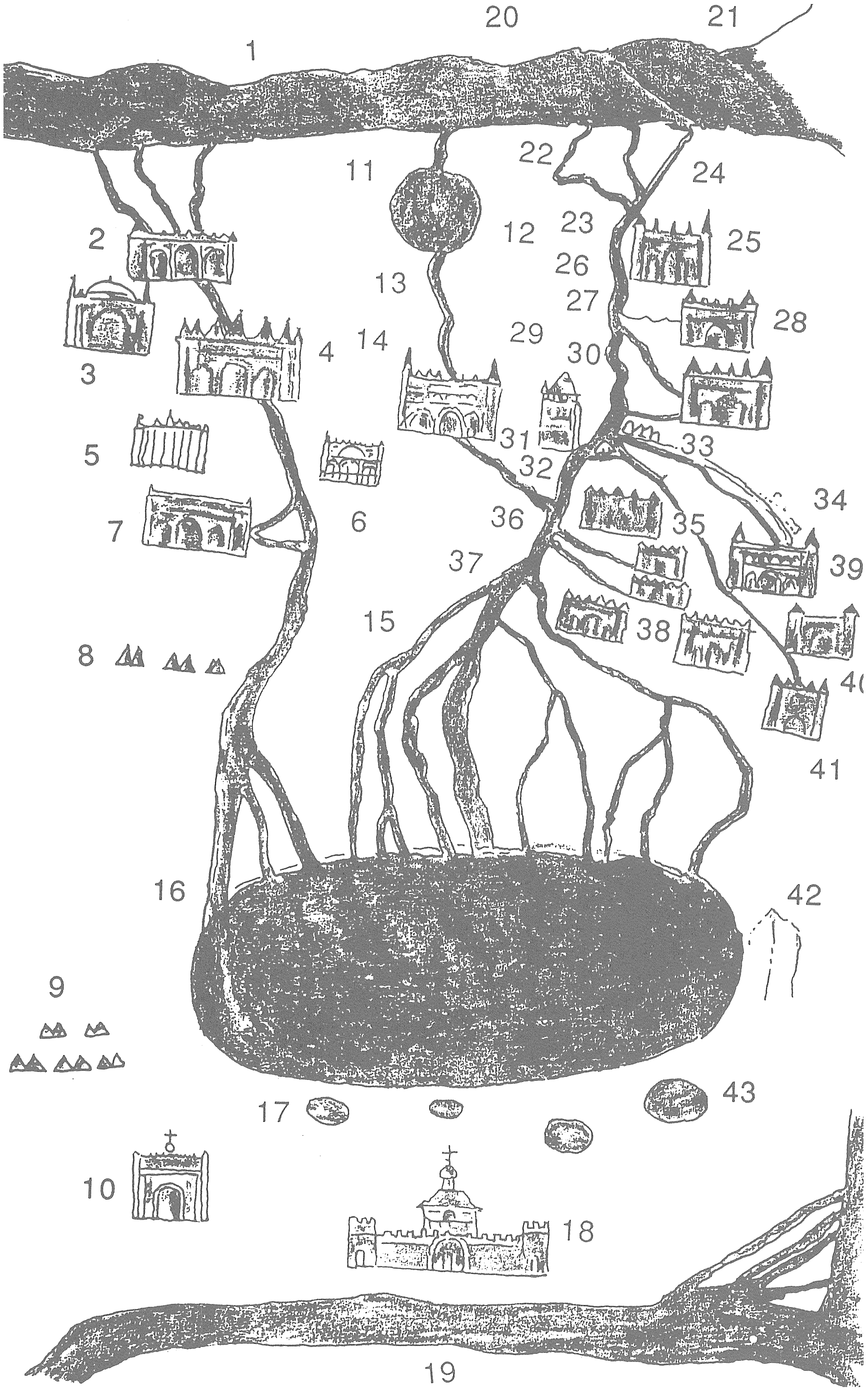


FIG. 5
A 12th century map shows a pictorial view of two tributaries flowing into an inland sea identified as the Aral. The map is consistent with a general understanding today, that water flows from the mountains to the Aral Sea, flowing past many major cities and landmarks in Central Asia.

water level in the river] is up to the climate, it depends on how much snow melts. And hydroposts [dams] are built everywhere upstream and it depends on how much water they give."[5] Oberkircher and Hornidge observe that farmers perceive the water system as a linear process:

> The spatial boundaries of the lifeworld reach from the mountains to the Aral Sea or the Turkmen Desert. Once water is diverted from the Amu Darya into the canal system, it flows down to the tail end. From there, it is impossible for the water to reach the Aral Sea. Instead, all water that is not used will eventually evaporate, seep into the ground, or run into the desert. As long as there are no [local] water-storage facilities, "leftover water" will not be associated with water that could go to the Aral Sea. It will instead be considered water wastage if this water is not used.[6]

In the absence of visible water storage facilities, Oberkircher and Hornidge argue that farmers struggle to understand the rationale of water saving and its regional environmental impact, and are accustomed to depending upon a water supply from a source outside of their locality and influence. Oberkircher and Hornidge's study reveals that cultural values associated with water and its use are influenced by the local visibility of water. The lack of visible water sources are a challenge to better water management. The spatial implications of their research demonstrates a need for a local water catchment.

Temporally, farmers describe three different ways of thinking about the past and future: 1) An eternal time associated with God: The Aral Sea, the Amu Darya river, and other lakes are understood as water bodies created by God, that existed before the oldest members of the community were born, and the fate of future water availability is addressed through hoping, praying, and having faith that "God knows about it. We cannot tell,"[7] and sometimes with dire predictions: "It is written in old books that Khorezm will perish because of water. Either because of flooding or because of water scarcity."[8] 2) Former Soviet times: Farmers speak fondly of former Soviet times as a period when birds and fish flourished, "water could be pumped by day and night,"[9] where it was "impossible to see the beginning and end of the water"[10] in the canals and water taps, an abundance that they attribute to centralized management under Soviet rule compared to present uncertainty linked to a water supply

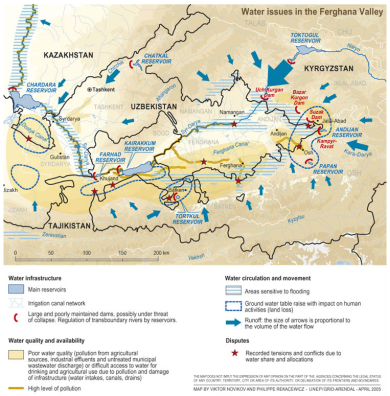


Fig. 6

United Nations Environment Program report on environment and security in the Ferghana Valley. Political tensions are high in the headwaters of the Aral Sea basin, where four major reservoirs are shared by multiple countries, each with different perogatives for water use including agriculture, industry, and hydroelectricity.

Fig. 7

One such conflict stems from the unequal distribution of resources post-Soviet rule. While Kazakhstan is rich in oil and gas resources, it depends on upstream Kyrgyzstan for its water supply. Kyrgyzstan lacks fossil fuel resources, so water flows are retained at the dam at Toktogul reservoir to generate hydroelectricity.

---

[5] Ibid.

[6] Ibid, p. 410

[7] Ibid, p. 402

[8] Ibid.

[9] Ibid.

[10] Ibid.

> *"There will be water as long as the heads of the countries [...] get along."*
>
> — Khorezm farmer

Fig. 8
The Aral Sea's transboundary water network

Upon the dissolution of the Soviet Union in 1992, the Central Asian states signed the Helsinki Convention on the Protection of trans-boundary Water Courses and International Lakes, a United Nations convention addressing equitable sharing of international waters. In the Helsinki Convention, international water bodies are seen as shared environmental resources, where principles of equality, reciprocity, and strategies to reduce transboundary impacts are outlined. The complex irrigation system installed by the Soviet Union provides a material framework for negotiating resources amongst the countries of the Aral Sea drainage basin. The hydraulic infrastructure of the Amu Darya river and Syr Darya river demarcates separate zones of management, with each member state responsible for the engineering and maintenance of corresponding reservoirs and canals, dams, and for regulating water release and intake. Regional water consumption patterns are ultimately governed by trade agreements: while an interstate Commission for Water Coordination establishes varying water allocations for each country, aimed at optimal water use, the designations reflect agreements for reciprocal exchange. Although 75% of the watershed the Aral Sea basin is found in the upstream nations of Tajikstan and Kyrgzstan, Turkmenistan and Uzbekistan, which irrigate the largest amounts of land, receive the highest quantities of water allocation. Downstream countries have agreed to supply upstream countries with natural gas, coal and electricity during the winter in exchange for irrigation water in the spring and summer.

that is subject to interstate politics. 3) An immediate future of uncertainty and speculation: To prepare for the immediate future, members of the community with connections to state water management organizations will spread news informally about water availability for the next season.

Creating a local water catchment and local water governance could provide better water security. Oberkircher and Hornidge's study indicates that the constructed environment can have a profound impact on water and its use. Moreover, water has symbolic, economic and ecological meaning to individuals and communities which influences its use and treatment by a social group, defining their communication, behaviour and action about water as a resource.[11] In "Water is Life," Oberkircher and Hornidge building from individual experiences and memories to reconstruct a "lifeworld"[12] constituted by a shared vocabulary and understanding of water: they describe a spatial and temporal understanding of the water system, user classifications or "typologies" of water, and cultural values about water, to gain insight on water use according to the users.[13]

The idea that matter is deeply entangled in human processes and embodies social, political and mental configurations resonates with new materialist philosophy. New Materialism argues that, far from being inert, matter has performative agency that defies human control. Matter is understood as active (with performative agency) rather than passively manipulated (instrumentalized) by humans.[14] Instead, humans must develop the ability to experience and empathize with the vibrancy of matter. [15] New Materialist philosophy is interested in relating to 'things,' to non-human actors in the environment that are often thought of as inanimate or inert. It calls for humans to develop empathy for matter, promoting greater ethical responsibility towards how non-human "actors" in the environment.

The writings of Michelle Addington and Hasan Fathy argue for a re-conception of the built environment as a zone of dynamic energy exchange, and is compatible with a new materialist view of the agency of matter. By applying concepts of thermodynamics and material properties, Addington and Fathy highlight the strategic role building materials can play in directing energy flow and the behaviour of phenomena for human comfort.

In *Smart Materials and New Technologies,* Michelle Addington

---

11. Ibid.
12. Ibid.
13. Ibid.

14 Goodbun, J. and Jaschke, K. (2012), Architecture and Relational Resources: Towards a New Materialist Practice. Archit Design, 82: 28–33. doi: 10.1002/ad.1424
15. Ibid.

and Daniel Schodek illustrate how useful it is to approach the environment scientifically as a zone of thermodynamic flow, of incessant energy exchanges. The authors point out that:

> Even within a room in which the air seems perfectly static and homogeneous, we will be surrounded by a cacophony of thermal behaviours – multiple types of heat transfer, laminar and turbulent flows, temperature/density stratifications, wide ranging velocities — all occurring simultaneously.[16]

They continue,

> The heterogeneity of different thermal behaviour offer unprecedented potential to explore the direct design and control of our thermal environment by addressing each of these behaviours at the appropriate scale and location.[17]

Although materials are conventionally seen as "tangible artifacts" in architecture, materials are selected based on their behaviour: their interaction with some energy stimulus. Rather than tangible boundaries, Addington and Shodek suggest thinking about the environment in terms of the thermodynamic boundary: a zone where energy exchange takes place. The boundary layer is transient in shape. It marks a difference between the material at its current state and its variable immediate surroundings.

Material systems can interact strategically with differing scales of energy phenomena. The internal structure of a material determines material behaviour. Addington and Schodek describe the body as a material system, with mechanisms of heat transfer: conduction, convection, radiation, each controlled by a predominant material property that determines how fast heat will transfer. They describe how the body has an intricate and versatile thermal regulatory system that accommodates a range of temperatures. Human thermoreceptors do not sense ambient temperature, but respond to difference.

Hasan Fathy's *Natural Energy and Vernacular Architecture*, a seminal text in propelling a scientific understanding of traditional building types, suggests that through a careful examination of thermodynamics and material properties, technologies from the past can still be relevant today. Vernacular buildings passively respond to the environment through the mutual interaction

Fig. 9
(left) Boundaries in architecture are traditionally understood as inert.
(right) A convective boundary layer surrounding the human body in physics,

Fig. 10
The traditional *Kiiz Ui* of Kazakhstan (along with the related Turkic *yurt* or Mongolian *ger*) is centred around a firepit. We can think of the circular *Kiiz Ui* and its various material enclosures as zones of radiating temperatures.

---

[16] Addington. p. 55-56
[17] Ibid.

of materials and atmospheric matter. Fathy presents a minute study of subtle natural phenomenon such as heat conduction and convection, or moisture condensation and evaporation, illustrating each as the result of dynamic fluctuations in density, porosity, temperature and moisture content. These dynamic interactions can be controlled through the physical properties of building materials.

Fathy considers building to be an act of consciously modifying the microclimate, and suggests that buildings should behave like an organism, exchanging heat and moisture with the environment:

> A plant provides a good example of the mutual interaction between a living organism and its environment. It possesses its own heat and water economies. Its respiratory heat is the result of metabolism which tends to raise its temperature, just as with animals. It perspires, and the evaporation of this perspiration leads to cooling, since every gram of water given off requires between 570 and 601 calories from the plant, depending on the air temperature. Consequently, plants exert a reaction on the microclimate of their environment and to some extent adjust their own temperature to their particular needs.[18]

Environmental response can be passive or active: a material system passively responds to the environment by filtering sun, wind, and humidity. Although heat and humidity are subtle, and elusive of control, Fathy's principles describe how, through their thermal mass, density and porosity, building envelopes in traditional buildings work with diurnal cycles to absorb and give back thermal energy, regulating temperature and moisture.

[18] Fathy, H. (1986). Natural Energy and Vernacular Architecture. Tokyo: United Nations Press., p.32

Photo Essays

The following three photo essays are personal observations of matter and materials in the built fabric of Aral'sk. The photos highlight opportunities for local water harvesting on the sidewalks and walls of the city. They also try to capture, with wonder, the complex entanglement of matter in the built environment.

The first essay, *Water* documents the presence of water in Aral'sk. Water is present in many forms, from the municipal pump, to large puddles that remain after flash floods during spring thaw, to growing plants that evince the presence of groundwater.

The second essay, *Earth*, looks closer at the particulate matter left in the wake of the Aral's receding waters. Earth, or dirt, is transient, and heterogenous, interacting with environmental forces that act upon it. The Aral Sea crisis is well-known for noxious dust storms that carry pollutants from the exposed sea bed across territorial boundaries. But earth can also be productive, retaining groundwater, and being fashioned into mud bricks for a building skin with thermal mass.

The third essay, *Skin*, portrays examples of the building fabric of Aral'sk. The wide range of facade materials, found or manufactured, interact differently with moisture. Scaffolds that support plant growth are also included.

Fig. 11
Standing water in Aral'sk after spring thaw

Water

Fig. 12
Water pumps serve older homes and informal housing in Aral'sk. New homes are connected to the Aral'sk's 82km water network. .

The water network was criticized for being inefficient due to its corroding cast iron pipes.

FIG. 13
Water is shared by a variety of users including residents, livestock, wild dogs, and birds.

Fig. 14
Free-flowing water pumps/standpipes providing drinking water are found throughout Aral'sk. Water is pumped from one of four reservoirs in Aral'sk, which are supplied by the Aral-Sarybulak Water Pipeline, originating near Baikonur, Kazakhstan. The water network was built in 1963, and has been repaired with funding from the International Fund for Saving the Aral Sea (IFAS) in 2000-2002.

Fig. 15
Standing water after spring thaw render the unpaved streets impassable.

Fig. 16

During spring thaw (in late March), a period of heavy rains and flash-flooding, residents dig trenches to prevent their homes from flooding.

Fig. 17
Puddle along main street of Aral'sk, after spring thaw. The main street is one of two paved roads in Aral'sk. It is landscaped with irrigated planting beds for shade and aesthetics.

Fig. 18
Market Square in Aral'sk

Fig. 19
Refuse along the shore of
one of Aral'sk's reservoirs.

Fig. 20 (left)
Market Square, park and ball court
in Aral'sk in early spring.

Fig. 21
Close-up of saltwort on
dried lake-bed.

Earth

Fig. 22
Hardened soil crust on the Aral lake-bed.

Fig. 24
The floodplains of the Aral Sea were historically a "living delta," naturally irrigated by seasonal flooding.

Fig. 23 (overleaf)
A dust storm in Tastubek, a fishing village on the shore of the Aral Sea.

Fig. 25
Loess (aeolian) soil of Aral'sk

Fig. 26
The dried lake-bed is a Sabkhat ecosystem -- a saline meadow or bog. Over time (in the span of 15-30 years of desertification), groundwater will seep below levels where they can reach the surface or root layer, while the topsoil hardens into a thick crust.

Fig. 27
In rural Kazakhstan, houses are typically built by their owners, using a combination of industrial, traditional, and found materials.

Fig. 28
The plaster on this two-storey colonial apartment shows water stains and efflorescences.

Skin

Fig. 29
A water pump that serves a community
of fify homes on a side street
in Aral'sk, winter 2012

Fig. 30
A residential side street in Aral'sk in winter.

Fig. 31
Puddle in early spring, along side street in Aral'sk.

Fig. 32

Courtyard enclosures provide shade and shelter from the desert dust storms,. Courtyard walls can be constructed from existing walls, corrugated sheet material, cast-iron fenching, or found materials like this copper sheet harvested from the ships decaying in the harbour of Aral'sk.

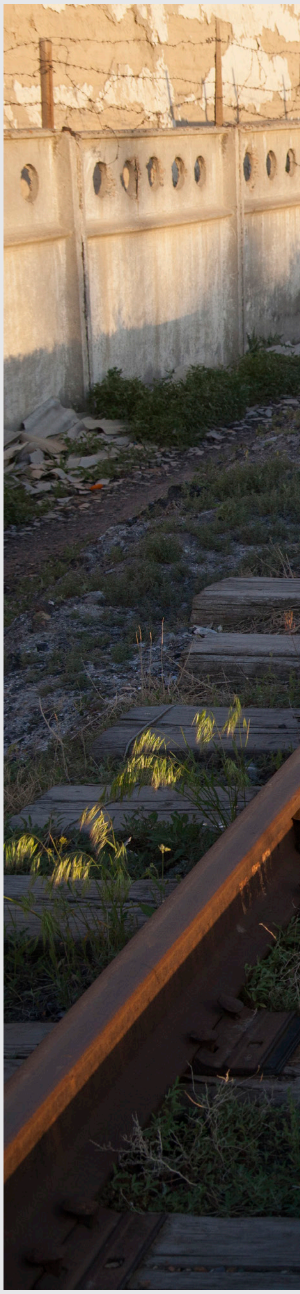


Fig. 33
Hardy desert plants take root amongst the abandoned railroad tracks that lead to the shipyards in Aral'sk.

Fig. 34
A trellis on the porch of a family home in Aral'sk, Kazakhstan. The trellis faces a courtyard containing a vegetable garden.

Fig. 35
This wall of a house is a palimpsest of old and new materials. Plants take root at the base of the wall, where moisture collects from the porous, perspiring stones and bricks.

3.0

DESIGNING WATER-SENSITIVE MATERIALS

This section illustrates a method for designing a material system that subtly controls moisture. Differentiated, water-sensitive materials are imagined as part of the vernacular building fabric of Aral'sk, capable of contributing to a local water catchment.

Designing with water demands an intimate engagement with material behaviour. "Water is the matrix of life,"[1] in biology, geology, and many indigenous building technologies, the mutual interaction of materials and moisture determines the geometry of matter and creates conditions for habitation and growth. Surfaces in architecture modulate the environment, acting as interfaces of energy exchange, buffering dynamic flows of heat and humidity through their innate structural composition. High performance textiles that use innovative fibres and weaves to control moisture movement can capture, store, and distribute omnipresent but elusive water molecules from the atmosphere. This may improve life in the desert by offering a way to temper the harsh and fragile environments of aridity through manipulating material properties.

Contemporary concerns of climate change and environmental degradation demand a new engagement with material ecologies and cultural practices of material knowledge. In particular, a renewed interest in the millenial traditions of vernacular architecture and local craft have much to teach us. Vernacular building practices are rooted in an intimate relationship to the environment through its direct engagement with locally-found materials, and through specific adaptations to local climatic conditions that result in strategic microclimatic modification. The subtle controls of moisture, temperature, light, and air in vernacular building envelopes allow for human thermal comfort and sustainable resource practices that exist in a delicate balance with the environment.

Digital and algorithmic[2] processes offer architects increasing access to the physics of materials and structures at multiple orders of scale.[3] The ability to simulate and visualize subtle environmental phenomenon using mathematically generated environmental force systems and their resultant formations allows us to acquire material knowledge at an increased resolution. There are synergies between the generative logic of computational design algorithms, where forms materialize

---

1. Capra, Fritjof. "Water is the Carrier and Matrix of Life." Global Oneness Project. Retrieved from http://www.globalonenessproject.org/library/interviews/water-carrier-and-matrix-life

2. de Beaureceuil, A. & Lee, F. (2008). Environmental Ornamentation. In Environmental Tectonics: Forming Climatic Change. S. Hardy (Ed.) London: AA Publications.

3. Andrasek, A. (2012). Open Synthesis: Towards a Resilient Fabric of Architecture. Log, 25. 45-54.

through simulated information flow, and Fathy's study of the mashrabiya[4] where material microstructure has a direct relationship to dynamic environmental flows. These synergies offer potential for the technology transfer of vernacular material intelligence using computational simulation and scalable textile craft processes.

3.1.2

Fabrics for Moisture Control

The interaction of material microstructure and environmental forces is clearly illustrated in the making of a textile. A fabric is a flexible surface constructed out of interlinked polymers which are assembled using a serial logic. The way in which the fibres are interlinked determine the characteristics of the fabric, including its structure capacity, material behaviour and performance. A fabric is thus an assembled structure or material system that is inherently hierarchical.[5] Following an algorithmic logic, sets of elements or nested elements are repeated to generate a pattern that determines the fabric's topology. By varying construction algorithms, textiles can be functionally graded, varying in material distribution to suit performance. Textiles are increasingly recognized as high-performance materials, with performance linked to its varied structural capabilities.[6]

Vernacular material systems offer a different but related framework for moisture control. Vernacular architectures can also capture, store and distribute ambient moisture for evaporative cooling and water harvesting. Like living organisms, vernacular architectures interact with their local environment by regulating the passage of heat and moisture through their envelopes to create new microclimatic conditions. Vernacular architectures use local materials, organic and inorganic, that are inherently sensitive to air temperature and humidity. These materials are reconfigured with a careful consideration of architectural thermodynamics to benefit from the material's capacity to absorb and release moisture over time.

