COOL SCHOOL

design for an extreme climate

TITLE
COOL SCHOOL
design for and extreme climate

PROJECT MODULE
MSc04 ARC
Master Thesis in Architectural Design

PERIOD
MSc04 ARK Spring 2015
IMA70132

GROUP
Maria Elena Beccaria Balduzzi & Martynas Didzys

SUPERVISORS
Peter Mandal Hansen
Lars Damkilde

AALBORG UNIVERSITY
Department of Architecture,
Design & Media Technology

Maria Elena Beccaria Balduzzi

Martynas Didzys

ABSTRACT

The report outlines an architectural design proposal for an international competition and a master thesis submission at Aalborg University, Denmark. The project focuses on the themes of climate and architecture, sustainability and education to design an expansion of a primary school in Khovd, Mongolia.

READING GUIDE

The body of the report is separated into four main parts, which represent the binary nature of our project.

Part one contains the preliminary research of themes and context and concludes with a concept and vision that inform the competition project proposal presented in part two. A process of the competition submission design proposal is also included in part two. Part three is a detailed analysis of the physical, social and economic context of the project arising specifically from a research trip undertaken to the site after the competition submission. Reflection on both this experience and the earlier research and project result in a new concept and vision that concludes part three. Part four is the presentation and design process of the final project, which considers both the general and detailed research undertaken in earlier parts and builds on the initial proposal of the competition to meet the ultimate vision of the thesis project.
The parts typify the iterative nature of the thesis, which is developed with consideration to the 'Integrated Design Process' supported at Aalborg University. Reflections made and conclusions reached from research inform the further design process and the ultimate presentation.

Relevant literature is identified within the text and referenced at the end of the report according to the Harvard style, as stipulated by the AAU study board. Images are identified by page number then by order.

An appendix, containing technical considerations and calculations, forms the last part of the report.

All plans in the report are presented with north oriented towards the top of the page and all images are our own, unless otherwise stated.

CONTENTS

07 INTRODUCTION

Part One: Research

10 CLIMATE AND ARCHITECTURE
14 EDUCATION
18 SUSTAINABILITY
20 MONGOLIA
CLIMATE
THE VERNACULAR
BUILDING TECHNOLOGIES
KHOVD
34 PROBLEM / PHASING AND ADAPTABILITY
35 VISION

Part Two: Cool School

40 SITE PLAN
42 PLAN
44 CLASSROOM
45 SUNSPACE
48 SECTION/ELEVATION
50 STRUCTURE/MATERIALITY

Part Three: Ховд

56 MARIA AND MARTIN GO TO MONGOLIA
NATURAL ENVIRONMENT
SUSTAINABILITY
BUILT ENVIRONMENT
ARCHITECTURAL EXPRESSION AND BUILDING CULTURE
EDUCATION IN KHOVD
64 TSAST ALTAI SCHOOL
OUTSIDE
INSIDE
INTERVIEW
70 CONCLUSION
71 VISION