To begin to create architectural fabrics capable of moisture control, we ask the questions of: how can the articulation of environmental forces in material microstructure be amplified to an architectural scale? What are the relationships between microstructure, pattern and overall topology and how can these be functionally graded for moisture management? The research builds upon existing work on moisture-sensitive biomimetic textiles and extends these experimental research traditions to

4. Fathy, p. 55, see Section 3.1.4

5. Eadie, L. & Ghosh, T. (2011). Biomimicry in Textiles: Past, Present and Potential. An Overview. Interface: Journal of the Royal Society, 8, 59. Retrieved from http://rsif.royalsocietypublishing.org/content/8/59/761.full

6. Warwick, P. (2005). In Extreme Textiles: Designing for High Performance. M. Mcquaid (Ed.) New York: Princeton Architectural Press.

include factors of porosity, density and time lag, which allow passive moisture regulation in vernacular architecture. The research aims to develop a workflow for creating functionally graded, moisture-sensitive textiles.

3.1.3

How can architectural materials support a local water cycle?

MATERIAL SYSTEMS

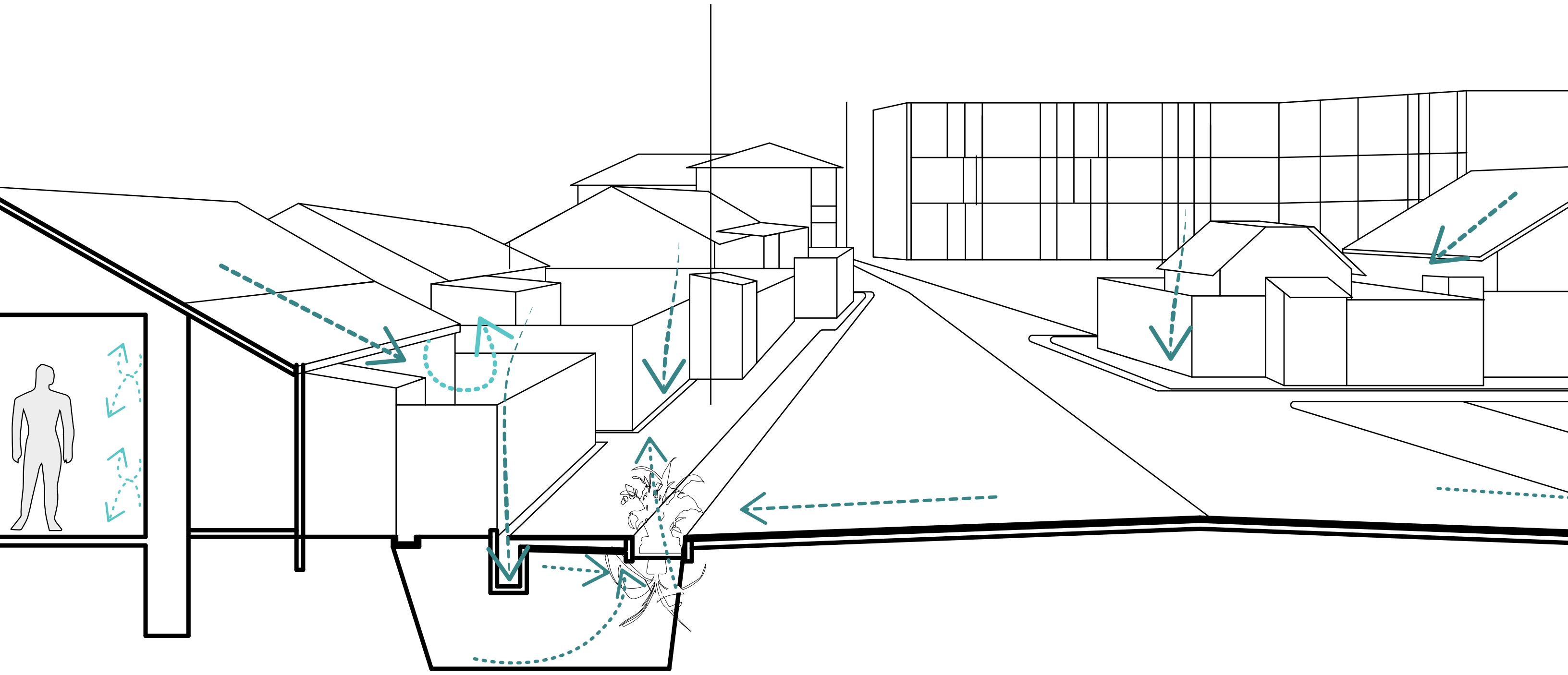
A material is an assembled structure of repeated elements.[7] Materials interact with moisture through their physical properties. Materials can be hydrophilic, hydrophobic, and hygroscopic, depending on their density, porosity, and surface patterning. By varying a material's physical properties, materials can capture, retain, or channel water. The fog collector and the mashrabiya are examples of material systems that capture elusive atmospheric moisture through their configuration. In this section, we examine how to construct a variegated, water-sensitive fabric using the flexible logic of knitting. Strategies for variegation include functional grading, heterogeneity, and hierarchy, drawn from examples in the natural world and from textile engineering.

LOCAL WATER CYCLE

The natural water cycle of evaporation, condensation, precipitation and infiltration is interrupted in urban areas, where 10-90% of city surfaces are impermeable.[8] Water-sensitive materials in the urban environment can aid water retention, groundwater infiltration, and evaporation or evapotranspiration, replenishing the groundwater table and modulating local climate. The section explores the potential of water-sensitive building skins that harvest moisture, modulating the local microclimate through evaporative cooling, or collecting moisture for groundwater infiltration and plant growth, augmenting existing techniques that support the local water cycle include rooftop rainwater collection, bioretention landscaping, water detention ponds and infiltration zones (rain gardens), and evapo-transpiration. The importance of decentralized water management and water-sensitive urban design are discussed further in Chapter Five.

[7] Eadie, L. & Ghosh, T. (2011). p.15

[8] Hoyer, Jacqueline. 2011. Water sensitive urban design : Principles and inspiration for sustainable stormwater management in the city of the future. Berlin: Berlin : Jovis. p. 9



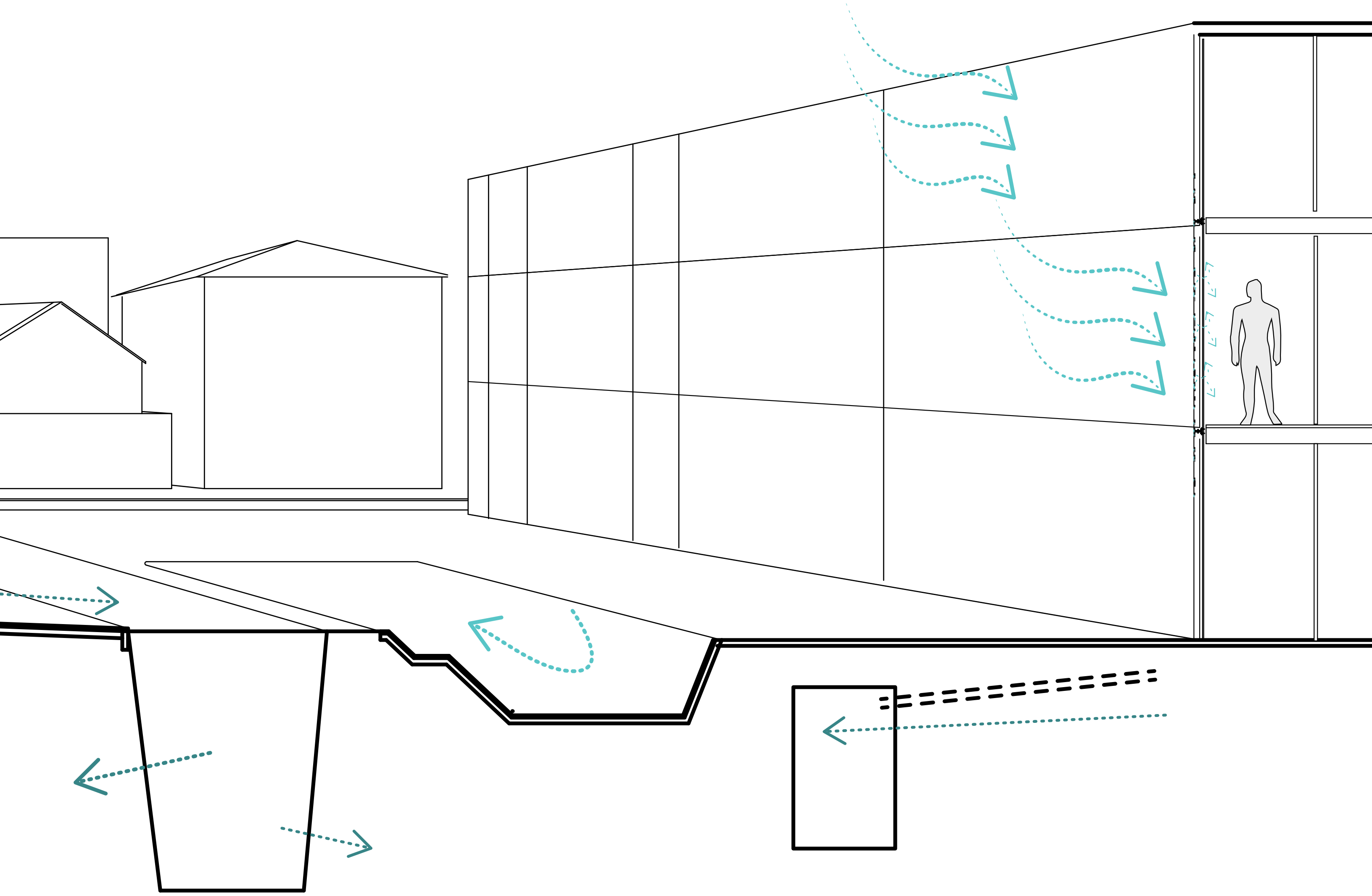


Fig. 36
Projected, site section through a typical residential area in Aral'sk. Shows two building types,

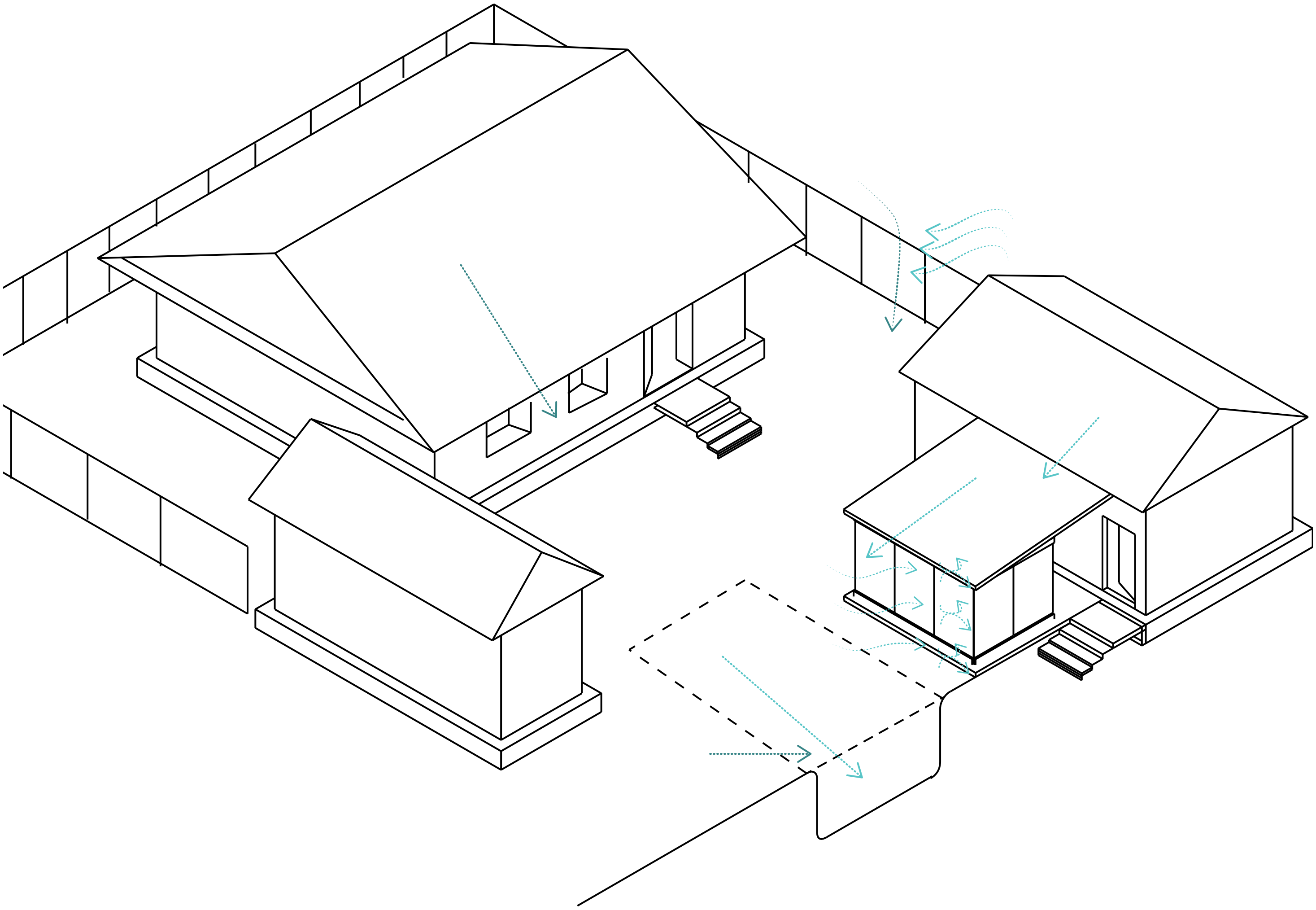


Fig. 37
Ways to install water-harvesting elements
at a typical self-built home in Aral'sk.

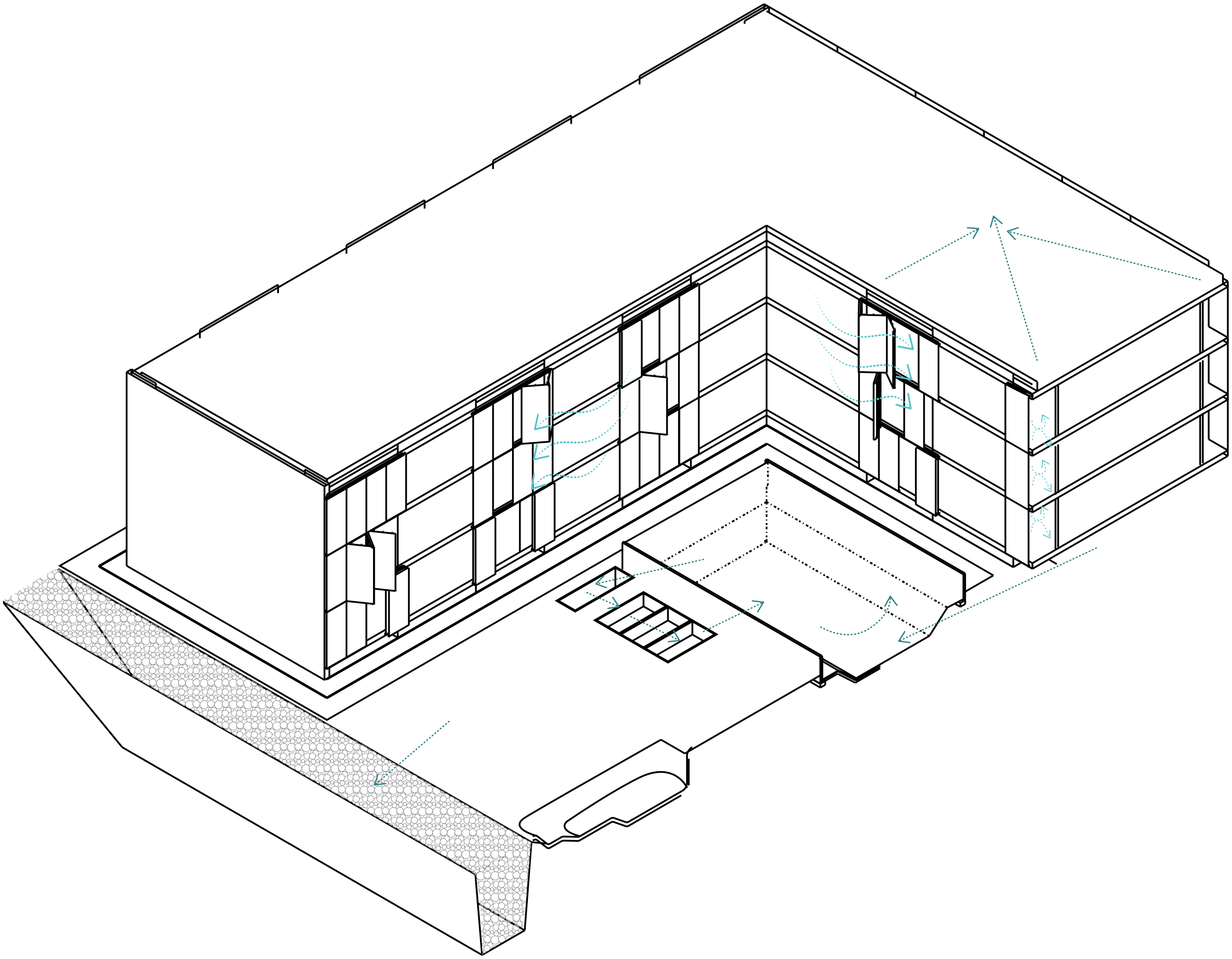


Fig. 38
Ways to install water-harvesting elements
at a typical low-rise apartment in Aral'sk.

3.1.4

Precedents

The Mashrabiya

The *mashrabiya*, a wooden lattice screen found on traditional Arabic houses, provides privacy and view, redirects light and air flow through its porous assembly, and cools and humidifies as wood fibres take in and give off moisture. It is a material system that modifies the hot, arid climate through the interaction of materials and atmospheric matter. *Mashrabiya* means “a drinking place,”[9] where clay water jars are stored so that as air flows into the building, water evaporates from the porous clay and cools the air inside. The wooden lattice controls the passage of light, heat, and humidity through the spacing of the mesh and the size of the wooden members. The density and porosity of the mesh calibrates light and airflow in a room Closely spaced members prevent the entry of direct sunlight (and resultant heat gain) at eye-level, while larger interstices under the overhang allow reflected light to brighten the space and provides greater air circulation. The size of the rounded wooden members control humidity: wood, an organic fibre, is hygroscopic, absorbing and releasing moisture over time. Larger wooden balusters have

Fig. 39
The *mashrabiya,* meaning “drinking place,“ is an ornate wooden lattice that modulates temperature, moisture, and privacy, allowing the house to ventilate and providing an interface between the inside and the outside.

Fig. 40
The mashrabiya has a gradient to control light, and subsequently heat flow, and views.

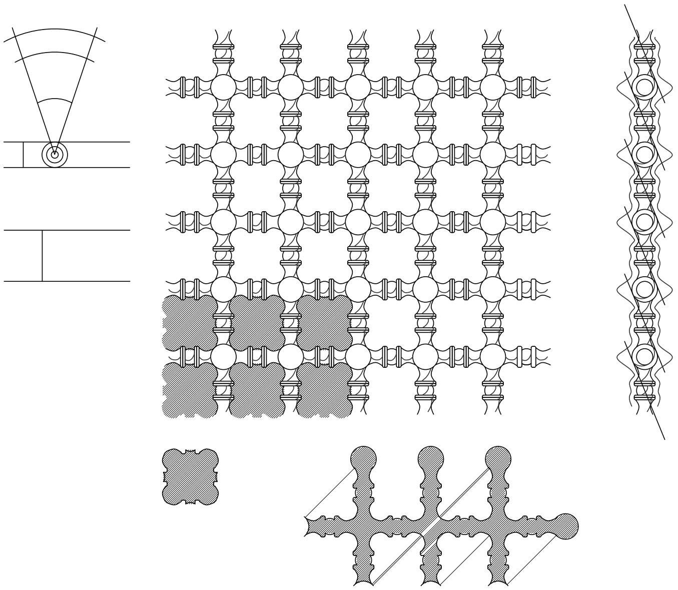


Fig. 41
By varying the density and porosity of the mesh, and the size of its individual wooden members, the mashrabiya controls the passage of light, heat, and moisture, for a comfortable living environment..

[9] Fathy, Hassan. 1986. Natural energy and vernacular architecture : Principles and examples with reference to hot arid climates, eds. Walter Shearer, ‘Abd al-Rahman Sultan. Chicago: Published for the United Nations University by the University of Chicago Press.

a greater capacity for absorption, and a larger surface area for evaporative cooling throughout the day. The performance of the mashrabiya at different scales, controlled by different parameters, is a useful model for thinking about differentiated material systems.

Fog Collectors

Fog harvesting nets are fine-mesh textiles that extract airborne moisture in foggy locations, capable of producing sufficient drinking water to meet the needs of a small rural community.[10] Current fog collection technology consists of a 40m^2 double layer of 35% shade coefficient Raschel mesh (an inexpensive, readily available polyethylene textile with an open triangular weave, used for shading greenhouses), tensioned on an upright frame, strategically located in an area with sufficient wind and humidity. Fog collection occurs as 1) water droplets present in the atmosphere are entrained on the mesh with passing winds 2) water droplets deposited on the mesh surface collide and coalesce into larger droplets 3) water drains down the mesh by gravity. The efficiency of the fog collector depends on its porosity: the radius of the fibre, which wind-blown water droplets deflect around, and the mesh spacing, which buffers wind velocity. Fibres dipped in a hydrophobic coating allows water droplets to slide down more quickly.

Fig. 42
Fog collectors in the hills near Lima, Peru harvest water from prevailing winds for a region that experiences less than 1.5cm of rainfall per year.

Prototype fog collectors have been successfully implemented in high-altitude rural communities in developing countries, and are considered an "extremely promising and low-cost water harvesting system for drinking water, crop irrigation, livestock beverage and forest restoration in dryland mountains" by the United Nations Food and Agricultural Organization.[11] Since fog harvesting technology is relatively new, it has sparked ongoing research and development. For instance, working from biomimetic models such as the Namib desert beetle, or sticky spider webs, MIT researchers identified controls for the fibre size, mesh structure, and chemical coating for optimal water yields.[10] On the other hand, architects have been experimenting with the geometry of water collectors. Argentinian architect Ciro Najile lead a design studio in the Atacama desert with the aim of intentionally creating inefficient geometries to slowly collect water for groundwater infiltration. Upon his return to the project site several years later, he discovered that the experimental structures built had created a fertile substrate, and were now inhabited by growing plants.[12]

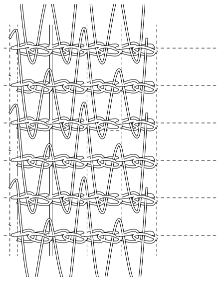


Fig. 43
The raschel mesh

---

[10] A standard fog collector produces between 200 L to 1000 L per day. An array of 100 fog collectors installed in El Tofo, Chile, produced an average of 15,000 L of potable water, with peak water production exceeding 100,000 L per day, adequate as a water source for a village of 300. Fogquest: Past Projects. Retrieved from http://www.fogquest.org/?page_id=671

[11] UNEP (1997) Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Countries in Asia, UNEP, Unit of Sustainable Development and Environment General Secretariat, Organisation of American States, Washington, D.C.

[12] Shanyengana, E. S., R. D. Sanderson, M. K. Seely, and R. S. Schemenauer. 2003. Testing greenhouse shade nets in collection of fog for water supply. Journal of Water Supply: Research and Technology - AQUA 52 (3): 237-41.

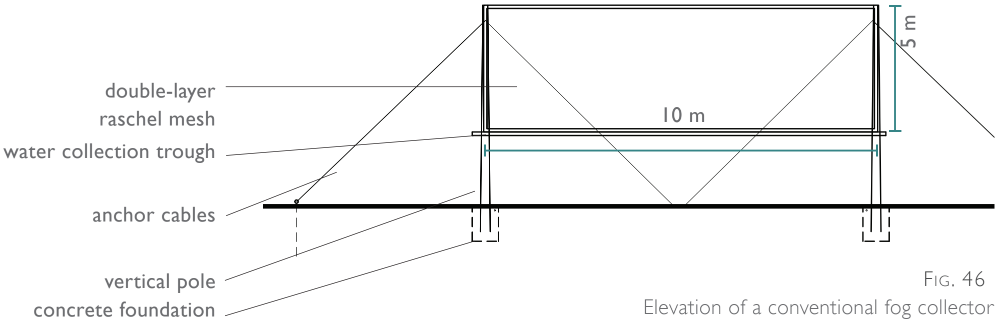


FIG. 46
Elevation of a conventional fog collector

3.1.5

Materials and Moisture

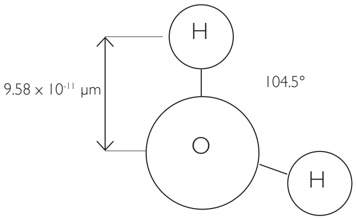


FIG. 44
A water molecule

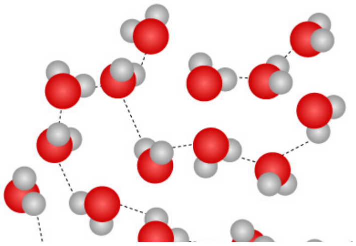


FIG. 45
Surface tension:
hydrogen bonds between water molecules.

The interplay of materials and moisture at different scales allows materials to be programmed for a wide range of functionalities. A water molecule—H_2O—has a polar nature, consisting of two positively charged hydrogen atoms and one negatively charged oxygen atom. Water molecules are attracted to each other: the hydrogen of one molecule is attracted to the oxygen of another, causing them to form clusters. As temperatures increase, water clusters gain more energy and will break apart into smaller clusters or evaporate as lone water molecules. Materials are thus capable of being both water-tight and water permeable by interacting with the difference in size between water clusters and lone water molecules.[13]

Materials can be hydrophobic (repel water), or hydrophilic (attracts water) and hygroscopic (capable of absorbing water) based on their pore structure. The contact angle of a water droplet and the surface beneath determines whether the material is hydrophobic or hydrophilic, where a contact angle greater than 90 degrees creates a hydrophobic surface, and one less than 90 degrees causes water to spread, creating a hydrophilic surface. Water absorption is governed by the porosity of a material, where larger pore sizes results in smaller spaces for water transport via capillary action, resulting in faster water absorption as well as greater heat conductivity. Porous materials have the tendency to capture and hold water molecules in their pores and capillaries. Once a material is fully saturated (has reached its

10. Personal conversation with Ciro Najile. Valparaiso, Chile. November 18th, 2013.

13. Straube, J. (2006). BSD-138: Moisture and Materials. Building Science Digest. Retrieved from http://www.buildingscience.com/documents/digests/bsd-138-moisture-and-materials/

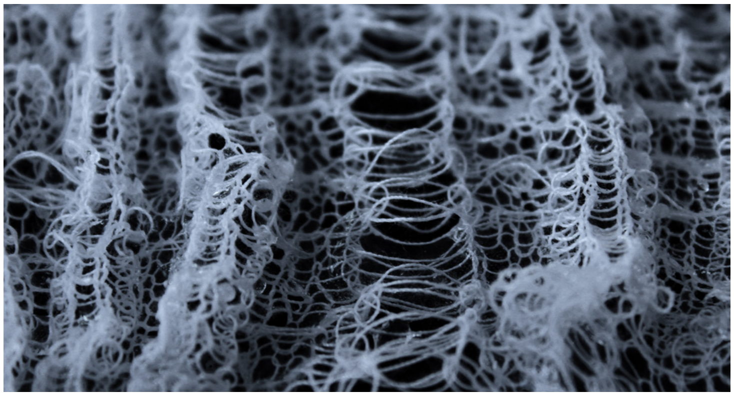
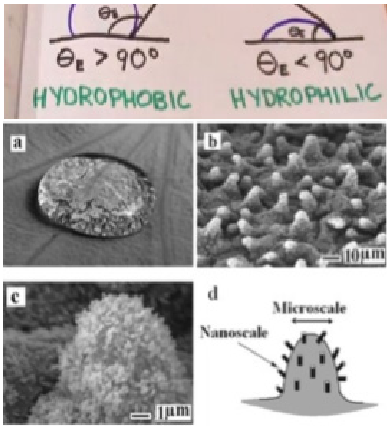


Fig. 47
Textile with variable density and porosity. Dense regions become saturated, storing moisture. Ridges and valleys in the material's structure helps channel water flow.

moisture storage capacity), it will no longer transmit moisture, but will release moisture back into the environment.

The rate at which moisture passes through a material is significant for climatic regulation. By exploiting a material's capacity for moisture storage so that it can absorb and give back heat and moisture throughout the course of the day, material systems can provide passive cooling. This capacity to delay the movement of moisture from outside to inside, known as the time lag factor, allows building materials to regulate and balance moisture and temperature in ambient air.

Fig. 48
Hydrophobic and hydrophilic materials



3.1.6
Heterogeneous Materials

Heterogeneous materials are capable of sophisticated moisture controls. A material is an assembled structure formed by repeated elements. Materials found in nature are seldom uniform in composition, instead, they are differentiated in structure according to various functional requirements.[14] Since all biological materials are made of fibres,[15] biomimicry often provides a framework for performance optimization in textile and material engineering. Fabrics, which are constructed by sequentially interlinking polymers, can mimic the construction of materials in nature. The way in which the fibres are interlinked determines the characteristics of the fabric, including its structural capacity, behaviour and performance.

[14] Eadie, L. & Ghosh, T..

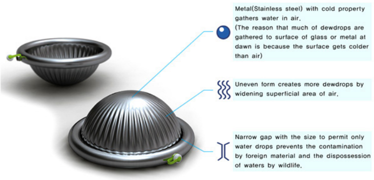
[15] Ibid.

3.1.7

Precedents for Performative Textiles

Fabrics that are capable of capturing, storing, and distributing atmospheric moisture have a wide range of contemporary applications, from fog harvesting to collect potable water, to athletic-wear that transports sweat away from the body to smart responsive shape-changing fabrics. The specific configuration of the weave or knit, creating a material structure with varying density, pattern and topology, allows fabrics to perform functions of water collection or transport. Notable examples of research that uses biomimicry as a framework to develop fibre configurations for water functions include polymer films that mimic the hydrophobic and hydrophilic bumps on the Namib desert beetle for fog collection,[16] double-layered knit fabrics connected by biomimetic branching stitches for better water adsorption,[17] and the design of shape-changing surfaces inspired by the cellular composition of the pine cone hygromorph.[18]

Fig. 49
The namib desert beetle has nanoscale bumps with hydrophilic tips and hydrophobic sides that collect and channel water.



Metal(Stainless steel) with cold property gathers water in air.
(The reason that much of dewdrops are gathered to surface of glass or metal at dawn is because the surface gets colder than air)

Uneven form creates more dewdrops by widening superficial area of air.

Narrow gap with the size to permit only water drops prevents the contamination by foreign material and the dispossession of waters by wildlife.

Fig. 50
A dew-harvesting bottle designed by Kitae Park mimics the uneven surface of the beetle's shell to collect airborne moisture

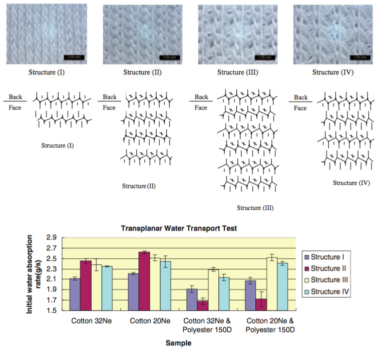
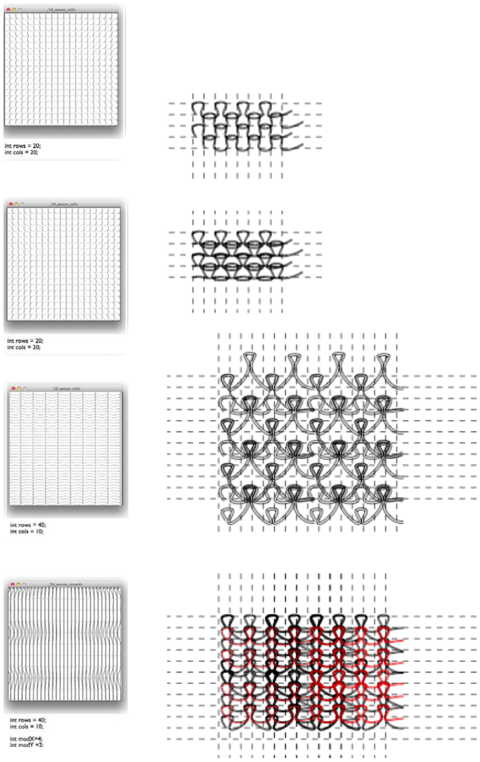


Fig. 51
Textile research for sportswear: increasing the number of "branching" tuck stitches, which connect the two layers of a double-knit fabric, can speed up the movement of moisture across the textile, so that it perspires.



```
int rows = 20;
int cols = 20;
```

```
int rows = 20;
int cols = 20;
```

```
int rows = 40;
int cols = 10;
```

```
int rows = 40;
int cols = 10;

int modX=4;
int modY =2;
```

Fig. 52
A fabric is a flexible plane built by repeatedly interlinking filaments. Stitches are repeated across successive rows, imparting different aesthetic and performance characteristics to the fabric.

Knitted and woven fabrics are constructed with a serial logic, lending themselves to computational logics.. Shown above are textiles generated using a modular grid in the programming language Processing..

---

16. Trafton, A. (2006). Beetle Spawns New Material. Retrieved from http://web.mit.edu/newsoffice/2006/beetles-0614.html

17. Chen, Q., Fan, J., Sarkar, M., & Bal, K. (2011). Plant-Based Biomimetic Branching Structures in Knitted Fabrics for Improved Comfort-Related Properties. Textile Research Journal. Retrieved from http://trj.sagepub.com/content/early/2011/03/25/0040517510397579

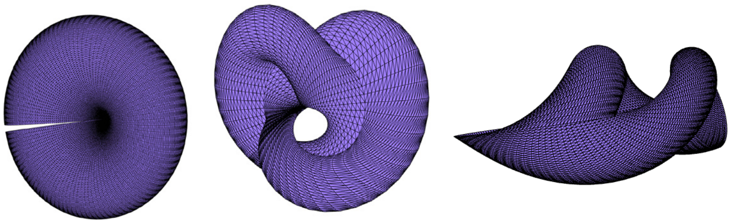


Fig. 54
Flexible geometries generated using a modular grid in the programming language Processing..

3.1.8

Strategies for Differentiation

- The composition, or internal structure of a material articulates environmental forces[17], or, in other words, the shape of matter is a "diagram of [the] forces acting upon it."[19]
- The arrangement of material constituents imparts desired mechanical properties.
- Strategies for differentiating the structure of a fabric are transferable to designing the microstructure of other materials.[20]

Strategy	Examples:	
	BIOLOGY	VERNACULAR
1. Heirarchy different scales for different roles	LOTUS LEAF • nanobumps repel water • epidermis has branch-like patterns to channel water	MASHRABIYA • density and porosity regulate entry of temperature and light, size of wood members control moisture
2. Functional Grading vary in density and material distribution	CELLULAR STRUCTURE OF WOOD • cells are distributed according to structural requirements	MUD/STRAW WALLS • straw-reinforced mud bricks and rammed earth walls, straw prevents mud from cracking
3. Composite Materials two materials with interacting properties	PINE CONE • stiff fibres are suspended within a softer matrix, which allows the material to morph	GREAT MOSQUE OF DJENNE • : the mosque's wall thickness varies with height

18. Scott, J. (2014). Heirarchy in Knitted Forms. In Proceedings from ACADIA Conference 2013. Toronto: Riverside Architectural Press.

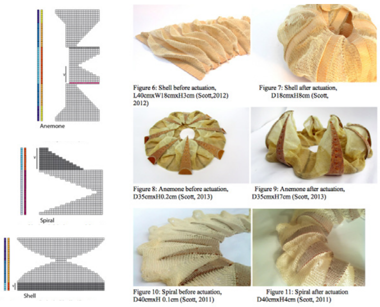


Fig. 53
By mimicking the cellular structure of a pine cone, textile designer Jane Scott created knitted textiles that contract and expand with moisture.,

19. de Beaureceuil, A. & Lee, F.

20. Thompson, D'A. 1997. On growth and form, ed. John Tyler Bonner. Abridged edition /. / edited by John Tyler Bonner. ed. Cambridge England] ; New York: Cambridge England ; New York : Cambridge University Press.

21. Research concerned with designing architectural material microsctructure that reacts to moisture include:
Lilley, Brian et. al, Ceramic Perspiration: Multi-Scalar Development of Ceramic Material, ACADIA 12: Synthetic Digital Ecologies [Proceedings of the 32nd Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) San Francisco 18-21 October, 2012), pp. 97-108

Fig. 55
Plan of a typical residence in Aral'sk

Fig. 56
Plan of a typical neighbourhood in Aral'sk

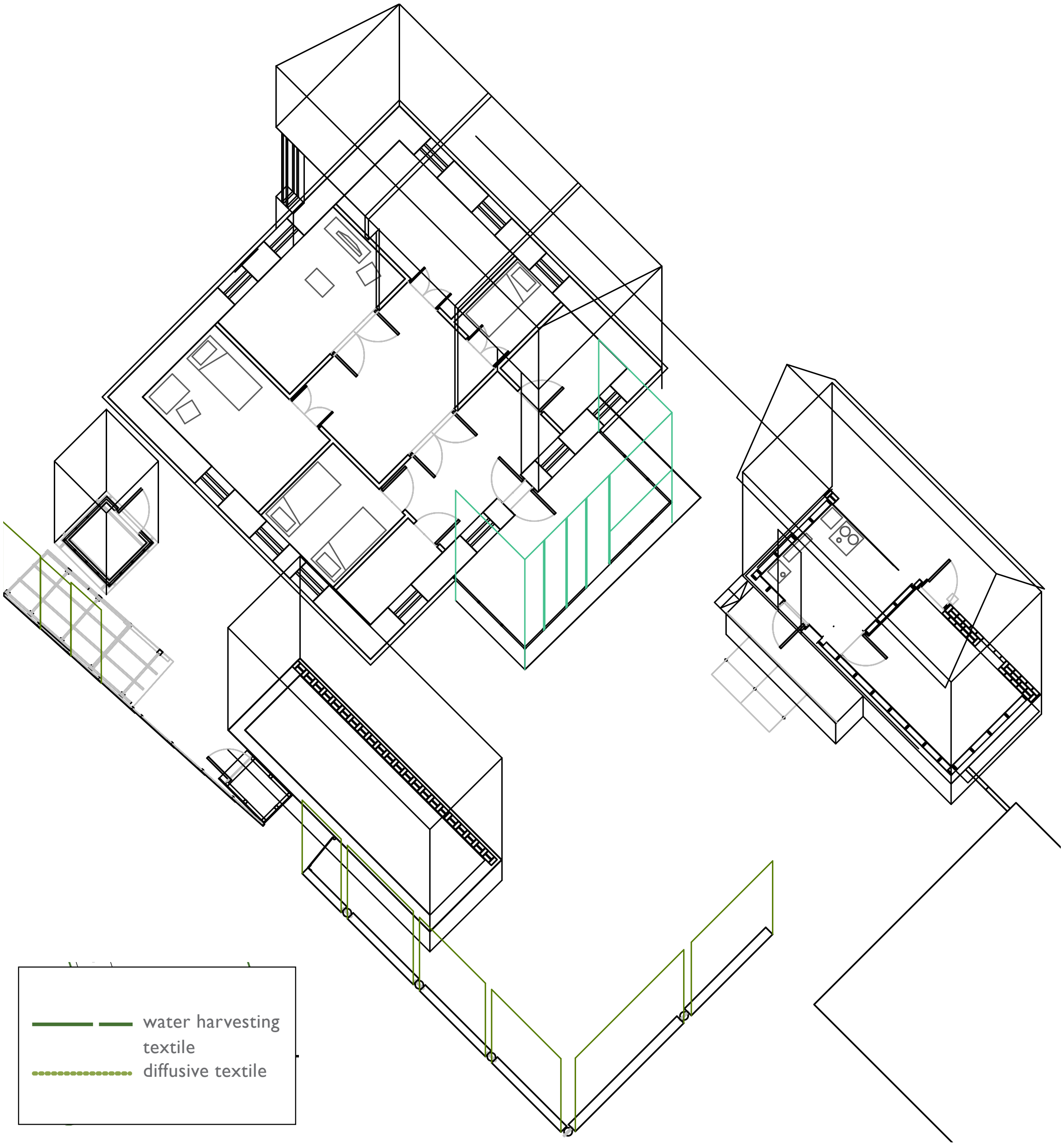


Fig. 57
Axonometric of a typical house in Aral'sk

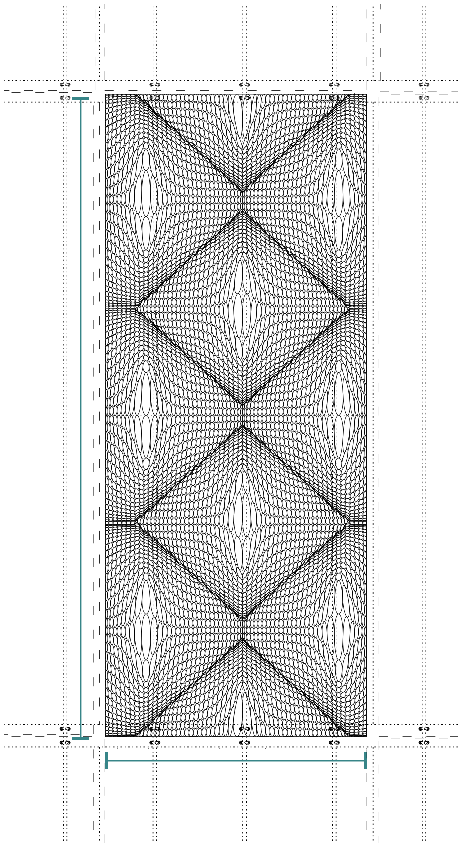


Fig. 58
Elevation of Diffusive Textile

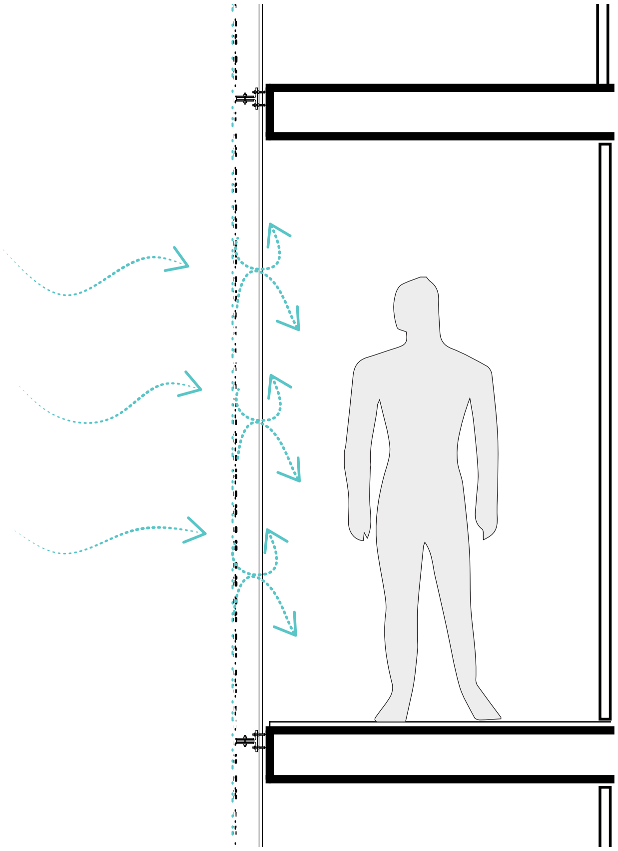


Fig. 59
Section through Diffusive Textile

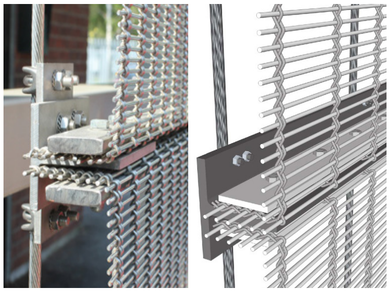


Fig. 61
Installation details for a precrimped wire mesh on vertical cables

Fig. 60
Mesh cladding on Cork County City Hall, Eire

DIFFUSIVE TEXTILE

- modulates heat and humidity for a comfortable microclimate
- captures, stores and releases atmospheric moisture over time
- filters light/views in a buffer zone between private and public (eg. balcony or porch)