Part Four: New Tsast Altai School

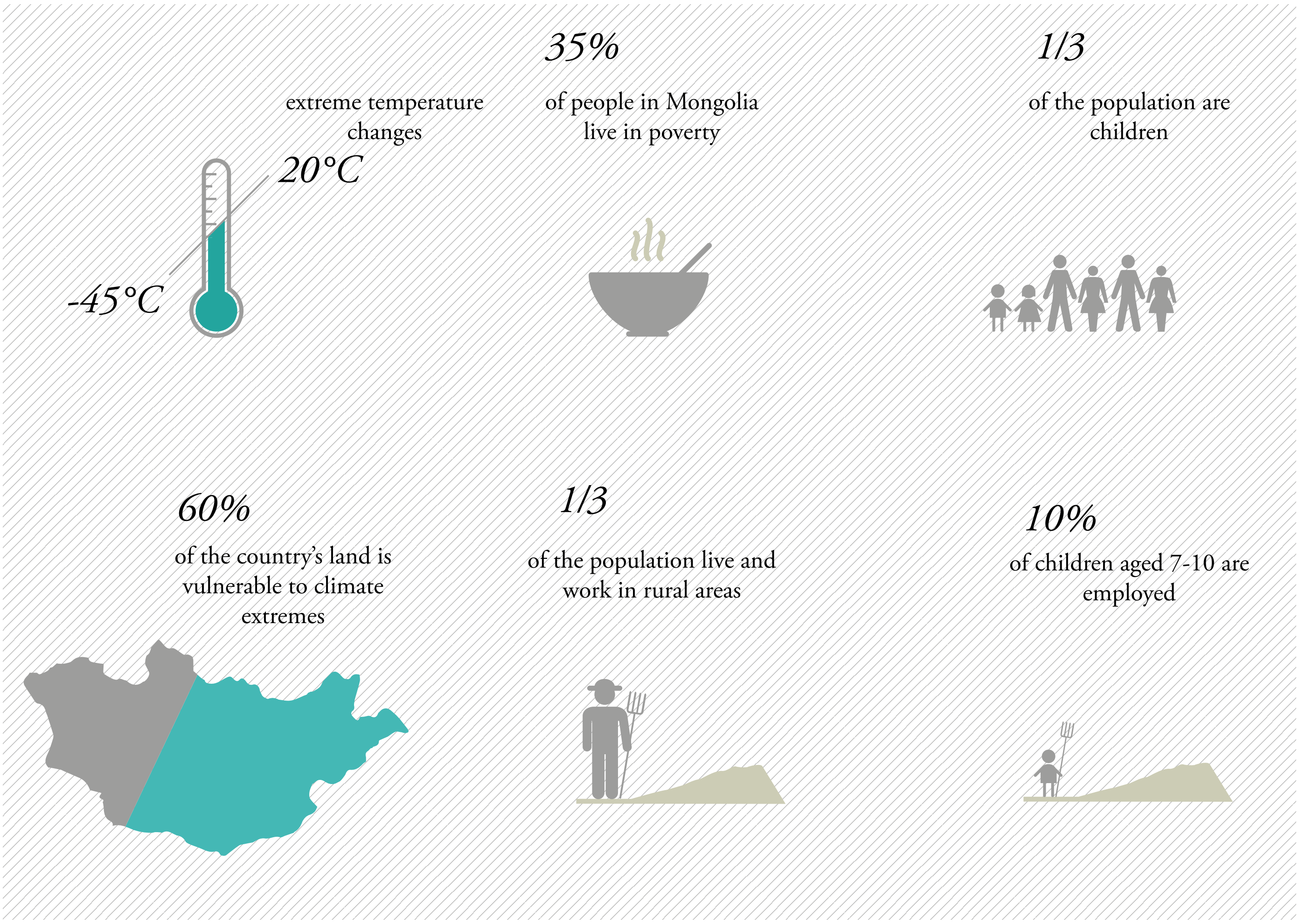
74 SITE PLAN
80 PLAN
82 VOLUMES
91 INDOOR ENVIRONMENT
95 MATERIALITY
99 STRUCTURE
103 DETAIL

Part Five: The end

83 CONCLUSION

Part Six: Appendix

115 APPENDIX I
117 APPENDIX II
119 APPENDIX III
120 APPENDIX IV
122 APPENDIX V


extreme temperature changes
20°C
-45°C
35%
of people in Mongolia live in poverty
1/3
of the population are children
60%
of the country's land is vulnerable to climate extremes
1/3
of the population live and work in rural areas
10%
of children aged 7-10 are employed

INTRODUCTION

Why 'Cool School: design for an extreme climate'?

The thesis is based on 'Cool School: design for an extreme climate,' - an international design competition for a safe, comfortable learning facilty in the Western Mongolian city of Khovd. The competition, which is organised by non-profit organisation 'Building Trust International', requests proposals for an extension to an existing over crowded and run-down school building. The program brief aims to improve the quality of the school which, despite the harsh climate, has no indoor toilet facilities and no indoor activity or physical education space. The competition evaluation criteria emphasises sensitivity to the extreme climate, ease of construction and ability to replicate on other sites, the originality and aesthetics of the design, sustainable approach, clarity and comprehensibility of the design, cost and affordability, impact and community involvement and the intelligent use of space and adaptability.

We believe that the project is a relevant topic for the thesis as it combines the competition evaluation criteria with both the technical and social aspects of sustainable architecture. The project attempts to develop a proposal that can be built sustainably using local resources with traditional technologies that empower and improve the quality of life for the general community, while responding to the constraints of the site, climate and budget and considering lighting, ventilation, environmental conditions, materials, space, comfort, accessibility, adaptability and aesthetics.

The thesis goes beyond the scope of the competition brief, developing a building that fulfills a new vision for a facility that best meets the needs of the school community identified during a research trip to the site. The project integrates function, structure and details with the need for education and attempts to respond to the following questions:

How can a building deal with extreme temperatures in an economical and practical way?