Fig. 62
Rendering of Diffusive Textile

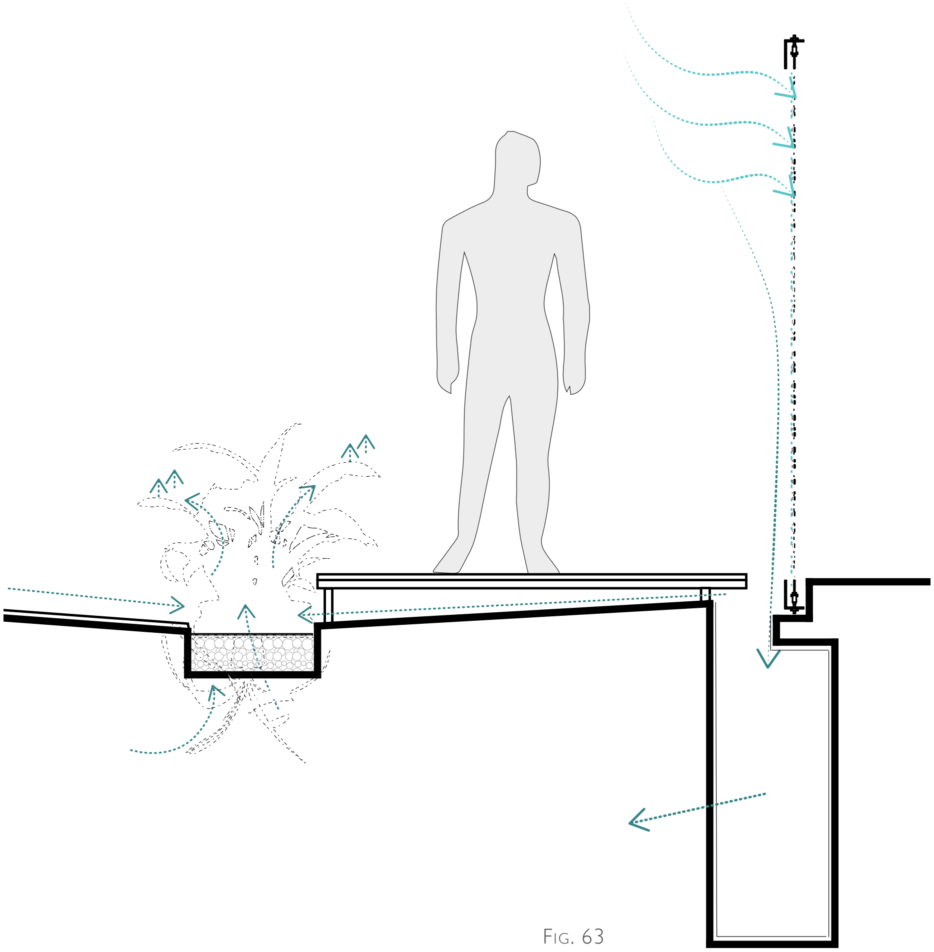


Fig. 63
Section through water harvesting textile

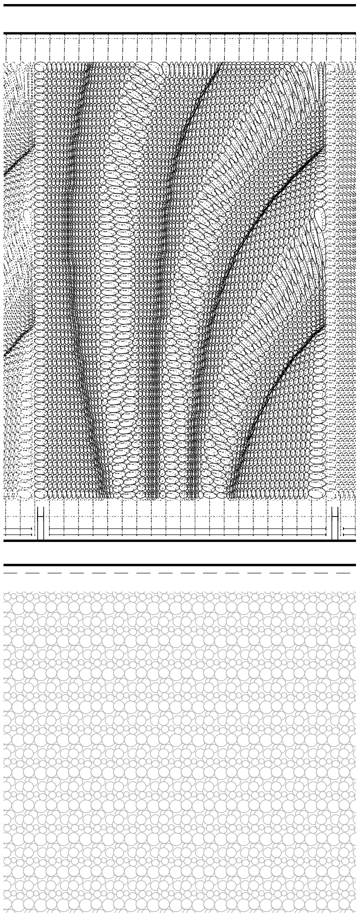
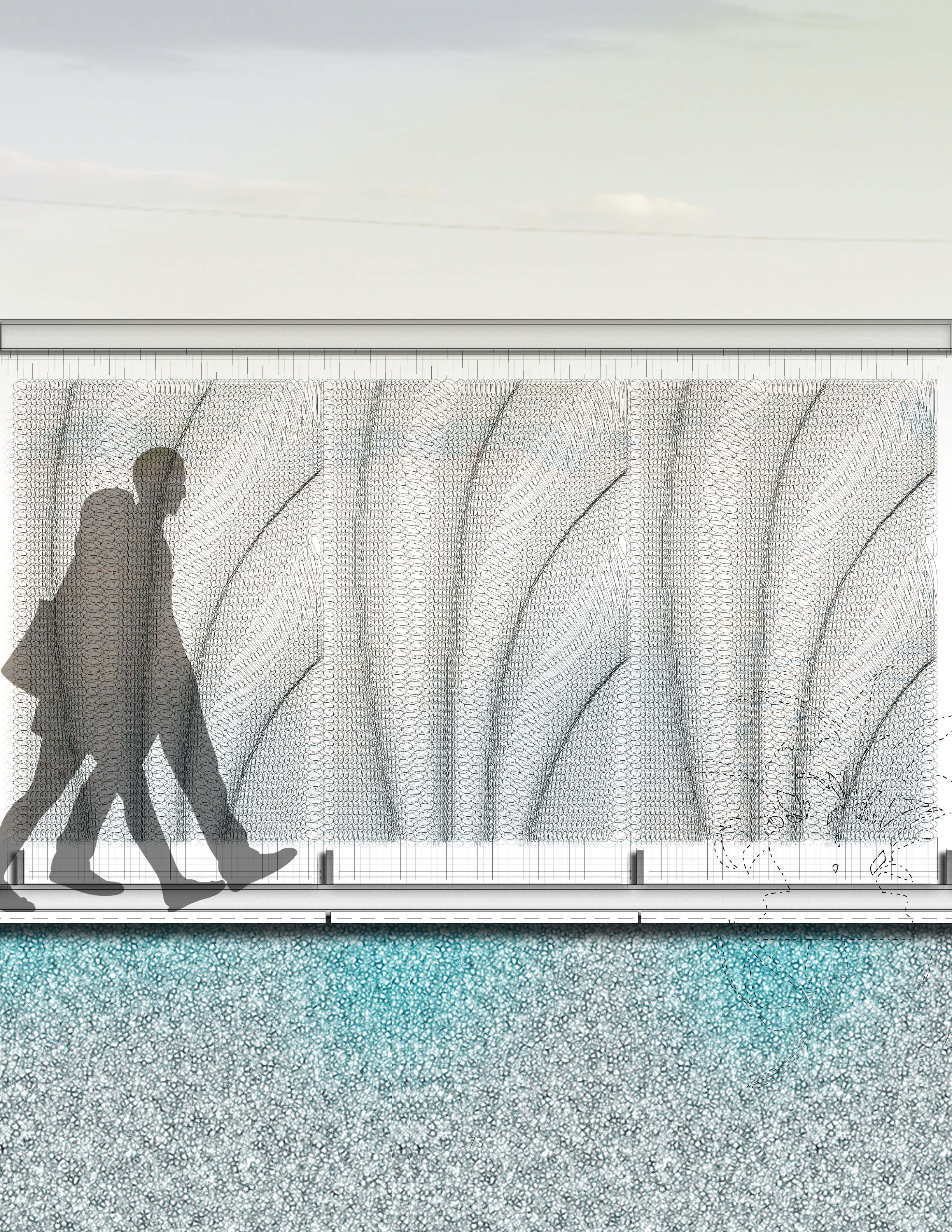


Fig. 64
Elevation of water harvesting textile

WATER HARVESTING TEXTILE

- harvests atmospheric moisture to augment groundwater levels
- captures and channels water flow
- provides shade and scaffold for plant growth

Fig. 65
Rendering of water harvesting textile



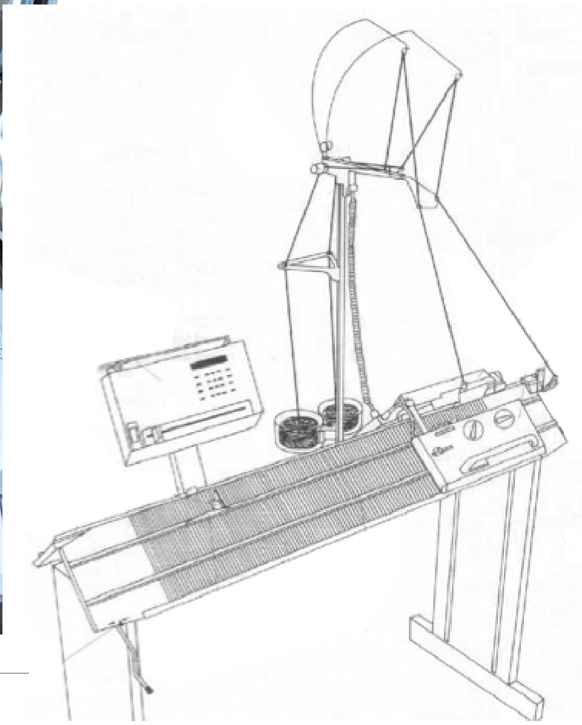
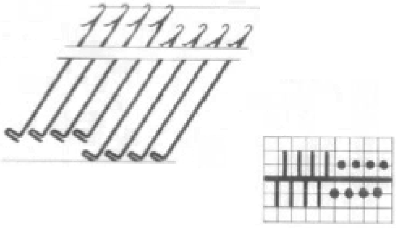


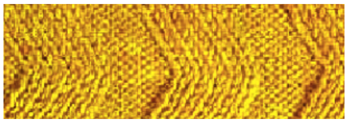
Fig. 66
Passap E6000 flatbed knitting machine

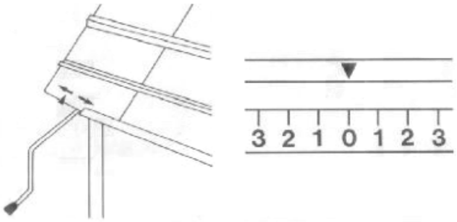
Parameters for Flatbed Machine Kniting

turn needles and pushers on / off to create lace and openwork

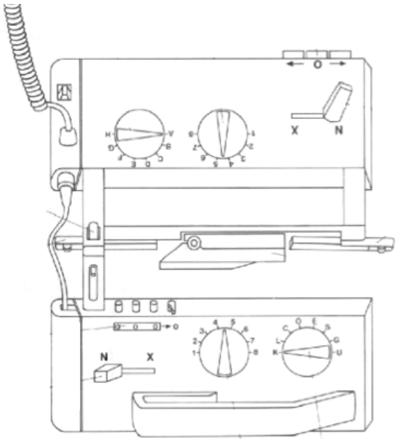


turn racking handle to create an offset pattern





different stitch sizes and stich types (stitch, tuck stitch, no stitch) can be selected



3.1.9

Notes on Fabrication

A series of protoypes were made on a Passap E6000, a computerized flatbed knitting machine. Various fibre and stitch types were tested. To see the effect of moisture on the materials, I used a spray bottle with cold water and misted each sample for up to two minutes. This test was not conductedly scientifically, but it gives a visual indication of how the material interacts with moisture.

Prototype	fibre type	yarn		knitting machine			observations	
		count (nm)	ply	stitch size (1-8)	stitch type stitch (S) tuck (T) no stitch (N)	racking (-3 to 3)	saturation time (s)	other
1	wool	1 / 18	3 ply	3.5	S, T	0	50	water collections in valley bumps saturated
2	wool	1 / 18	3 ply	4.5	S, N	-3 to 3	90	water collection on drop stitches
3	nylon	n/a	1	6	S, N	0	n/a	water remained collected, did not evaporate after 30 minutes
4	polyester	1 / 36	2	2 - 8	S	0	25	saturated quickly in dense areas
5	wool/polyester	2 / 28	3	3 - 6	S, N, T	0	75	collection along drop stitches saturation in dense ribs

Why *knitting?*

- knitting follows a serial logic that lends itself to manual or digital fabrication
- knit mesh fabrics create local turbulence in airflow that can help with water harvesting
- knit fabrics can embody complex geometries
- knit fabrics are flexible and can be prefabricated, easily transported and installed on site

Why *fabrication?*

- although digital technologies may seem inaccessible to rural areas in the developing world, many residents of Aral'sk have a background in skilled trades and would adapt easily to small-scale manufacturing
- while mass-manufactured building materials are increasingly available and are socially desirable, textile craft, woodworking and ceramics are significant in Central Asia's heritage and cultural identity
- new, modern building materials, convey higher social status and are coveted
- small-scale fabrication can be an opportunity for residents of Aral'sk to reinvent and modernise traditional building crafts

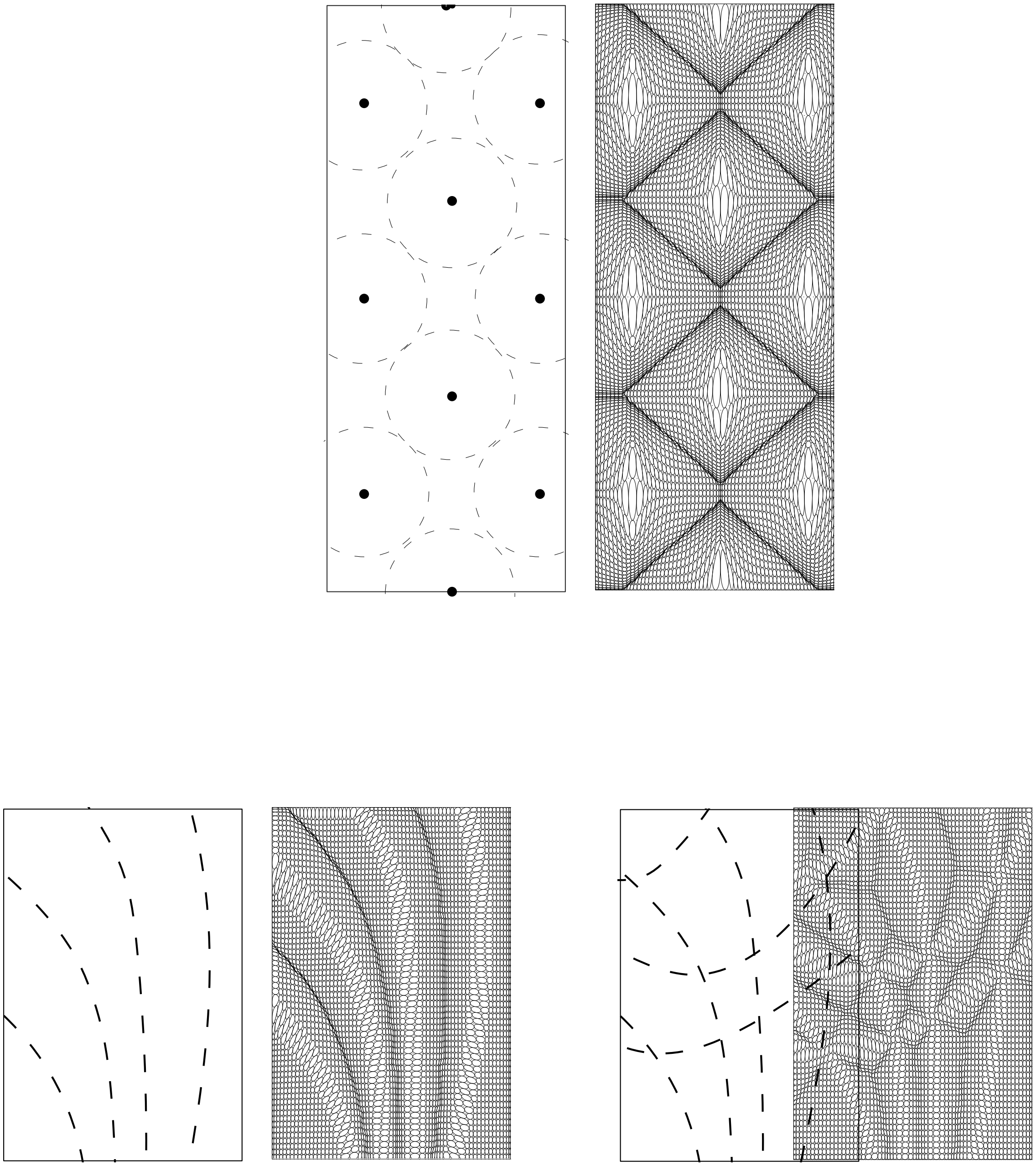
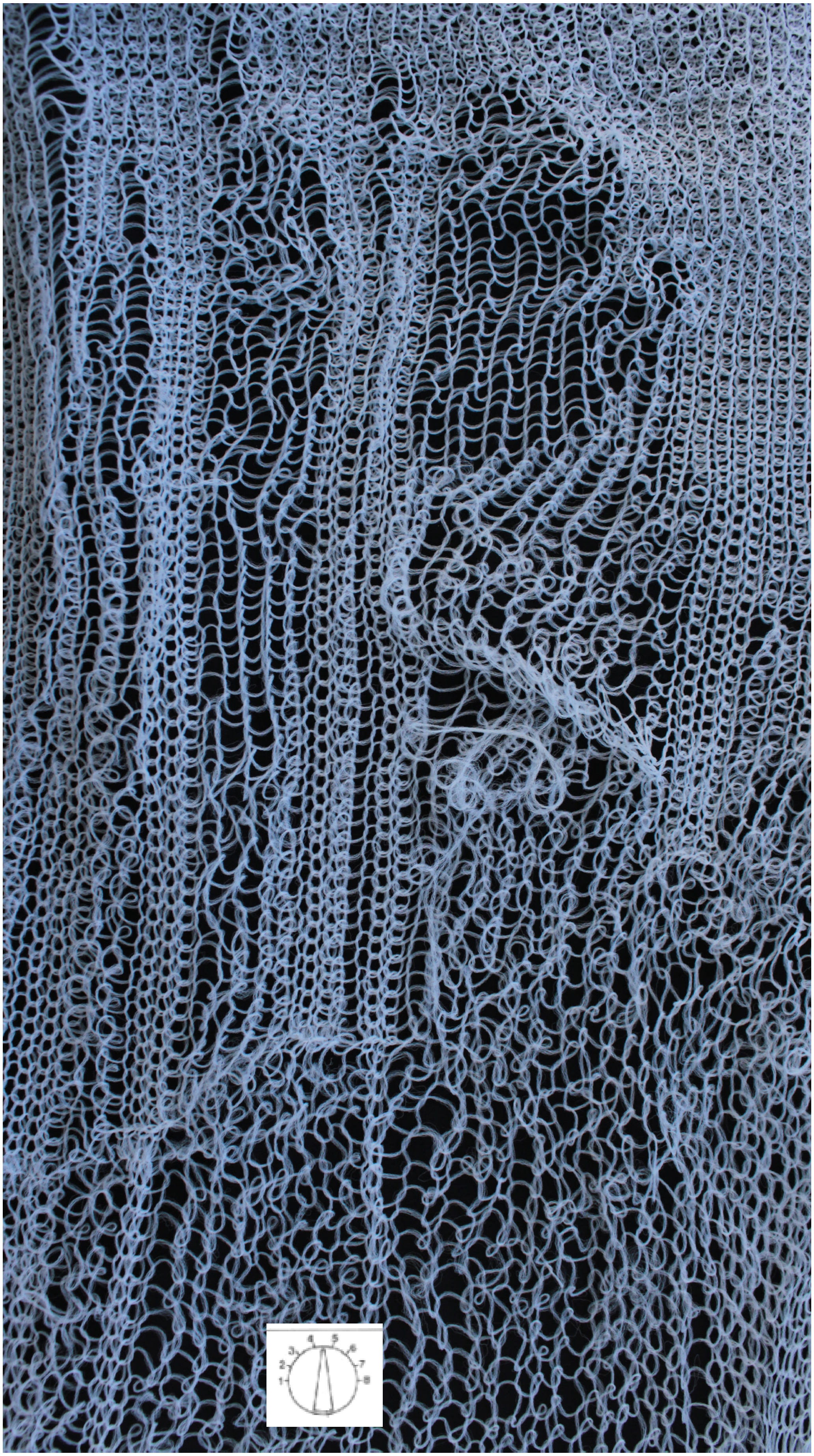
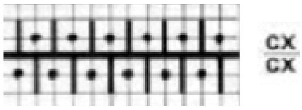


Fig. 67
Attractor points (top) and attractor curves (bottom) were used to generate dense or porous areas in a grid





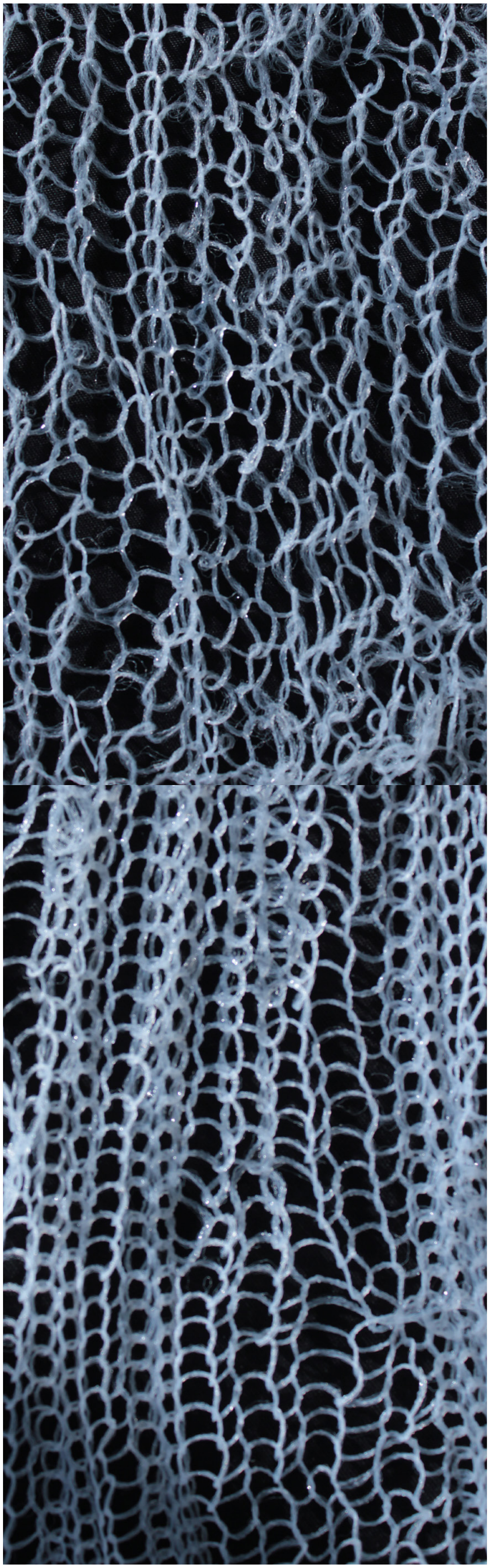
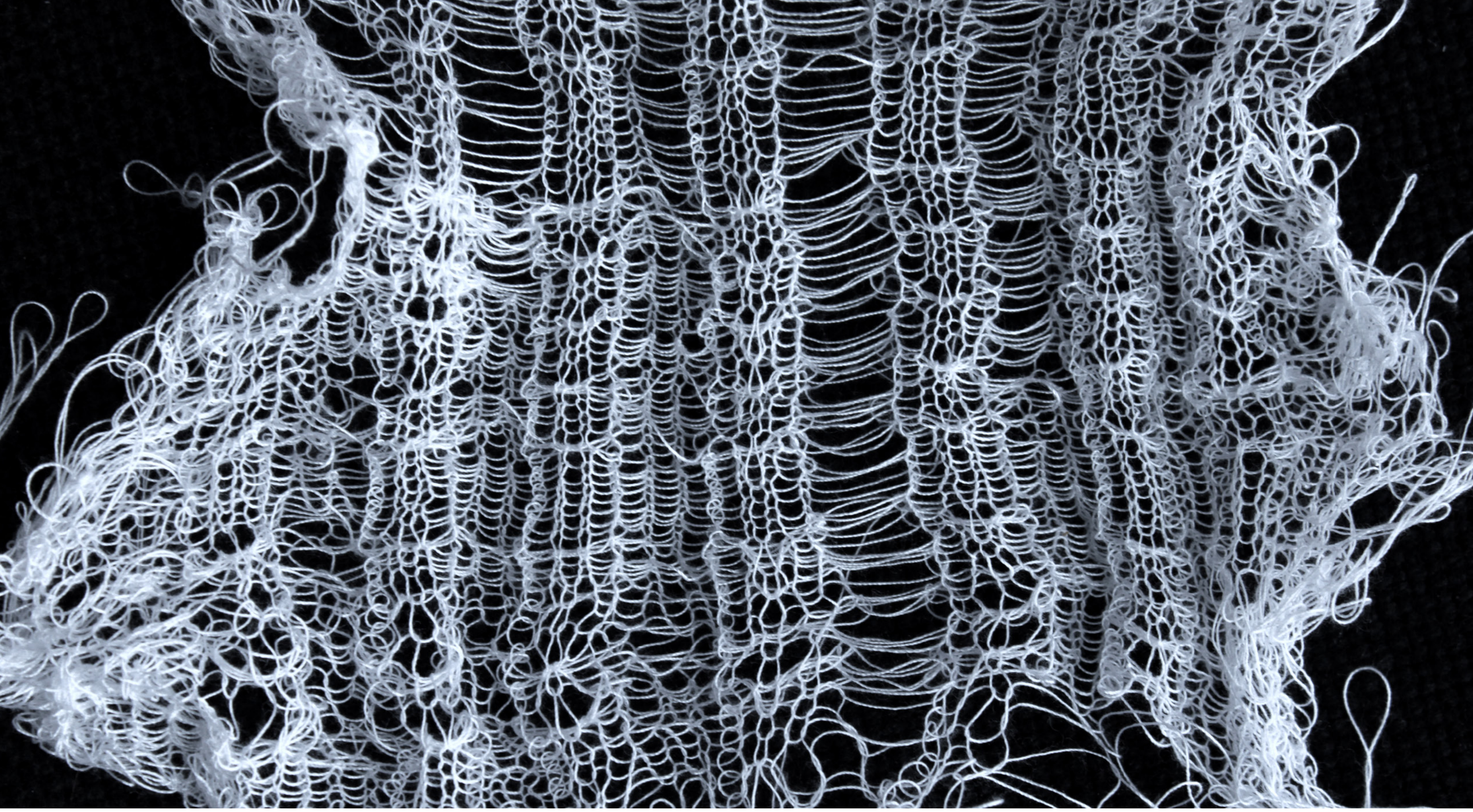