How can different functions be integrated into a building to most effectively meet the needs of the community?

How can the scale of a building be optimised for its physical, social and economic context over time.

How can we design a building that becomes a precedent for other schools facing similar challenges?

1

Research

Climate and Architecture

© Flickr: 40457697@N05

FREEZING HOT

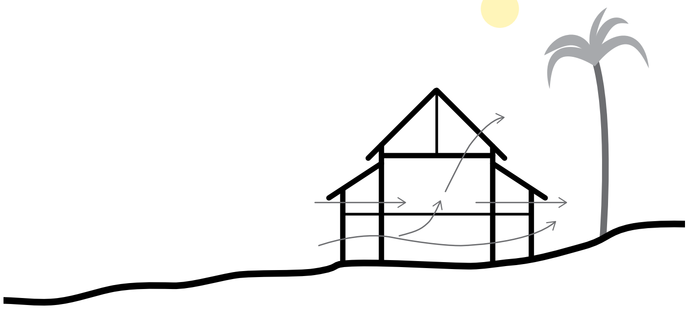
THE CLIMATE OF ARCHITECTURE

“Architecture is the connecting link between place, climate and human life.”[1] Protection against the weather is the earliest primary function of buildings – this basic human need for shelter is what directly led to the development of architecture. Climate is the measure of average weather over a period of time. It includes solar radiation, (temperature and light), wind, humidity and precipitation. Each of these climatic elements has the potential to cause discomfort to people and have a strong impact on the structure. A building must, therefore, protect both its interior environment, to provide comfortable spaces for the people inside, and its exterior, so that it can protect itself from erosion by harsh weather.1 Climate varies significantly in different regions, with several distinct climatic zones identified, each of which has led to the development of architectural styles that adapted to their particular conditions. These include hot, moderate and cold regions, each of which is also either humid or dry.[2]

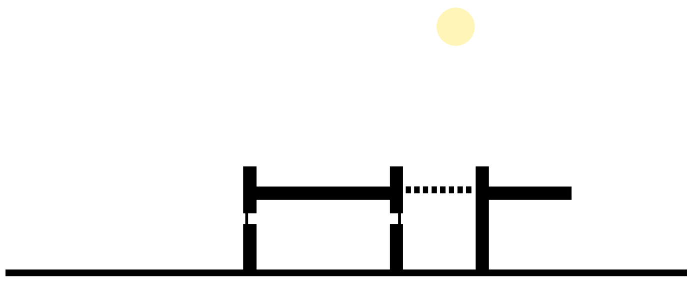
Architecture must adapt to its climate. This adaptation can be through both passive and active strategies. Vernacular architecture is an example of passive climate control, where layouts, materials and construction methods are optimised to suit weather conditions. Spaces do not change, rather their use is adapted throughout the day or according to the changing seasons.
Active climate control allows us to dynamically change a building to adapt to a changing climate.[3] In contemporary buildings a combination of passive and active climate control strategies can allow an optimum response of architecture to climate.

The process of building has been occurring for thousands of years, therefore the most effective adaptation to climate is evident in traditional architecture. Typically, the harsher the climate, the more characteristic the architectural solutions. Most traditional architecture has adapted to deal with the climatically worst time of the year – the summer heat or the winter cold or the rainy monsoonal season. In some cases such adaptation is to the detriment to usability for the rest of the year. Different strategies can be observed for different climatic regions.[4]

‘Vernacular buildings offer more elementary experiences of space, matter and climate usually working with, rather than against, the principles of nature.’[5] Therefore, studying vernacular architecture and its principles of adaptation can inspire us to apply the knowledge and experience gained over time in designing contemporary architecture that more effectively relates to its climatic environment.