FIG. 68
One way to vary density is to adjust the stitch size



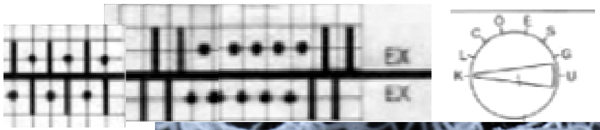
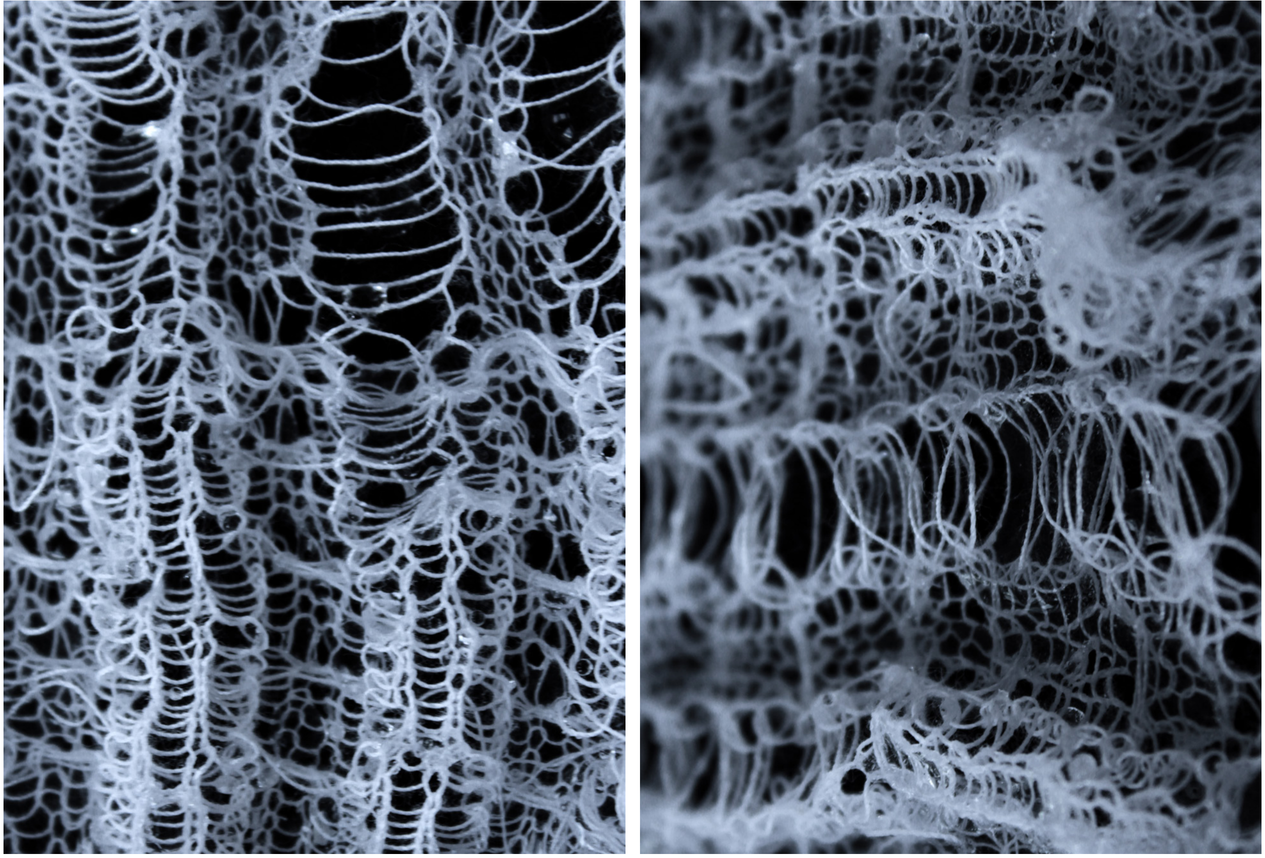


Fig. 69
Another way to vary density is by turning needles on or off, to create openwork (lace) stitches



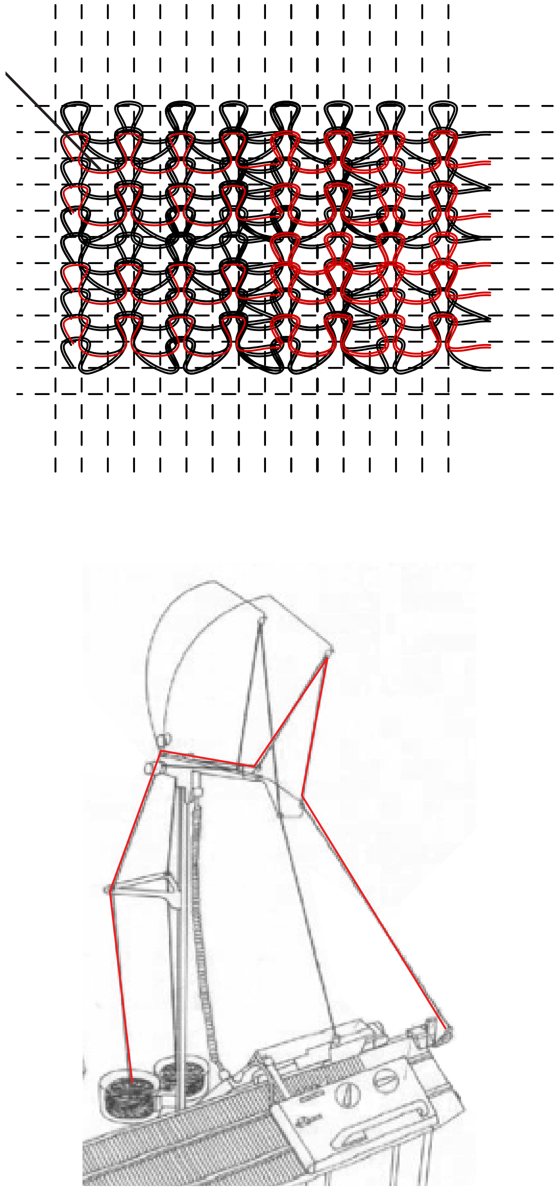


FIG. 70 A composite fabric can be made by interlooping two different fibre types. We tried a matrix with a hydrophobic (polyethylene) and a hydrophilic (cotton) fibre.

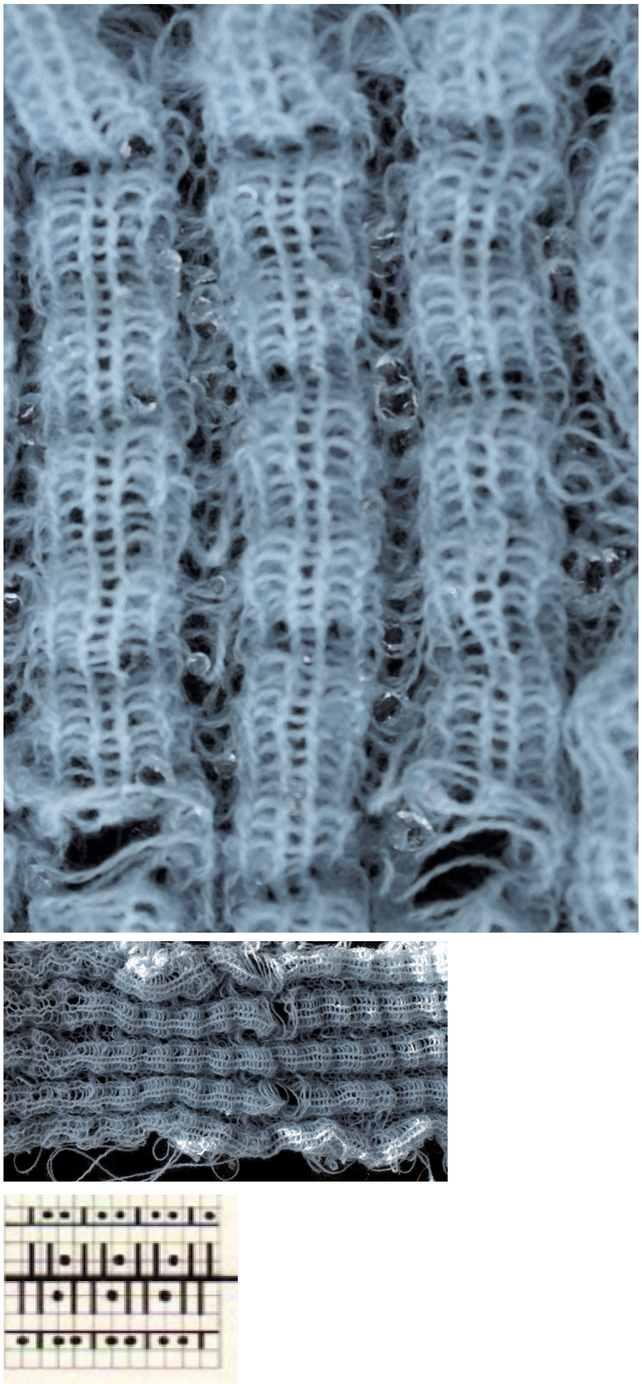
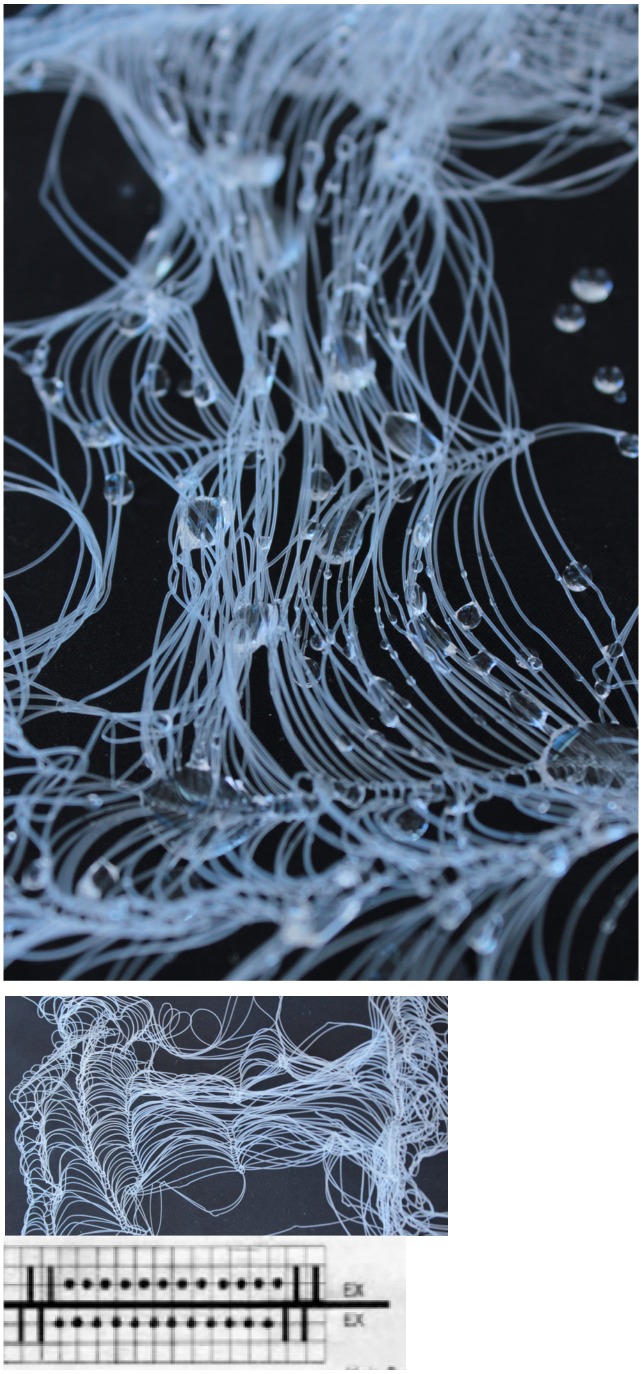


Fig. 71
Reticulated surface creates more surface area to trap moisture



Fɪɢ. 72
Water droplets collect on a polyethylene thread

Fig. 73
Vernacular building materials, sourced locally: mud bricks, straw/reed mats, wool from livestock.

4.0

VERNACULAR ARCHITECTURE AND BUILDING MATERIALS OF KAZAKHSTAN

Fig. 74
Readily available raw materials for construction: animal wool and reeds

Fig. 75
Mud bricks made from loess, an aeolian clay found in the Aral region.

4.1

This section presents two vernacular building traditions in Kazakhstan, the fabric *Kiiz Ui* and the mud and straw compound house, describing each as a heterogeneous material system with mechanisms to filter heat and moisture for human comfort.

1. Michaels, Paula A. Curative powers medicine and empire in Stalin's Central Asia. Pittsburgh, Pa: University of Pittsburgh Press, 2003

4.1..2

Climate, Materials, and Seasonal Patterns of Use

The traditional *Kiiz Ui*, which means felt home, is related to the Turkic *yurt* or the Mongolian *ger*. It was the predominant dwelling type found in Kazakhstan prior to the 1930s, when nomadic Kazakhs were settled onto Soviet collective farms. Made of a lightweight wooden scaffold with a layered skin of felt and wool, the *Kiiz Ui* is part of a way of life that is attuned to the climate and the land. Nomadic Kazakh animal herders followed their camels, cattle, and sheep to seasonal pastures in the steppes and river deltas. The portable *Kiiz Ui* allowed nomads to live lightly on the earth, seeking out water and fodder with migration patterns tied to an indigenous knowledge of the land.

Fig. 76
Layers of the Kiiz Ui: a wood scaffold, lined with felt and reed mats

The *Kiiz Ui* is a circular dwelling with a vaulted roof, and is made of components that can be quickly taken apart and put together: The walls are formed by joining 6-8 collapsible trellisses. The roof is formed from bent wooden poles joined at a top ring for a smokehole, leaving the *Kiiz Ui* open to the sky. When assembled, the *Kiiz Ui* is tensioned with woven straps and insulated with felts. All of these fabrics are ornamented with particular iconographies and motifs that tell stories.

The materials for the *Kiiz Ui* comes from the immediate environment. The lattice wall panels are made of bendable woods such as poplar, white willow, reed, or meadowgrass, and the joints are bound together with strips of camel hide. Water-resistant and insulating felts are made from the nomads' own sheep and camels, breeds that are accustomed to the local climate. Every spring and fall, the animals moult, and their fleece is felted via pressure and shrinkage into a waterproof fabric. Wood and wool are organic fibres that have the ability to absorb and give off moisture in balance with the environment. This layered skin of wood and felt allows the *Kiiz Ui* to ventilate in the summer and insulate in the winter, modulating Kazakhstan's harsh continental climate of hot, arid summers and bitterly cold winters.

Fig. 77 (TOP)
The *Kiiz Ui* is made using local reeds.

Fig. 78
Each awl, or clan, camped near a water source.

Under Soviet rule, permanent compound homes were built using traditional earth construction techniques found throughout the region. Most compounds contains a summer and winter house, which families lived in alternately to deal with the extreme heat and cold. These homes are made of reeds and loess, a local aeolian clay of fine silt, sand and clay particles that can be moulded without any admixtures. Heavy fabric curtains are hung inside doors and windows, and the floors are lined with felt carpets. Like the layers of the *Kiiz Ui*, each material contributes to regulating heat and humidity. The summer house is a wood-frame construction with thin walls (~ 25cm) formed by bundles of vertical reeds covered with clay. The winter house has a thicker wall (1-1.5m) created by sandwiching reeds between wythes of loess mud brick, also plastered with clay for waterproofing. Reeds, or interchangeably straw, are a good thermal mass to capture solar heat during the day and to release it at night. In the winter house, thicker mud brick walls provide yet greater capacity for diurnal heat storage. Both materials also absorb and release atmospheric moisture, which has cooling effects.

Fig. 79
A typical Kazakh home has a summer house (left) and a winter house (right)

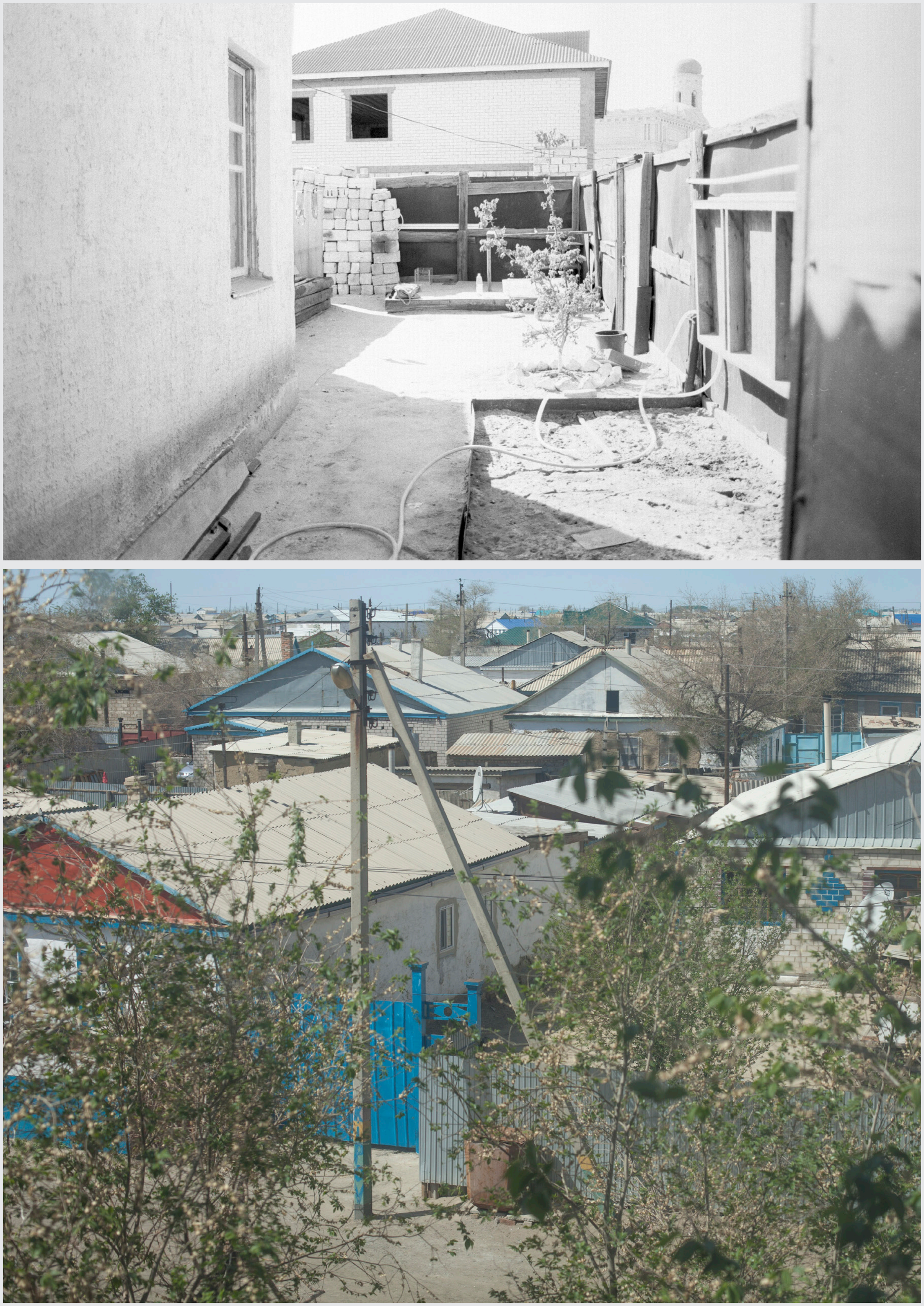


Fig. 80
Homes in an urban area typically have a courtyard, which provides a shaded outdoor living space and workspace, a place to keep livestock, and shields the home from dust storms and pollution.

Fig. 81
Heavy felt or pile velvet curtains keep the heat, cold, and dust out.

Fig. 82
New, affluent homes in Aral'sk have brick cladding.

Fig. 83
The construction of a summer house, filled with straw/reed walls

Fig. 84
Mud brick building finished with an outer coat of *paqsa*.

4.1.3

Aral'sk: The Evolving Vernacular

With the rapid desertification of the North Aral Sea in the 1990s, Aral'sk has experienced rapid climate change and loss of local livelihoods. Desertification caused a mass exodus of the Soviet community, and the relocation of fishermen to other regions, leaving behind a marginalized Kazakh population. However, with the construction of the Kok-Aral dam, water levels in the North Aral Sea have stabilized, a small-scale fishing industry has revived. More recently, renewed growth has occurred through construction work peripheral regional oil and gas extraction at the Caspian Sea.

In Aral'sk, a typical home consists of a summer and winter house, bound by a walled enclosure to provide shade and to keep out blowing sand. The enclosure may also contain an outhouse, storage sheds, a bathhouse, stables, and yard space for keeping animals, gardening, or for various skilled trades. Homes are built by individual families and expanded upon over time, evolving with a family's needs: rooms are multi-functional, new rooms are added for a growing family. An old house may become a stable; and a defunct outhouse is filled in and used as a storeroom.