1. Thai stilt house



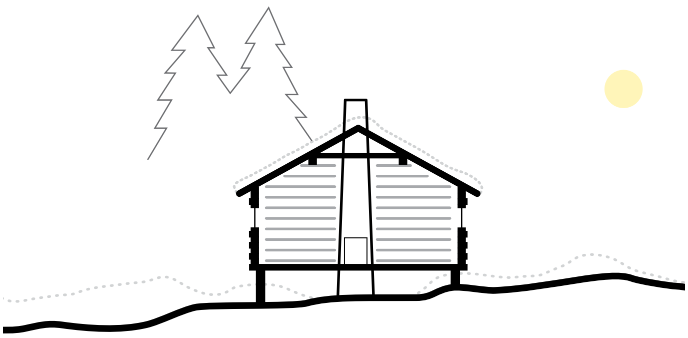
2. Moroccan mud house

Hot humid

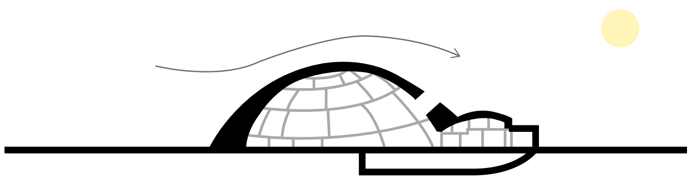
In hot and humid climates the primary concern of the building is to protect against and divert rain. Lightweight construction with many large openings attempts to also maximise ventilation opportunities to give relief from the humidity and achieve a comfortable indoor temperature through natural evaporative cooling. Differing heights of the openings allows maximum natural ventilation in different wind and temperature conditions.[1]

Hot dry

In hot and dry areas that experience extreme heat and little precipitation, the architecture demands maximum shade and ventilation in buildings. Vernacular buildings in these conditions tend to make use of the significant daily variation in temperature, to cool buildings to comfortable levels at night. Shade is achieved by overhanging roofs and small openings.[2]



3. Swedish log house



4. Arctic Eskimo igloo

Cold humid

Cold climates have led to the development of very different architectural traditions. In subarctic zones, where the humidity is high, protection against the cold and, most importantly, the wind has been achieved by heavy insulation and/or by digging buildings into the terrain to make use of the stable temperature under the ground. Snow caught on low sloped roofs provides an added layer of insulation during the winter months.[3]

Cold dry

In cold and dry arctic environments, protection against the freezing cold is the biggest challenge and critical for human survival. Often in these regions, circular structures, which minimise external envelope and are heavily insulated, can be observed. The circular shape, as well as the typically low height, achieves greater stability against the wind in the often barren landscapes.[4]