One can read the urban fabric of Aral'sk as a catalogue of social change, as reflected through changes in available materials and technology. Building materials are indicators of available resources and social status. As ecology declined with desertification, it was no longer possible to make foundations and roofs out of reed mats sealed with a layer of waterproofing clay. Instead, concrete foundations and sheet metal roofs are popular. As an infill for concrete plinth foundations, rubble harvested from decayed buildings is used. Recycled materials from abandoned factories are also used. Scrap metal, stripped from abandoned ships or from old oil drums, are commonly seen on roofs and enclosure walls.

With renewed wealth, building facades reflect the new affluence. At its simplest, mud houses are finished in a compacted mixture of clay and straw called *paqsa*. Families who can afford to will add more coats for a better finish, or opt for an outer coat of fine clay and sand, whitewashed plaster, stucco or painted friezes. Newly wealthy families often choose to clad exterior walls in kiln-fired bricks, which are highly regarded

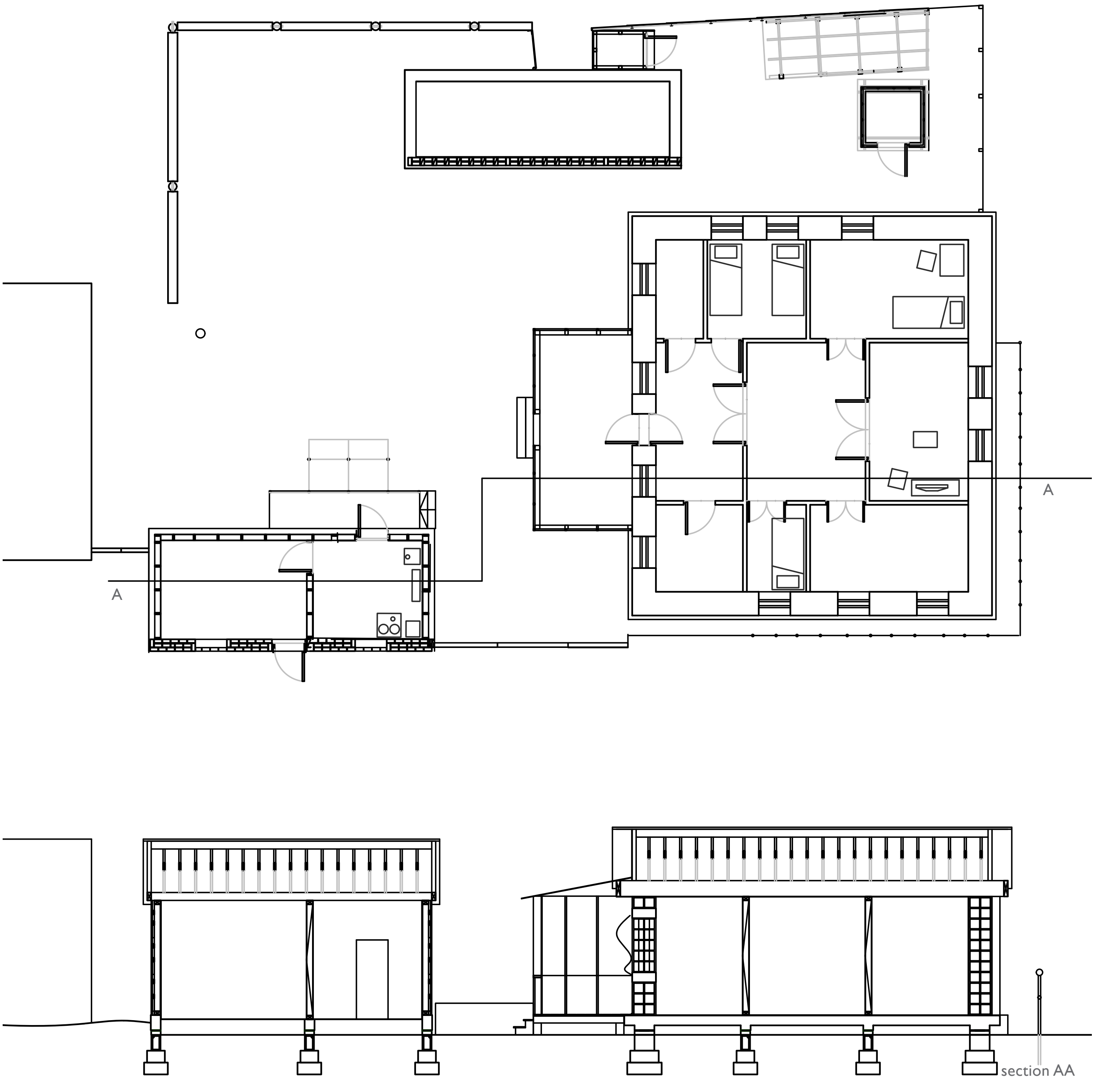
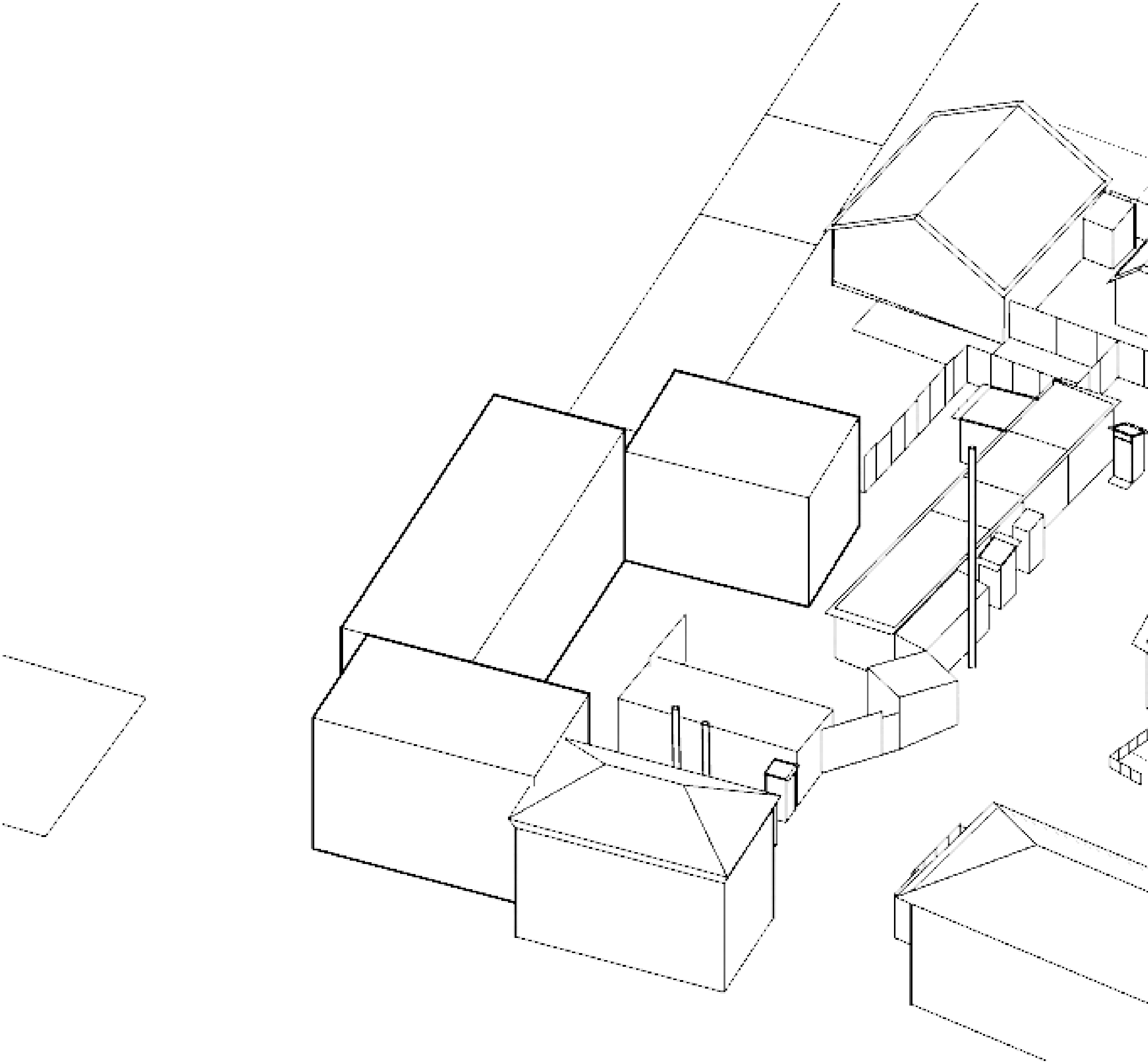


Fig. 85
A typical Kazakh home has a summer house (left) and a winter house (right) and various outbuildings



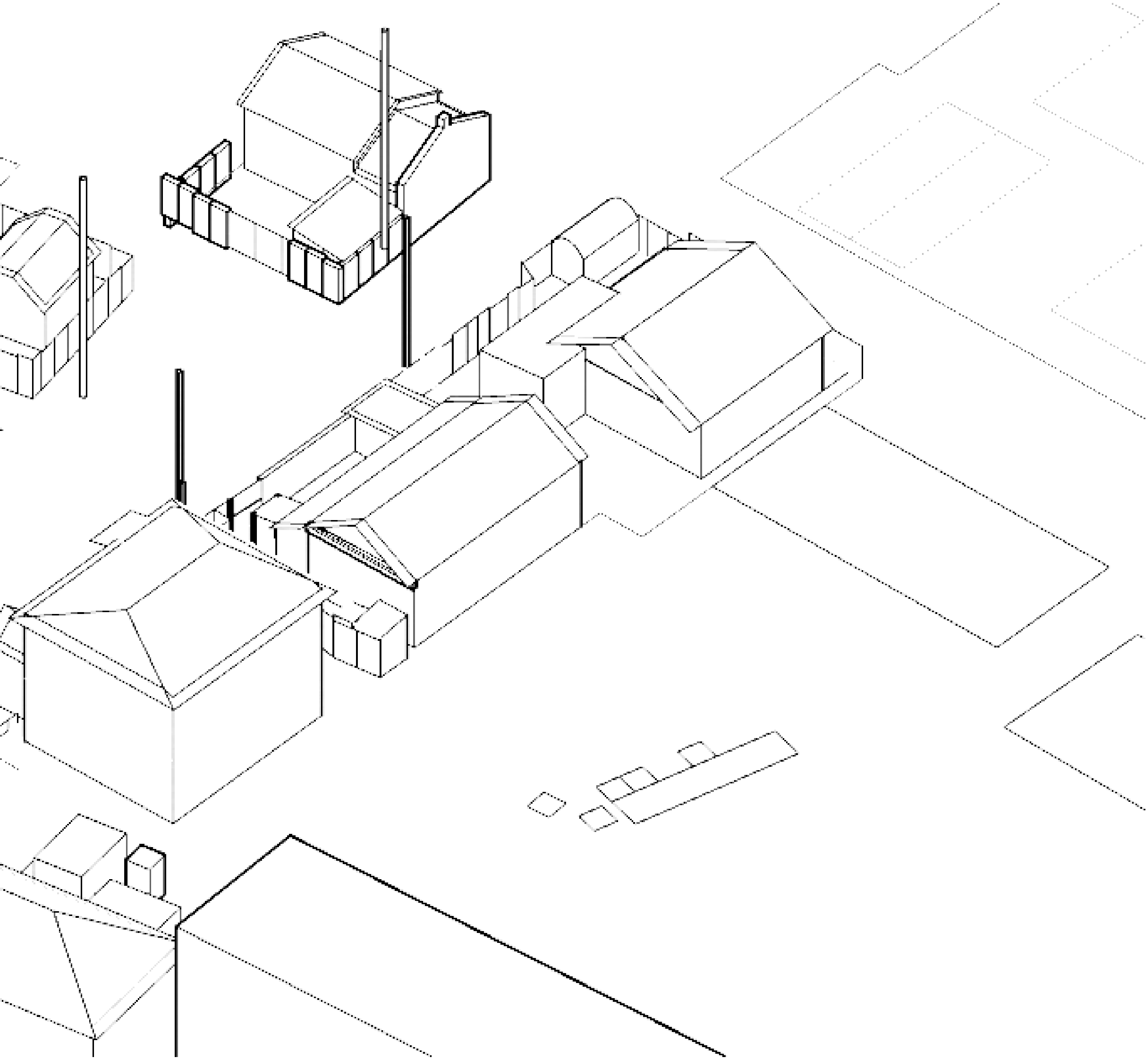


Fig. 86
An urban neighbourhood
in Aral'sk is composed on
incrementally built homes.

FIG. 87
The tapchan is an outdoor space to dine and work.

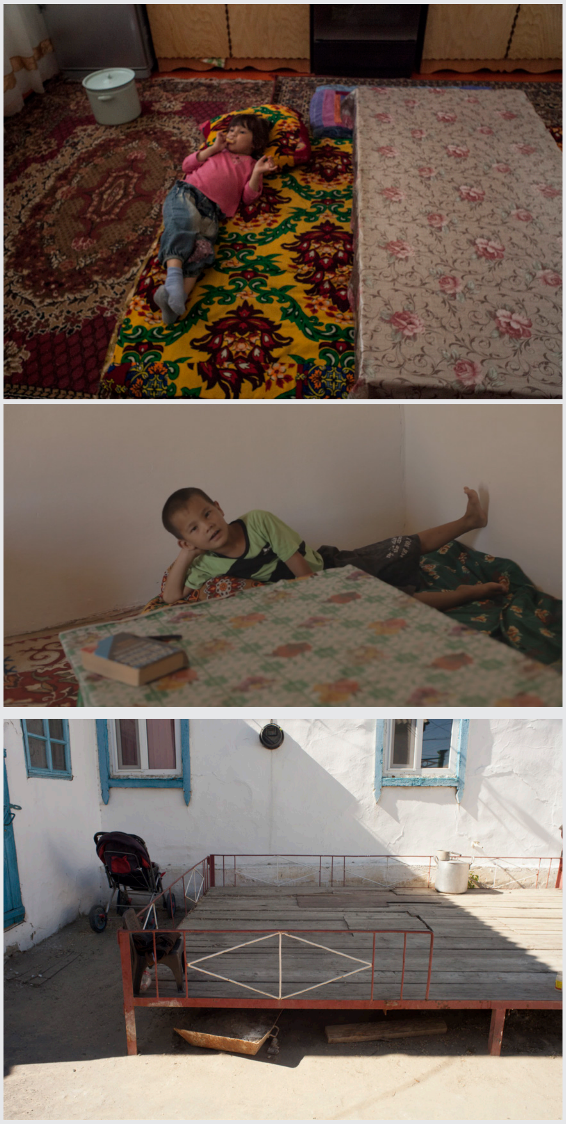


FIG. 88
The felt rug is used as a seat during mealtimes, and as a bed at night.

Fig. 89
The fishermen's hut

aesthetically. The thermal properties of mud and reed or straw. are still preferred for wall cavities.

One of the oldest dwelling types found at the Caspian and Aral Sea is the *shoshala*, a dugout made of logs, adobe, or wattle and daub. The roof is covered with a thick layer of turk. In Tastubek, a newly revived fishing village Aral'sk, fishermen live in dugouts made with sandbag walls and corrugated metal roofing, which is covered with thick layers of grass and earth to prevent heat gain, providing cooling shelters on the exposed sandshore.

4.1.4
Furnishings and Living Spaces

Living spaces are created by taking out and putting away small, nomadic furniture throughout the day. A low table is brought out for meals, and patterned felt rugs are spread around it for seating. The same felt rugs are unrolled for sleeping. The *tapchan*, an elevated wooden platform built in the yard, or any indoor room can be transformed into dining or sleeping spaces, according to the season. Many Kazakh families own European furniture sets, but this is usually a status symbol, since the transient furnishings of their nomadic customs are more commonly used from day to day and deeply cherished.

One can read the felt rug as an intimate architecture, a second skin, that modulates different seasonal climates: when sleeping in the open on a cool summer's night, it encourages perspiration yet wicks moisture away from the body; in the winter it is used indoors and retains heat.

Fig. 90
The tapchan is a raised platform for eating, reclining, sleeping, shaded and cooled by reed screens or trees. Felt bedding piles spread out during mealtimes to make a place for eating.

4.1.5
Summary

To create comfortable living conditions for humans in a hostile climate, the building envelope of Kazakh vernacular architecture modulates heat and humidity through its subtle material properties and multi-layered assembly. Although industrial products like sheet metal and mass-manufactured brick are increasing available, and socially desired, traditional crafts using materials gathered from native plants, animals, and local soil continue to be prized for their ability to provide thermal comfort. The revival of traditional crafts are also cherished as part of the Kazakh culture. The instrumental, and cultural relevance of material craft continue to find their way into modern Kazakh homes.

The materials studies in the previous chapter were conceived as part of this tradition of composite building envelopes that control the passage of heat and humidity through their material properties. Older technologies have been effectively adapted for building envelope of Kazakhstan's rural and informal homes today. New materials, and new material fabrication methods, are relevant to the ongoing development and transformation of the Kazakh vernacular.

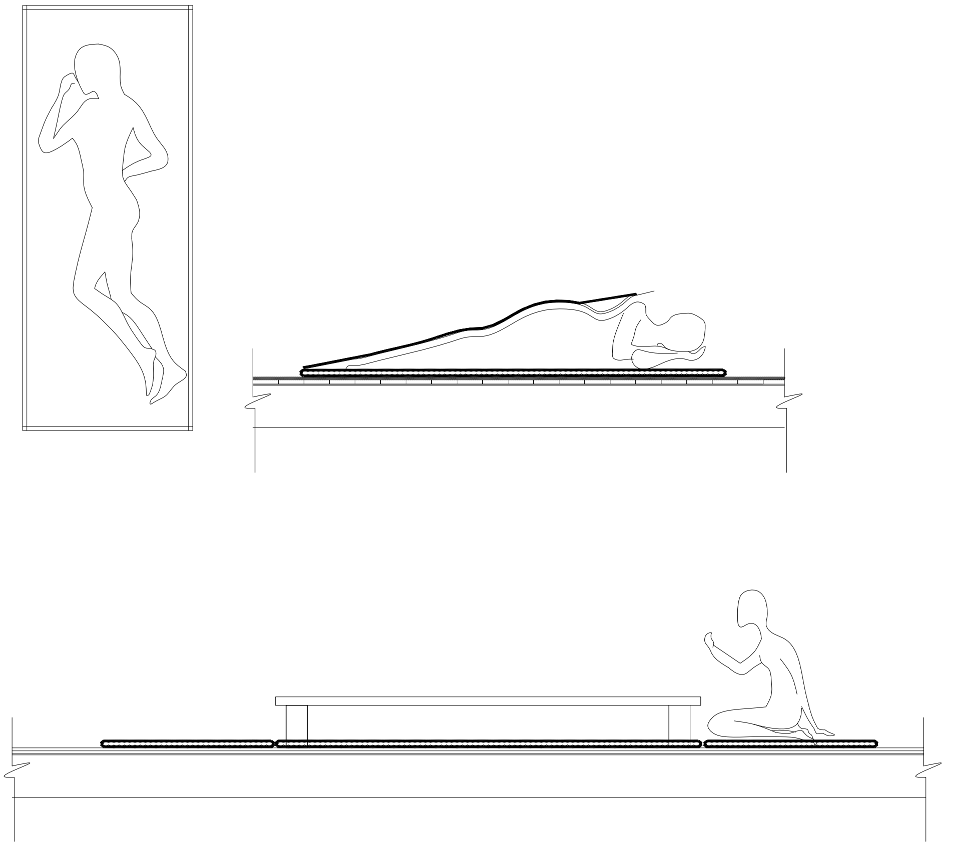


Fig. 91
The felt rug is used as a bed at night, and a seat during mealtimes.

FIG. 92
Industrial ruins (foreground) and
new homes (background) in Aral'sk.

5.0

TOWARDS A LOCAL WATER CATCHMENT

5.1

New Paradigms for Local Water

Amid growing concerns over resource insecurity, unequal distribution, environmental degradation, and a disconnect between state decisions and how they affect communities, there are many examples of community groups around the world that have responded to the volatile effects of climate change with local action. An emerging paradigm in water issues is that of decentralized water management with "soft," diversified, low-impact strategies. Emphasis is placed on improving the local watershed by finding multiple ways for water to flow through cities instead of out of them, of slowing down the movement of water.

FIG. 93

Local knowledge and low technologies offer creative solutions that are a subtle response to scarcity.

A selection of material systems that harvest moisture from the air, found in vernacular buildings in arid regions.

TOP LEFT: Stone mounds surround olive trees in the Negev desert. Plants that grow within this enclosure do not need to be watered.
TOP RIGHT: Double-wythe stone walls closed on the top rows form a condensation chamber, condesnsing dew for irrigation as temperatures shift diurnally
BOTTOM LEFT: Rounded earth bricks moulded in a wicker basket, used for garden walls in the Sahara. The open lattice actually protects living spaces from sandstorms, since a closed wall would cause sand build-up. :

5.1,2

The Pacific Institute's "Soft Paths Approach" for Water

The Pacific Institute's "soft paths approach" to water management prioritizes user needs over simply supplying water. Different demands require different water quality/types. In opposition to hard infrastructure engineered to deliver and treat water for generic use, it promotes "water systems that supply water of various qualities for different uses,"[1] necessitating direct consultation with water users at various community scales. It also defines strategies for collective action, where parties with an interest in the water source or its use can engage collectively, pursuing common goals or sharing benefits, and sharing responsibility.

---

[1] Soft Path for Water. The Pacific Institute, Oakland, California. Retrieved from http://pacinst.org/issues/sustainable-water-management-local-to-global/soft-path-for-water/

5.1.3

Water Sensitive Urban Design

Water Sensitive Urban Design is a guideline for reducing stormwater runoff in cities, based on interdisciplinary cooperation between water management, urban design, and landscape planning.[2] It is predicated on the awareness that hard urban surfaces disrupt the natural water cycle of precipitation, infiltration, and evaporation. Water functions are also invisible in the city's hard infrastructure, and are revealed only during extreme events of flood or drought. Guidelines for water sensitive urban design identifies strategies and technical systems that interact with the water cycle to provide practical and aesthetic benefits for various community scales. Water Sensitive Urban Design aims to shift existing water management paradigms towards:

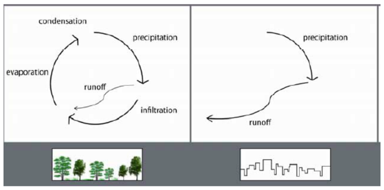


FIG. 94
The water cycle in
natural systems (right)
vs. water in an urban area (left)

- urban water management systems that enable local water detention
- decentralized, on-site water treatment, local water source
- technologies: rainwater harvesting, treatment, detention, infiltration, transport and evapotranspiration
- filtration and retention techniques into landscape, "multiple use corridors" that become aesthetic and recreational amenities
- minimizing impervious areas using local detention and retention measures
- strategies and systems to harvest and recycle rainwater in the landscape, and materials and shapes in the playground that make water more visible, interactive, and engaging for visitors of all ages
- implementation at different levels, from a local park to a city masterplan

[2] Hoyer et al. p.18

5.2

Social Connection to Water

In *Architecture for Rapid Change and Scarce Resources*, Sumita Sinha, an educator with extensive experience in development activism, candidly discusses the challenges and complexities of working in situations affected by climate change, the scarcity of natural resources, and economic inequality. Sinha stresses that these issues mean different things to different people, communities and cultures. "Architecture," Sinha writes, "is linked to our senses and social communication - a development of visual and cultural identities."[1] She attributes a major challenge of development, where people and governments do not appear to consider the environmental consequences of their actions, to a "failure to make connections between how we live and what effect this may have on the environment."[2] The movement of material goods and the interdependent networks of their making are largely invisible to the average person. People are better at linking cause and effect to things that they can touch and feel, than to something distant.[3] This suggests that our immediate environment can help foster these connections. Sinha carefully cautions against giving the built environment a deterministic role that absolves users of responsibility for their actions, such as treating a slum settlement as an explanation of poor social behaviour, rather, she turns to wide-ranging topics including traditional cultural philosophy, economics, foreign aid, and women's issues to identify how the individual may relate to the environment.