Education

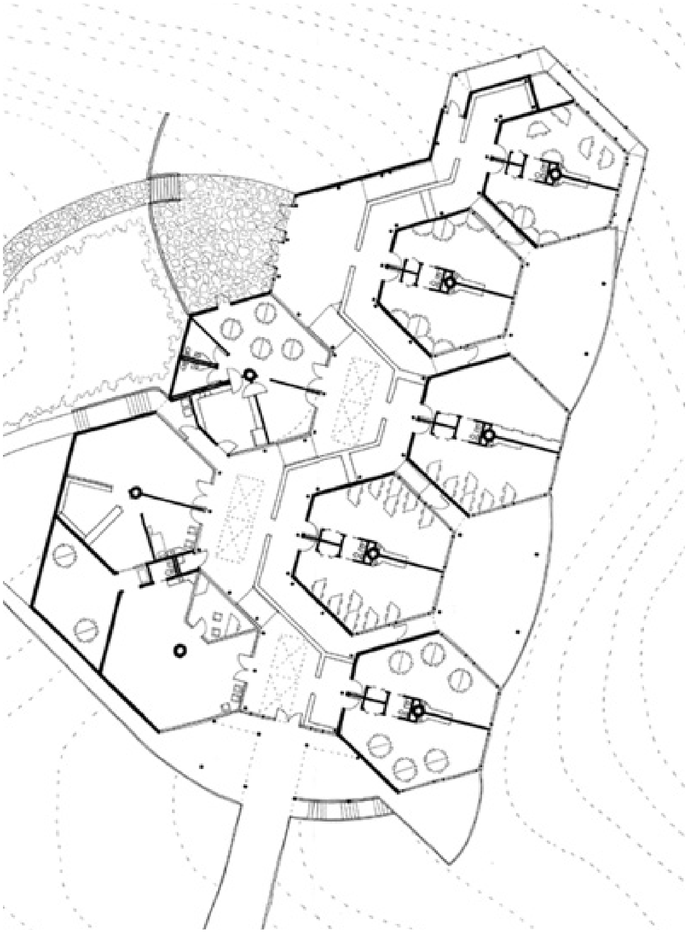
EDUCATION

A GENERATION OF CHANGE

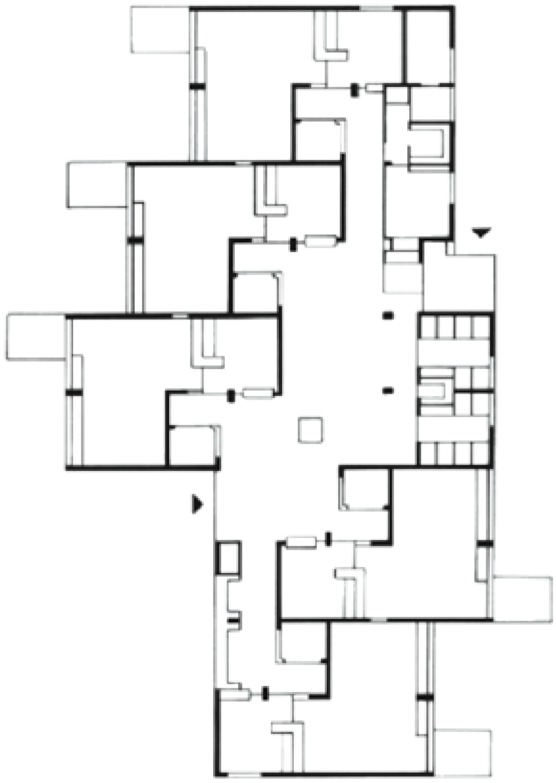
Knowledge and education are among the major factors contributing to sustainable development and the reduction of poverty around the World today.[1] With a rapidly growing global population and an ever increasing number of children having the opportunity to go to school, greater emphasis must be placed on providing effective and universal education for all. The Council of Global Education states that education in the 21st Century must change from the 19th Century model - the school should become the 'lighthouse' of society in order to educate not only the child but the entire community. The new educational method should aim to inspire every student to strive for knowledge and become valuable contributors to both their families and society as a whole, while teachers must recognise and motivate this potential in every child.[2]

Several different teaching models are active in the world today, from traditional to the most experimental. The didactic method follows a scientific approach to engage students' minds in a way that induces passive learning. It is very much teacher-centric, as the teacher is the primary agent in learning. The role of the student is to be passive, open, receptive, trusting and unquestioning. The methods used are lectures, storytelling and the use of analogy.
The socratic method, in contrast, is also known as active learning as it is problem centered and based on the assumption that the student is the primary agent in learning. The student, who must be active, critical and exercise independent thinking plays the main role, while the teacher acts more as a co-learner that helps to evoke questions from the given answers. The methods used are discussions, dialogue and problem solving. The ultimate goal is the socratic paradox - knowing that one doesn't know.[3] Both the didactic and socratic methods of education are based around the traditional classroom layout, with students seated at desks and the teacher teaching from the front of the room.
The Montessori and Waldorf Steiner educational methods, which evolved from the socratic model, differ substantially in their teaching environments. Great care is placed on the design of the buildings, which applies not only to study spaces, but also to places for relaxing, meditation and social activities. Buildings and outdoor spaces are designed to support students as the subject in their education. Steiner schools, for example, are characterised by warm colours and natural materials in home-like classrooms for the early years. The colour schemes become gradually cooler in older years as the intellectual capacity of the students increases. Individual classrooms are often linked together by outdoor meeting spaces that foster personal growth by facilitating the social interaction between students of different ages.[4]

As the capacity for education to improve standards of living becomes more widely recognised, it is clear that building with children in mind is 'a subject that is crucial for the future.'[5] Suitable spaces should be designed to facilitate the shifting focus from traditional forms of teaching to 'autonomous learning.' Time spent playing and relaxing allows children to develop communication, problem-solving and movement skills and is as important as traditional cognitive learning. Therefore, schools should be flexible and contain a variety of spaces. 'They should provide different kinds of teaching environments and scope for spontaneous play and communication, as well as areas to which children can retreat and be alone'[5] in order to become places of holistic education.