In an essay in *The Guardian* on April 2014, Rebecca Solnit demands direct engagement with the consequences of climate change: "That's a tired phrase, the destruction of the Earth, but translate it into the face of a starving child and a barren field – and then multiply that a few million times. Or just picture the tiny bivalves: scallops, oysters, Arctic sea snails that can't form shells in acidifying oceans right now."[4] Her impassioned writing directs us to small stories connected to global events, through which we can refocus our priorities.

Working among marginalized communities in developing countries, Sinha prefers philosopher Tsunesaburo Makiguchi's definition of happiness as a way of measuring value. Makiguchi writes that happiness can be found in three forms:

1. Beauty: an aesthetic value that enhanced specific aspects

---

[1] Sinha, Sumita. 2012. Architecture for rapid change and scarce resources. London ; New York: Routledge. p.4

[2] Sinha. p. 17

[3] Sinha. p. 18

[4] Solnit, Rebecca. 7 April 2014. Call climate change what it is: Violence. The Guardian, http://www.theguardian.com/commentisfree/2014/apr/07/climate-change-violence-occupy-earth.

of an individual's life
2. Gain: enhance individual's life
3. Good: enhance entire community or society

Together, beauty, goodness and gain "create value,"[5] values that are not absolute but are based on a sensory response, relative to the observer and context. Sinha hopes that architecture for people affected by limited resources engage with and create beauty, gain and good. Beauty can bring about discovery and engagement.

In designing material behaviours, and making legible material performance, architecture and its materials allows us to imagine more meaningful connection to water and its flows.

---

[5] Sinha. p. 23

Conclusion

Water is a cyclical phenomenon, yet conventional building materials in contemporary architecture are typically uniform materials that reject, rather than engage in the dynamic flows of water. This thesis presents a strategy for designing a textile that passively collects moisture to augment the local water catchment at the Aral Sea. By varying a material's physical properties, materials can modulate energy flows for thermal regulation or water collection.

The writings of Michelle Addington and Hasan Fathy demonstrate how, by manipulating material properties, building materials can play a strategic role in calibrating subtle thermodynamic flows to create a comfortable living space. Building materials that filter heat and moisture are important in the vernacular building traditions of Kazakhstan. Water-sensitive building materials play an important role in contributing to the local water catchment, improving the local climate and sustaining fertility.

For communities in the Aral Sea basin, research shows a disconnect between local water values and practices and the spaces of contemporary water delivery. This supports a need water to be visible locally, and for local water sources. 'Soft' water management paradigms, which have emerged in response to fraught, and politically contested water sources, shift focus to local water harvesting strategies to create a local watershed. If architectural materials are consciously designed to work with the water cycle, they can temper conditions of aridity, and aim to foster tangible connections among people and the dynamic flows of water.

Bibliography

THE ARAL SEA

Austin, P. (2006). Peter Zavialov, Physical Oceanography of the Dying Aral Sea. Journal of Paleolimnology, 36(3), 323-324.

Boomer, I., Aladin, N., Plotnikov, I., & Whatley, R. (2000). The Palaeolimnology of the Aral Sea: A review. Quaternary Science Reviews, 19(13), 1259-1278.

Ellis, W. (1990). A Soviet Sea lies dying. National Geographic, 177(2), 72-92.

Michaels, P. A. (2003). Curative Powers: Medicine and Empire in Stalin's Central Asia Pittsburgh: University of Pittsburgh, Digital Research Library 2011.

Micklin, P. P. (1988). Desiccation of the Aral Sea: A water management disaster in the Soviet Union. Science, 241(4870), 1170.

Micklin, P., & Aladin, N. V. (2008). Reclaiming the Aral Sea. Scientific American, 298(4), 64.

Oberkircher, L., & Hornidge, A. (2011). " Water is life"--farmer rationales and water saving in Khorezm, Uzbekistan: A lifeworld analysis. Rural Sociology, (3), 394-421.

A Way of Life Evaporates. (the Aral Sea).(1991). The Economist (US), 320(7725), 59.

Ziegler, C. E. (1985). Soviet Images of the Environment. British Journal of Political Science, 15(3), 365-380.

ENVIRONMENTAL THOUGHT, INCLUDING NEW MATERIALIST PHILOSOPHY

Bennett, J. (2010). Vibrant matter : A political ecology of things. Durham; Durham N.C.]: Durham : Duke University Press.

Goodbun, J., & Jaschke, K. (2012). Architecture and Relational Resources: Towards a New Materialist Practice. Architectural Design, 82(4), 28-33.

Goodbun, J., Till, J., & Iossifova, D. (2012). Themes of Scarcity. Architectural Design, 82(4), 8-15.

Halsey, M. (2006). Deleuze and Environmental Damage : Violence of the Text. Aldershot, England ; Burlington, VT: Ashgate.

Harman, G. (2009). Prince of Networks : Bruno Latour and metaphysics. Melbourne: Melbourne : Re.press.

Latour, B. (1993). We have Never Been Modern. Cambridge, Mass.: Cambridge, Mass. : Harvard University Press.

Morton, T., 1968-. (2007). Ecology without Nature : Rethinking Environmental Aesthetics. Cambridge, Mass.: Harvard University Press.

Vogel, S., 1940-. (1994). In nd ed.,rev.and expanded / illustrated by Susan Tanner Beety and the author. (Ed.), Life in Moving Fluids : The Physical Biology of Flow. Princeton, N.J.: Princeton University Press.

COMPUTATIONAL TEXTILES

ACADIA (Conference) (28th : 2008 : Minneapolis,,Minn). (2008). In Kudless A., Oxman N., Swackhamer M. and Association for Computer-Aided Design in Architecture. (Eds.), ACADIA 08 : Silicon + skin : Biological processes and computation : Proceedings of the 28th annual conference of the association for computer aided design in architecture (ACADIA) : October 13-19, 2008. United States: Association for Computer-Aided Design in Architecture.

Albers, A. (1972). On Weaving. Middletown, Conn.,Wesleyan University Press 1972: Middletown, Conn.,Wesleyan University Press 1972.

Aronson, S. (2008). Aridscapes : Proyectar en tierras ásperas y frágiles = designing in harsh and fragile lands. Barcelona: Barcelona : GG.

Bainbridge, D. A. (2007). In Society for Ecological Restoration International (Ed.), A guide for desert and dryland restoration : New Hope for Arid Lands. Washington, DC: Island Press.

Barrow, C. J. (1999). Alternative irrigation : The promise of runoff agriculture. London: Earthscan.

Chen, Q., Fan, J., Sarkar, M. K., & Bal, K. (2011). Plant- based biomimetic branching structures in knitted fabrics for improved comfort- related properties. Textile Research Journal, 81(10), 1039-1048.

Eadie, L., & Ghosh, T. K. (2011). Biomimicry in Textiles: Past, present and Potential. An Overview. Journal of the Royal Society Interface, 8(59), 761-775.

Emery, I. (1966). In Textile Museum (Washington D. C.). (Ed.), The primary structures of fabrics : An illustrated classification. Washington, D.C. : Textile Museum.

Flake, G. W. (1998). The Computational Beauty of Nature : Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation. Cambridge, Mass: MIT Press.

Hardy, S.T. (2008). Environmental Tectonics : Forming Climatic Change. London : AA Publication.

Kolatan, F. (2010). In Sabin J. E., University of Pennsylvania. School of Design and Pratt Institute. School of Architecture (Eds.), Meander : Variegating Architecture (1st ed. ed.). Exton, PA : Bentley Institute Press.

McEwen, I. K. (1993). Socrates' ancestor : An Essay on Architectural Beginnings. Cambridge, Mass.: MIT Press.

Oxman, N. (2010). Material-based Design Computation. Massachusetts Institute of Technology.

Park, K., Chhatre, S. S., Srinivasan, S., Cohen, R. E., & McKinley, G. H. (2013). Optimal design of Permeable Fiber Network Structures for Fog Harvesting. Langmuir : The ACS Journal of Surfaces and Colloids, 29(43), 13269.

Scott, J. (2013). Hierarchy in knitted forms: Environmentally responsive textiles for architecture. , ACADIA 13: Adaptive Architecture [Proceedings of the 33rd Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) ISBN 978-1-926724-22-5] Cambridge 24-26 October, 2013). pp. 361-366.

Semper, G., 1803-1879. (1989). The four elements of architecture and other writings. Cambridge England; Cambridge University Press.

Smith, C. S., 1903-1992. (1981). Search for structure : Selected essays on science, art, and history. Cambridge, Mass.: MIT Press.

Spuybroek L. (Ed.). Research & design : The Architecture of Variation(2009). New York: Thames & Hudson.

Spuybroek, L. (2011). Sympathy of things : Ruskin and the ecology of design. Rotterdam : New York, NY: V2 Publishing : NAi Publishing ; Available in North, South and Central America through D.A.P./ Distributed Art Publishers Inc.

Spuybroek L. Textile tectonics(2011). Georgia Institute of Technology. College of Architecture. (Eds.), . Rotterdam: NAi Publishers.

Straube, J. Moisture and Materials. Building Science Digest, Building Science Press, 138

VERNACULAR ARCHITECTURE, INCLUDING CENTRAL ASIAN VERNACULAR

Fathy, H. (1986). In Shearer W., Sulṭān '. a. (Eds.), Natural Energy and Vernacular Architecture : Principles and examples with reference to hot arid climates. Chicago: Chicago : Published for the United Nations

University by the University of Chicago Press.

Fodde, E. (2009). Traditional Earthen Building Techniques in Central Asia. International Journal of Architectural Heritage, 3(2), 145-168.

Laureano, P. (2011). The Water Atlas- Traditional Knowledge to Combact Desertification (A. W. Anna Cirella Trans.). Turin, Italy: Bollati Boringhier.

May, J. (2010). In Reid A. (Ed.), Handmade Houses & other buildings : The world of Vernacular Architecture. London: Thames & Hudson.

Oliver, P. (1997). Encyclopedia of Vernacular Architecture of the world. Cambridge ; New York : Cambridge University Press.

Oliver, P. (2003). Dwellings : The Vernacular House World Wide. London ; New York : Phaidon.

Petruccioli, A. (2007). After Amnesia : Learning from the Islamic Mediterranean Urban Fabric. Bari, Italy: Bari, Italy : ICAR.

URBAN WATER & DESIGNING FOR DESERT CONDITIONS

Aronson, S. (2008). Aridscapes : Proyectar en tierras ásperas y frágiles = designing in harsh and fragile lands. Barcelona: Barcelona : GG.

Bainbridge, D. A. (2007). In Society for Ecological Restoration International (Ed.), A guide for Desert and dryland restoration : New Hope for Arid Lands. Washington, DC: Island Press.

Barrow, C. J. (1999). Alternative irrigation : The Promise of Runoff agriculture. London: Earthscan.

Hoyer, J. (2011). Water Sensitive Urban design : Principles and Inspiration for Sustainable Stormwater Management in the City of the Future. Berlin : Jovis.

SOCIAL ACTIVISIM

Sinha, S. (2012). Architecture for Rapid Change and Scarce Resources. London ; New York : Routledge.

Solnit, R. (2007). Storming the Gates of Paradise : Landscapes for politics. Berkeley: University of California Press.

OTHER MATERIAL SYSTEMS

Addington, D. M. (2005). In Schodek D. L. (Ed.), Smart Materials and New Technologies : For the Architecture and Design Professions.

Amsterdam ; Boston: Architectural Press.

Margolis, L. (2007). In Robinson A. (Ed.), Living systems : Innovative Materials and Technologies for Landscape Architecture. Basel : Boston : Birkhäuser.

Appendices

The appendix contains two projects that point to how different aspects of this thesis research can be applied, or further developed.

Appendix 1

The first appendix contains a grant application I had written and submitted to the Toronto Arts Council for an art installation entitled *WaterWise* in 2013, intended as part of a grassroots water harvesting masterplan developed by the non-profit organization Friends of Roxton Road Parks in Toronto. The grant application suggests a possible way of connecting people to local water, and ways of making water visible and engaging in a public space. It is included here because the social and cultural context of Toronto is vastly different from the cultural and material history of Aral'sk, in both situations, it is important connect to water as a resource, in order to care about it and make decisions about its use based on a meaningful connection. By making visible the mechanisms of water and materials in everyday spaces, perhaps fundamental shifts can occur in how we think about water.

Appendix 2

The second appendix contains a conference paper presented at Sigradi 2013 in Valparaiso, Chile on the computational generation of moisture-sensitive fabrics. Computationally generating fog-harvesting fabrics is an area of further development for the thesis.

Appendix I

(excerpt from a participatory art grant application to the Toronto Arts Council)

Water is a vital resource that is deeply connected to human health, culture and development, yet the connection between the city and where our water comes from is largely invisible. In *WaterWise*, a primary goal is to restore the material reconnection of the community of the Prettie Ravine to a significant lost environmental and cultural resource, the Garrison Creek of Toronto. Drawing on the universal relationship that people of all cultures have to water, its sensuous delight and its presence in different cultural mythologies, WaterWise aims to reveal Toronto's natural water cycle and to reinstate the dynamic presence of water in the urban environment, to increase awareness of an important shared cultural heritage and legacy. By encouraging urban users to gain tacit knowledge of water and its transformative properties, firstly through guided craft-based innovation, and secondly through immersive play, this public art project has extended objectives of cultivating greater social responsibility for water as a shared neighbourhood resource.

WaterWise is a participatory sculpture of interlinked rope in an undulating topography designed to capture water, encouraging the diverse community groups of Little Italy and Little Portugal to explore the urban water cycle through intergenerational play. Drawing on forms and patterns found in the natural world where water collection and transport are intrinsic biological functions, the sculpture makes these dynamic water processes more visible, interactive and engaging to the public. By increasing the visibility of water in the urban landscape and encouraging a more intimate connection to the properties of water through participatory making, this public art project aims to promote greater social responsibility for water as a shared neighbourhood resource. Through its direct engagement with [...] Friends of Roxton Roads Park and their outreach efforts to foster meaningful social ties amongst user groups of all ages and cultures, the sculpture is also intended to serve as an model for collective learning and better water stewardship in the city of Toronto.

WaterWise forms part of FoRRP's larger revitalization efforts to improve urban water practices at Fred Hamilton Park, George Ben Park, Roxton Road Parkette and their adjacent residential areas [by] developing incremental infrastructures for water harvesting for community use in park programmes. A critical next phase to further community involvement in the master plan is a public art piece that allows community members to become co-authors in the design and creation of their neighbourhood green space. *WaterWise* is a participatory art piece that manifests the values and goals of The Water Harvest by inviting community groups to take part in making a local, water-sensitive landscape, empowering the neighbourhood and ensuring its vitality through a collaborative cultural art piece that will inspire future generations of water-sharing.

WaterWise draws on the artists' own art and research interests in the dynamic properties of environmental forces and ways to intimately connect with the everyday environment. Drawing on forms and patterns found in the natural world where water collection and transport are intrinsic biological functions, *WaterWise* celebrates these natural water processes by making them more visible, interactive and engaging in an urban setting. In the participatory design process, we encourage community groups to reinterpret nature's patterns and forms into a contemporary landscape topography that encourages imaginative and productive play, making the dynamic movement of water not only more visible but also more meaningful through the public's active participation. In doing so, this promotes public awareness of water, its various sources and roles in urban ecology and community development.

Fig. 95 "The Water Harvest," a masterplan for incremental water harvesting systems for Roxton Road Parks in Toronto. Drawing by F_RMlab.

---

overleaf

My contribution to the research for WaterWise includes examples of materials that interact with water to provide stimulating, sensorial experiences. The examples are inspired by nature and tradition, and aim to render urban water processes visible.

Making Water Visible

Inspiration from Traditional Architecture

“People...[in hot climates] have always cherished water and tried to remain in contact with it as long as possible. Apart from its refershing effect physically, it has always had a pleasing psychological effect.” - Hassan Fathy, Natural Energy and Vernacular Architecture

In vernacular architecture, there are many examples of using materials creatively to work with the water cycle and with water movement to create a feeling of sensual delight.

These strategies can be applied to contemporary landscape design.

Case study: Systems that Seep by Eleanor Pries documents water systems around the world that capture, convey and store rainwater, using natural materials

http://archinect.com/features/article/104336/branner-fellowship-summary-drip-dry-systems-that-seep

Case study: The Princess Diana Memorial Fountain (precedent for the wading pool) uses patterns and textures from stone fountains in the Middle East to create a variety of water flows, recreating the movement of a mountain stream, small waterfalls, wavy movements recalling wind and water, and a reflecting pool

Fig. 96

Inspiration from Nature

Plants work with the water cycle, absorbing water from the ground, transporting water through stems and leaves, and evaporating through its pores.
For the playscapes, we are inspired by shapes found in nature - mimicing plant geometries and the way water moves through them, creating areas that support plant growth

For example:
branch-like networks can channel water flow along a surface. eg. the way the water starts to move along the grooves of a leaf: image 15
loops, feathers, pine needles can wick water away from a surface, creating dew droplets. eg. image 16
pine cones expand and contract according to moisture content, providing inspiration for responsive materials that change shape according to water content
Wood structure that moves according to moisture: image 18
Nets/fabrics inspired by how a pine cone expands/contracts according to moisture: image 21

These are ideas that we would like to investigate further for an all-ages climbing structure

FIG. 97

The Water Harvest

Strategies and Techniques

several strategies and systems to harvest and recycle rainwater in the landscape, and materials and shapes in the playground that make water more visible, interactive, and engaging for visitors of all ages.

Strategies for The Water Harvest

collecting rainwater and preventing water runoff
using permeable paving and landscaping materials
using native plants that slow down the movement of water
encouraging maintenance of water harvesting systems through education (eg. local school programs) and outreach
details and designs that make water visible, to improve our relationship and shared responsibility to water as a resource

Natural Systems that Enable Water Harvesting and Recycling in the Landscape

Rain Garden
uses native species that require little to no watering
helps water retention
sited to catch rainwater from downspouts
during heavy rainfall, works like a sponge and natural filter to clean the water and let it percolate slowly into the surrounding soil
mimic the natural absorption and pollutant removal activities of a forest, or a meadow or or a prairie and can absorb runoff more efficiently, sometimes as much as 30% - 40% more then a standard lawn

[Resource: http://www.cmhc-schl.gc.ca/en/co/maho/la/la_005.cfm]

Case Study: In the Kitchener-Waterloo region, a local water conservation non-profit, Reep Green (http://www.reepwaterlooregion.ca), have used rain gardens to harvest rainwater capable of irrigating an entire soccer field at Kitchener Collegiate Institute.

Fig. 98

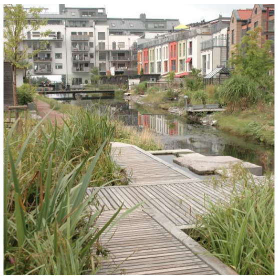
Natural Water Filtration

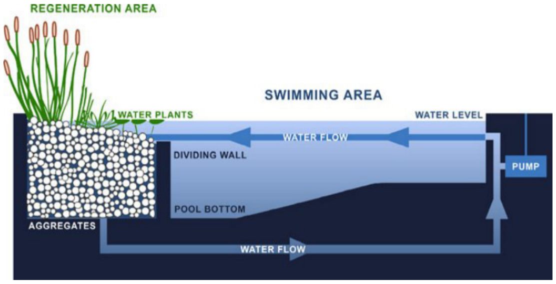
Water filtration system developed for swimming pools which could be implemented for the wading pool
consists of a separate pool adjacent to the pool that uses indigenous aquatic plants to filter water
water is pumped back into the main pool when clean
a natural pool consists of half regeneration area, half swimming area
natural water filtration pools take a year to self-adjust, but a UV sterilizer can be installed to clean water immediately, or to supplement regeneration
currently in use in UK, Germany, etc., with consultants available in Ontario

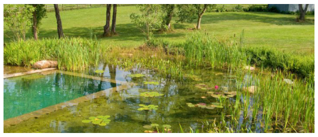
Biotopes, - use natural plants to clean water, so they're
similar to the natural filtration systems for the wading pool, but not
associated with a public pool so we don't have to follow the chlorine
regulations: image 8

Infiltration trenches, swales, geocellular systems and
detention ponds could work instead of cistern. These water storage devices seem to be more integrated with the landscape and more visible: image 9 and image 10

Case Study: In the Kitchener-Waterloo region, a local water conservation non-profit, Reep Green (http://www.reepwaterlooregion.ca), have used rain gardens to harvest rainwater capable of irrigating an entire soccer field at Kitchener Collegiate Institute.







Left: Fig. 14. Detention pond (dry), Gelsenkirchen, Germany (© J. Eckart).
Right: Fig. 15. Detention pond (wet) in Tanner Springs Park, Portland, Oregon, USA (© J. Hoyer).

Left: Fig. 12. Rain garden, Police Department, City of Brisbane, California, USA (© J. Hoyer).
Right: Fig. 13. Swale, Police Department, City of Brisbane, California, USA (© J. Hoyer).

FIG. 99

Appendix II

Fibre Configurations for Moisture Control

Abstract

This research describes a theoretical framework for making water-sensitive architectural fabrics based on an examination of the subtle moisture controls in vernacular architecture. It explores a workflow for the articulation of environmental forces in material microstructure and how these can be amplified at an architectural scale. The interaction between moisture and material properties is modelled using physics simulations in Processing, offering a method to manipulate fibre configurations for new construction logics. The research is illustrated through parallel explorations in computationally generated fibre configurations and multi-scalar textile prototypes. The research aims to demonstrate the potentials of technology transfer from traditional knowledge to contemporary material manipulations.

Keywords: *Vernacular architecture, Simulation, Environment, Textiles*

1. Introduction

Environmental design strategies are being rapidly transformed by new computational paradigms in generative algorithms;[1] at the same time, contemporary concerns of climate change and environmental degradation demand a new engagement with material ecologies and cultural practices of material knowledge. In particular, a renewed interest in the millenial traditions of vernacular architecture and local craft have much to teach us. Vernacular building practices are rooted in an intimate relationship to the environment through its direct engagement with locally-found materials, and through specific adaptations to local climatic conditions that result in strategic microclimatic modification. The subtle controls of moisture, temperature, light, and air in vernacular building envelopes allow for human thermal comfort and sustainable resource practices that exist in a delicate balance with the environment.