1. Primary school, Cincinnati, USA



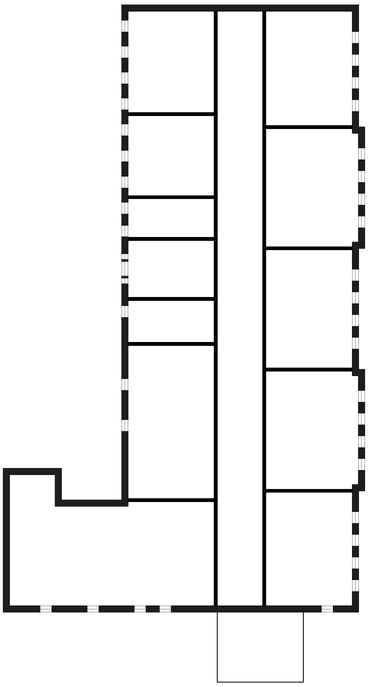
2. Primary school, Delft, Netherlands

Waldorf Steiner

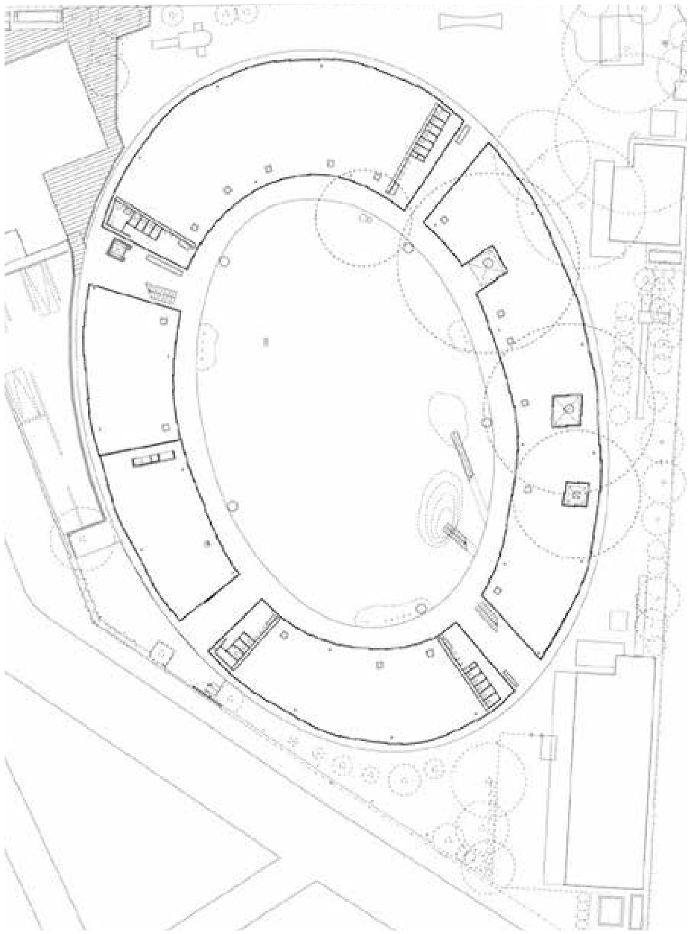
The Waldorf education model emphasises creativity, imagination and a strong connection to the natural environment.
In the case of the design of the Cincinnati primary school, the study rooms each open out to a shared communal terrace, which forms an outdoor extension of the interior spaces. Each classroom contains a composting toilet and heating and cooling needs are met independently in each room. Rainwater is collected for reuse in the building.
The circulation spaces in the building become a connection between the interior rooms and the surrounding landscape.[1]

Montessori

Fundamental in the design of a montessori school is the participation of spatial forms as an integral part of the education.
The central hall of the Delft school, designed by Hertzberger, is analogous to a public street, while the classrooms are the private houses considered and equipped as complete units. In contrast to traditional classrooms, the L-shaped layout defines different spatial zones while merging the concept of individual study and community life. The layout is adapted to the Montessori concept of freedom in space and study provided to every student.[2]