Hasan Fathy's Natural Energy and Vernacular Architecture, a seminal text in propelling a scientific understanding of traditional building types, suggests that through a careful examination of

---

[1] de Beaureceuil, A. & Lee, F. (2008). Environmental Ornamentation. In Environmental Tectonics: Forming Climatic Change. S. Hardy (Ed.) London: AA Publications. p.3

thermodynamics and material properties, technologies from the past can still be relevant today. Vernacular buildings passively respond to the environment through the mutual interaction of materials and atmospheric matter. Fathy presents a minute study of subtle natural phenomenon such as heat conduction and convection, or moisture condensation and evaporation, illustrating each as the result of dynamic fluctuations in density, porosity, temperature and moisture content. These dynamic interactions can be controlled through the physical properties of building materials.

Algorithmic processes offer architects increasing access to the physics of materials and structures at multiple orders of scale.[2] The ability to simulate and visualize subtle environmental phenomenon using mathematically generated environmental force systems and their resultant formations allows us to acquire material knowledge at an increased resolution. There are synergies between the generative logic of computational design algorithms, where forms materialize through simulated information flow, and Fathy's study of the vernacular, where material microstructure has a direct relationship to dynamic environmental flows. These synergies offer potential for the technology transfer of vernacular material intelligence using computational simulation and scalable textile craft processes.

Fabrics for Moisture Control

The interaction of material microstructure and environmental forces is clearly illustrated in the making of a textile. A fabric is a flexible surface constructed out of interlinked polymers which are assembled using a serial logic. The way in which the fibres are interlinked determine the characteristics of the fabric, including its structure capacity, material behaviour and performance. A fabric is thus an assembled structure or material system that is inherently hierarchical.[3] Following an algorithmic logic, sets of elements or nested elements are repeated to generate a pattern that determines the fabric's topology. By varying construction algorithms, textiles can be functionally graded, varying in material distribution to suit performance. Textiles are increasingly recognized as high-performance materials, with performance linked to its varied structural capabilities.

Fabrics that are capable of capturing, storing, and distributing atmospheric moisture have a wide range of contemporary applications, from fog harvesting for collect potable water to

2. Andrasek, A. (2012). Open Synthesis: Towards a Resilient Fabric of Architecture. Log, 25. 45-54.

3. Eadie, L. & Ghosh, T. (2011). Biomimicry in textiles: past, present and potential. An overview. Interface: Journal of the Royal Society, 8, 59. Retrieved from http://rsif.royalsocietypublishing.org/content/8/59/761.full

4. Warwick, P. (2005). In Extreme Textiles: Designing for High Performance. M. Mcquaid (Ed.) New York: Princeton Architectural Press.

athletic-wear that transports sweat away from the body to smart responsive shape-changing fabrics. The specific configuration of the weave or knit, creating a material structure with varying density, pattern and topology, allows fabrics to perform functions of water collection or transport. In developing fibre configurations for water functions, researchers often use biomimicry as a framework: notable examples include polymer films that mimic the hydrophobic and hydrophilic bumps on the Namib desert beetle for fog collection,[5] double-layered knit fabrics connected by biomimetic branching stitches for better water adsorption,[6] and the design of shape-changing surfaces inspired by the cellular composition of the pine cone hygromorph.[7]

Vernacular material systems offer a different but related framework for moisture control. Vernacular architectures can also capture, store and distribute ambient moisture for evaporative cooling and water harvesting. Like living organisms, vernacular architectures interact with their local environment by regulating the passage of heat and moisture through their envelopes to create new microclimatic conditions. Vernacular architectures use local materials, organic and inorganic, that are inherently sensitive to air temperature and humidity. These materials are reconfigured with a careful consideration of architectural thermodynamics to benefit from the material's capacity to absorb and release moisture over time.

To begin to create architectural fabrics capable of moisture control, we ask the questions of: how can the articulation of environmental forces in material microstructure be amplified to an architectural scale? What are the relationships between microstructure, pattern and overall topology and how can these be functionally graded for moisture management? The research builds upon existing work on moisture-sensitive biomimetic textiles and extends these experimental research traditions to include factors of porosity, density and time lag, which allow passive moisture regulation in vernacular architecture. The research aims to develop a workflow for creating functionally graded, moisture-sensitive textiles.

2. Research Context

Interaction of Moisture and Materials

The interplay of materials and moisture at different scales allows material assemblies to be programmed for a wide range

[5] Trafton, A. (2006). Beetle Spawns New Material. Retrieved from http://web.mit.edu/newsoffice/2006/beetles-0614.html

[6] Scott, J. (2014). Heirarchy in Knitted Forms. In Proceedings from ACADIA Conference 2013. Toronto: Riverside Architectural Press.

[7] Chen, Q., Fan, J., Sarkar, M., & Bal, K. (2011). Plant-Based Biomimetic Branching Structures in Knitted Fabrics for Improved Comfort-Related Properties. Textile Research Journal. Retrieved from http://trj.sagepub.com/content/early/2011/03/25/0040517510397579

of functionalities. At the molecular scale, a water molecule – H2O – has a polar nature, consisting of two positively charged hydrogen atoms and one negatively charged oxygen atom. Water molecules are attracted to each other: the hydrogen of one molecule is attracted to the oxygen of another, causing them to form clusters. As temperatures increase, water clusters gain more energy and will break apart into smaller clusters or evaporate as lone water molecules. Materials are thus capable of being both water-tight and water permeable by interacting with the difference in size between water clusters and lone water molecules.[8]

Materials can be hydrophobic (repel water), or hydrophilic (attracts water) and hygroscopic (capable of absorbing water) based on their pore structure. The contact angle of a water droplet and the surface beneath determines whether the material is hydrophobic or hydrophilic, where a contact angle greater than 90 degrees creates a hydrophobic surface, and one less than 90 degrees causes water to spread, creating a hydrophilic surface. Water absorption is governed by the porosity of a material, where larger pore sizes results in smaller spaces for water transport via capillary action, resulting in faster water absorption as well as greater heat conductivity. Porous materials have the tendency to capture and hold water molecules in its pores and capillaries. Once a material is fully saturated (has reached its moisture storage capacity), it will no longer transmit moisture, but will release moisture back into the environment.

The rate at which moisture passes through a material is significant for climactic regulation. By exploiting a material's capacity for moisture storage so that it can absorb and give back heat and moisture throughout the course of the day, material systems can provide passive cooling. This capacity to delay the movement of moisture from outside to inside, known as the time lag factor, allows building materials to regulate and balance moisture and temperature in ambient air.

The Vernacular Thatch Roof Model

Like many vernacular systems, thatch roofs, a fibrous assembly of woven or bundled straw/reed, combines the hygroscopic properties of natural fibres with an overall geometry that directs water and airflow. Though varying regionally in construction materials and techniques, typically a thick waterproof shell (up to 2 metres) is created by layering bundles of watershedding plants. Roofs slopes vary from 45 – 60 degrees and roof shapes

[8] Straube, J. (2006). BSD-138: Moisture and Materials. Building Science Digets. Retrieved from http://www.buildingscience.com/documents/digests/bsd-138-moisture-and-materials/?searchterm=moisture%20and%20materials

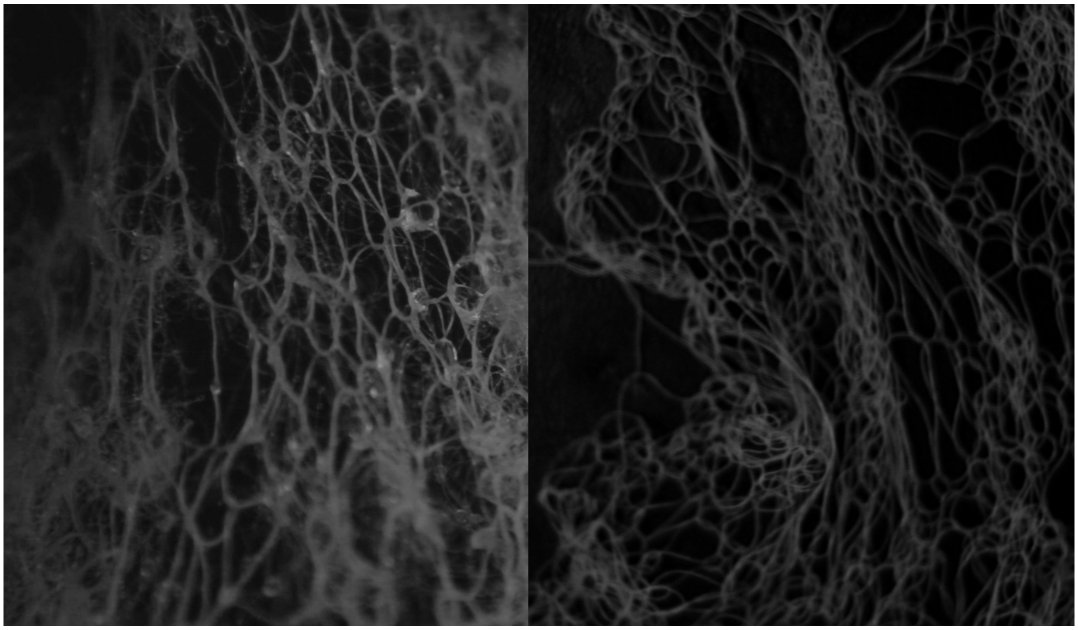


Fig. 100 Tests showing knitted prototypes in wool/mohair (right) and nylon (left) fibres. Wool droplets collect and bead while the nylon net simply becomes saturated..

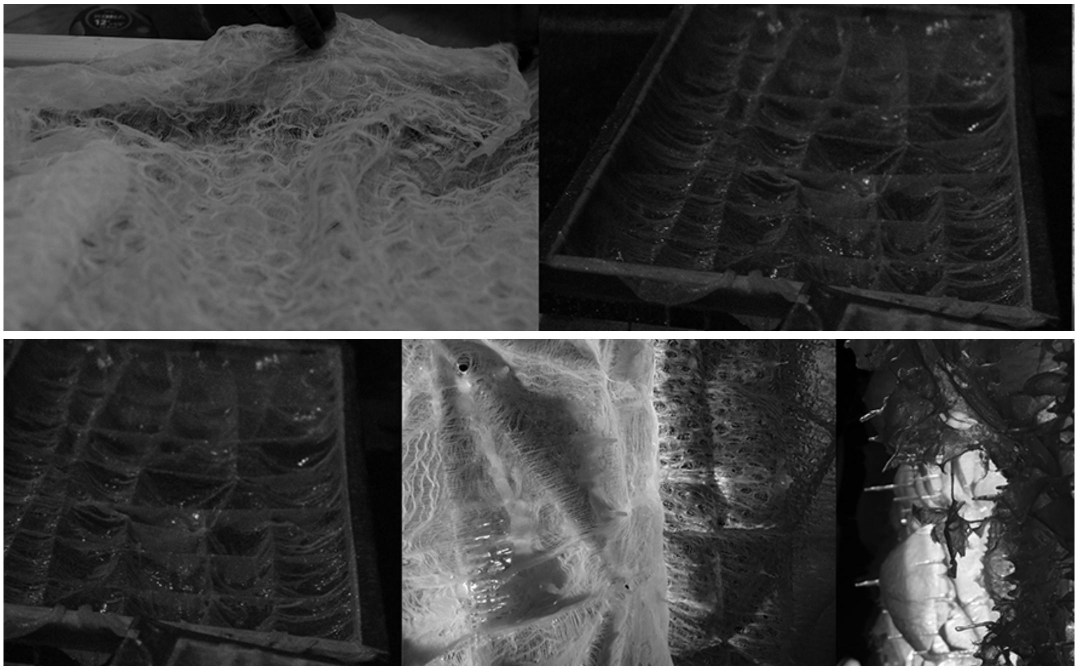


Fig. 101 Craft process and results for Lemon. From left to right, top to bottom: (i) pinching fabric by hand to variegate fabric microstructure (ii) deformed "bumps" (iii) frozen water textures on deformed fabric (iv) water capture and freezing on layered fabric with laser-cut connections.

may be angular or undulating. Water can penetrate the topmost layers of the roof. Straw and reeds have a cellular composition of long, hollow, overlapping parallel fibres that allow for flexibility and surface water repellence.

In this research, the thatch roof is treated as a heirarchical material system. It is programmed with hydrophobic and hydrophilic behaviours at different scales. The roof's surface texture and topology repels water. The bundling and layering of thatch creates a matrix of interstitial air spaces for ventilation and insulation, where variations in density and porosity will control airflow. The cellular structure of straw or reed has the capacity to absorb and release water in balance with the environment. While a thatch roof does not retain large amounts of water, thatch materials with larger diameters have more surface area for water absorption and a greater capacity for moisture storage, creating an increased delay in ambient moisture flows. The thatch roof serves as a conceptual model for a thickened, reticulated fabric with functionally graded moisture controls.

3. Physical Experiments

Early material studies explore ways to gain a visual understanding of the relationship between fibre, pattern and water capture. These experiments consider how fibre type influences water cohesion and collection, and how the fabric's structure affects water transport. Figure 1 demonstrates the collection of moisture on prototypes knitted with different fibres using a mist spray nozzle. Organic fibres such as wool, which "wicks" moisture – absorbing and transporting water – show water droplets on the fabric's surface, while synthetic fibres like nylon thread – which do not absorb but does transport moisture easily – do not collect water droplets, but effectively repels and carries water across its surface.

The studies were extended into a larger project, Lemon, which explores a multi-scalar approach to moisture collection and channelling through fabric deformation. Lemon, a fibre and ice installation at MNBAQ, sought to capture the changeable properties of water in a material state of freezing, specifically testing deformed fabrics and the time required for freezing. Tests were conducted using manufactured cotton cheesecloth of a specified density – 28 threads per inch - and a mist-spray nozzle at -23 degrees celcius. Fabrics were deformed to given new curvatures at the material scale and at a 'human' scale.

At the scale of the material, by pinching the cheesecloth to variegate the fibre distribution, a reticulated surface was created for improved moisture collection. At a larger scale, by gathering panels of 1m x 2m fabric along specified grid lines, curved topologies were generated. Finally, by layering multiple fabrics connected by more porous interstitial layers (which were laser-cut to create porosity), moisture transport could be faciliated across different layers by 'misting' the top layer and watching secondary layers soak through and expand.

These material manipulations offer an (albeit imprecise) way of visualizing water transport on different fibres and patterns, by artificially spraying water across the fabrics, and using freezing to capture the movement of water. Far from addressing more the more complex and subtle phenomenon of time lag across material assemblies for atmospheric moisture balance, the fabrics nevertheless show moisture movement over time.

4. Digital Tool Development

Physics simulation in Processing (a java-based programming language) provides access to the dynamic interaction of moisture and material microstructure, topology, and time. By modelling the interaction between water particles and curvature for water repellence, we determine the conditions for a reticulated hydrophobic surface. This conditions are applied to a simulated fabric by applying curvature onto a deformed grid. Further applying branching systems and source/sink flows, an overall topology can be generated that directs water movement across a fabric, while patterned reticulations enhance water flow and retention.

Particle System Simulation

Particle systems have recently been adopted by architectural researchers to provide an elementary means of modelling and generating iterative patterns such as tension-active structures.[9] Particle systems simulate the dynamic movement of a group of particles, where each particle carries attributes of mass, location, velocity and acceleration that can influence how the system behaves as a whole. Particles responds to programmed environmental forces at each moment in timse which can in turn change where and how they are rendered. A flexible quantity of particles are stored in an arraylist and retrieved as new actions are applied. Particle systems are used to emulate the behaviour

[9] Ahlquist, S. (2009). Computational Spring Systems. Architectural Design, 79, 130-133.

of natural phenomenon with irregular quantities,[10] and to articulate soft and rigid bodies using interconnected particles.

In this investigation, two types of particle systems are modelled: liquid movement and the simulation of a fabric using a particle spring system where material properties can manipulated and applied as forces. Both systems are modelled in relation to surface curvature as a starting point to determine the interaction between fibre configurations and moisture movement.

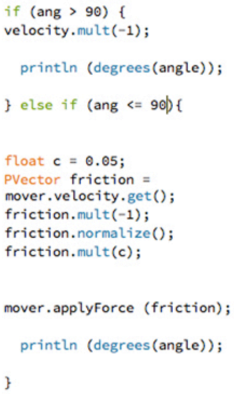
Simulating Hydrophobia and Hydrophilia

While sophisticated means of dynamic fluid simulation exist in computer graphics to visualize fluid motion over time, this investigation simply tests the interaction of water molecules with a curved surface in a two-dimensional diagrammatic tool. Liquid movement is encoded as a particle system, with water molecules represented by each particle, programmed to attract, repel, or cohere based on contact angle with one another, and to permeat or collect upon interaction with a curved surface. Iterations of a curved surface, represented in section by a two-dimensional line, is generated using basic trigonometry.

Fibre Configurations for Moisture Control

Cloth simulations are modelled using particle spring systems, where particles are connected by a network of springs. Particles carry a scalar attribute of mass and vector attributes of location, velocity, acceleration to track motion, with the location of a particle is given by f = ma, where f is the vector sum of all forces. Individual particles are connected by springs calculated using Hooke's law, which states that the force of the spring is directly proportional to the extension of the spring, given by Fspring = - k * x, where k is a spring constant that determines the elasticity or rigidity and scales the force applied, and x refers to the displacement of the spring's current length from its rest length. Vector forces oscillating between springs resolve the system to a force equilibrium state, transforming the spring network into a defined geometry. A Verlet Physics integration algorithm based on acceleration and change in position solves the accumulation of vector forces in a spring network, while constraints that specify a fixed distance between connected particles enable the simulation of a soft fabric body. By varying the number of springs, the distance specified for the constraints,

[10] Shiffman, D. (2012). Particle Systems, The Nature of Code. Retrieved from http://natureofcode.com/book/chapter-4-particle-systems/



```
if (ang > 90) {
velocity.mult(-1);

  println (degrees(angle));

} else if (ang <= 90){


float c = 0.05;
PVector friction =
mover.velocity.get();
friction.mult(-1);
friction.normalize();
friction.mult(c);


mover.applyForce (friction);

  println (degrees(angle));

}
```

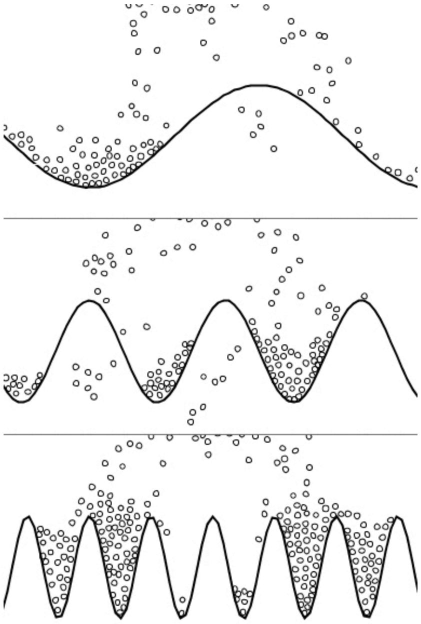
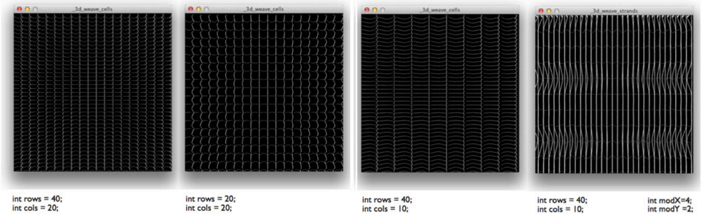


FIG. 103 Simulation showing curvature and moisture repellence. Curvature varies by changing increment on sine wave.
Water droplet size is exaggerated for clearer graphics.



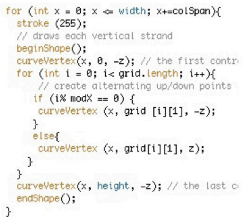
```
int rows = 40;
int cols = 20;
```

```
int rows = 20;
int cols = 20;
```

```
int rows = 40;
int cols = 10;
```

```
int rows = 40;
int cols = 10;
```

```
int modX=4;
int modY =2;
```



```
for (int x = 0; x <= width; x+=colSpan){
  stroke (255);
  // draws each vertical strand
  beginShape();
  curveVertex(x, 0, -z); // the first contr
  for (int i = 0; i< grid.length; i++){
      // create alternating up/down points
     if (i% modX == 0) {
      curveVertex (x, grid [i][1], -z);
     }
     else{
      curveVertex (x, grid[i][1], z);
    }
  }
  curveVertex(x, height, -z); // the last c
  endShape();
}
```

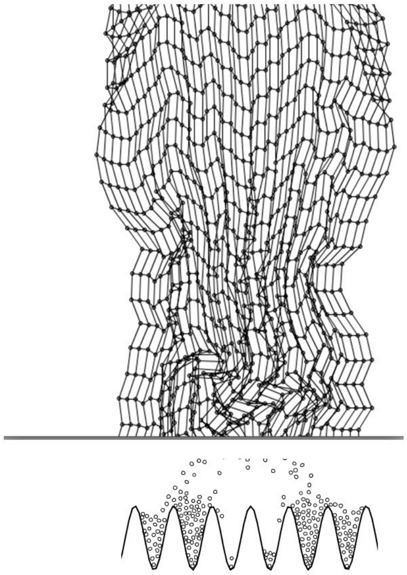


FIG. 102 Fabric patterns generated by alogrithmically controlling how fibres are distributed in a grid (top); applying sine curvature to deform a regular particle spring grid.

and the spring stiffness across the network, different topologies are created.

To generate a fabric, particles are organized into a double array via a nested for-loop, generating a grid with x and y coordinates. A basic orthogonal grid of rows and columns can thus represent a basic fabric constructed as successive rows with regular stitch counts, while diagonal springs added to the basic structure helps mimic fabric shear and stiffness. Shifting how the for loop populates or reads variable data in the array provides a means to deform the regular grid to create surface topologies and pattern configurations. These patterns, along with varying material inputs for the springs, allow the material to interact with moisture.

As an array of interconnected particles, the particle spring system illustrates the forces acting upon it and articulates an algorithmic network topology. It is important to note that a network topology is both logical and physical: the arrangement or particles or nodes in the network are defined by pathways of communication and associations within the network.[11] This is consistent with mechanical assembly of a fabric, where the form and material behaviour of the fabric is given by the relationship between interlinked elements.

5. Conclusion and Further Steps

This preliminary research explores a method for making water-sensitive architectural fabrics based on an examination of the subtle moisture controls in vernacular architecture. It illustrates the synergies between the passive environmental response of vernacular material systems and new design paradigms using simulated environmental force systems and generative algorithms. Through complementary studies in computationally generated fibre configurations and physical experiments, the research develops algorithmic relationships between material microstructure, topology and moisture movement. It explores the potential for fabricating functionally-graded fabrics capable of the subtle moisture controls found in vernacular architecture, and also raises questions about new possibilities and methods to learn from the intelligence of vernacular material craft.

---

[11] Ibid.