3. Tsast Altai Primary School, Khovd, Mongolia



4. Fuji School, Tokyo, Japan

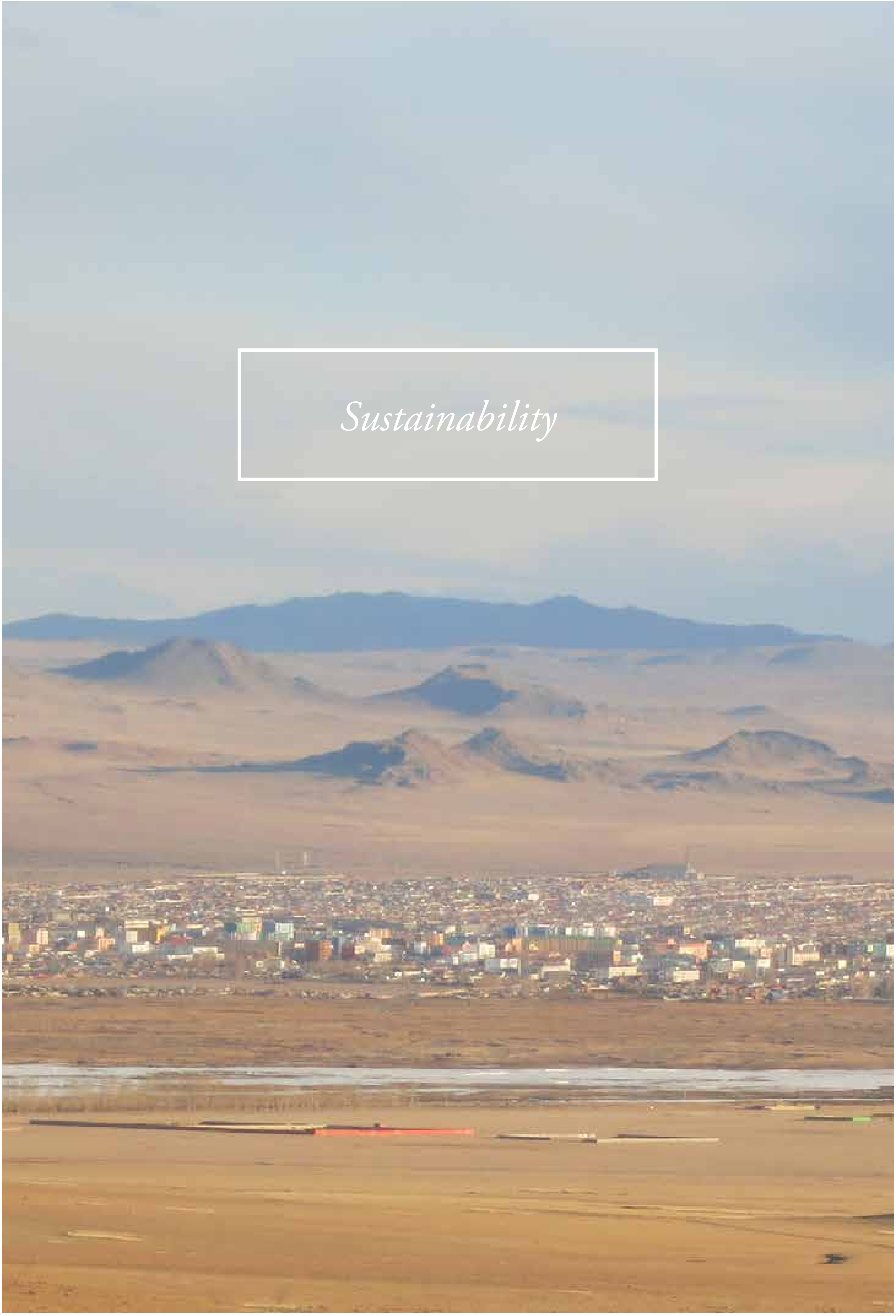
Mongolian school

The current education system in Mongolia is a traditional model influenced by the didactic Soviet model. Attendance is compulsory until the age of twelve. Since many students in rural areas live far from schools, some have dormitories that allow students to stay and live at the school.[3] The layout is generally traditional with a long corridor serving the classrooms. Toilets are often located outside, where no cure is given to the landscape. Mongolia generally acknowledges the importance of education in improving quality of life and development of the country, which is reflected in the fact that 'enrolment in primary education and literacy are considerably higher than for other countries at similar levels of economic development.'[4]

Future trend

Current trends in school design, favour open-plan learning environments over traditional formal classrooms as a more functional and flexible alternative for learning space.
The Fuji Kindergarten designed by Tezuka Architects in Tokyo embraces these ideas. It has been designed to accommodate the existing nature of the site and to leave as much freedom as possible to the students. The classrooms have no internal partition walls so that children are forced to develop their concentration ability. The only fixed internal wall in the building separates the staff area from the classroom.
Furthermore the roof serves as a playground and open air study area.[5]

Sustainability



SUSTAINABILITY

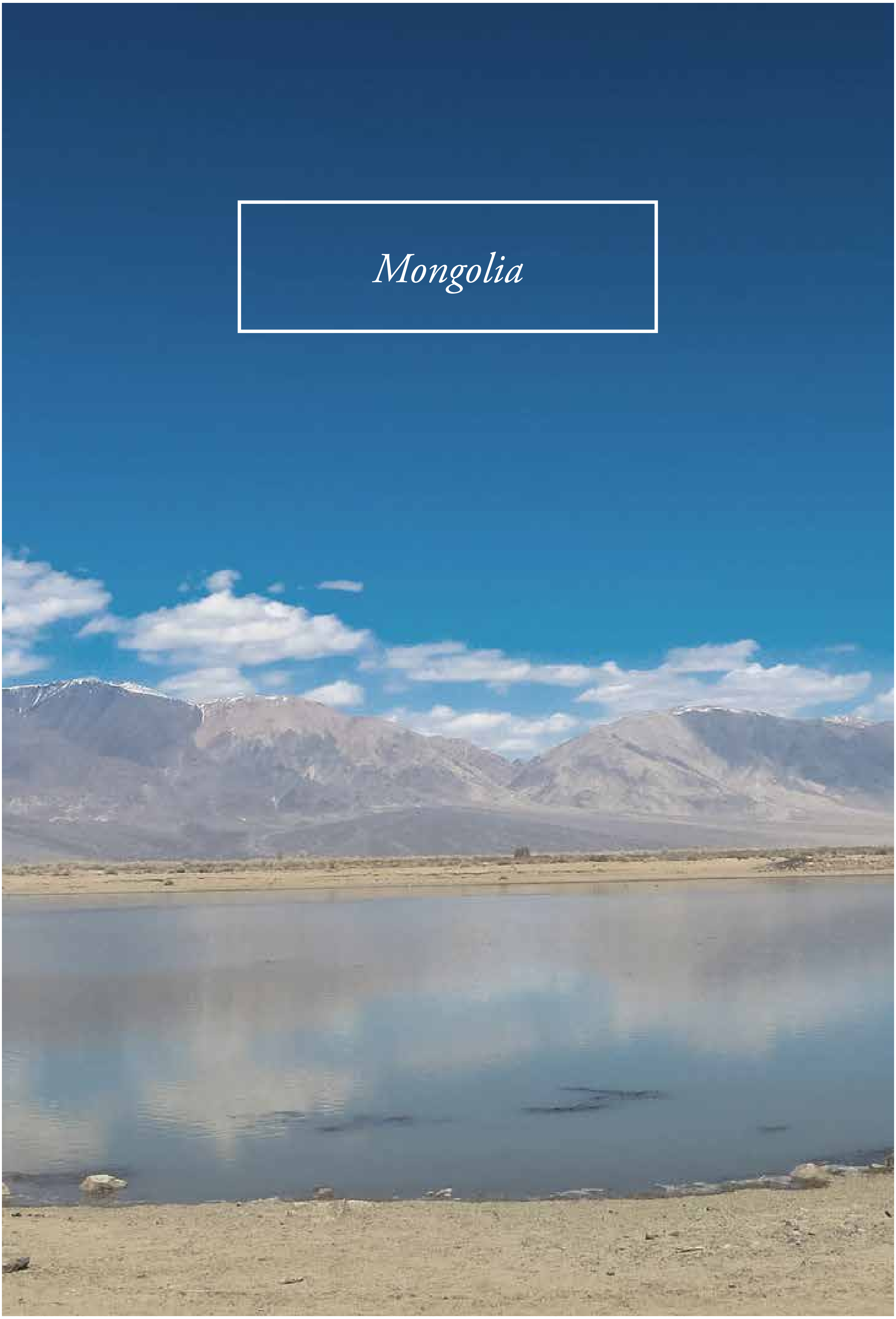
WHAT'S NEXT?

To what extent built architecture influences the development of society is a long dated question and one that is difficult to answer. Architecture of the 20th century modernist period already had visions not only regarding the wellbeing of individuals, but also of society as a whole. 'Architecture or Revolution'[1] was Le Corbusier's mantra for utilising modern industrial techniques to increase the standards of living and efficiency of society. During postmodernism most architects focused on the architectural form, rather than on social and environmental concerns, but in the past century urban sprawl, the rise of megacities and rapidly developing climate change, has forced architects to become socially and environmentally responsible once again.[2]

In 1983 the UN established a world commission to manage ongoing world development and its effects on the environment. Four years later it released a document referred to as the 'Brundtland Report', in which it defined sustainable development as '…Development that meets the existing needs without compromising the ability of future generations to meet their needs.'[3] The report concluded that development as it was occurring was 'unsustainable,' a term not commonly used previously. Since then the notion of sustainability has become prevalent throughout the developed world, not only in architecture, but also more broadly when referring to environmental, social or economic issues.

Sustainability requires an initiative to be taken in accepting the responsibility of our present actions and their implications in the future - a responsibility that must be shared by all of humanity. Everyone must be actively involved in cultivating sustainable development. However, this is not equally possible throughout the world. It is much more difficult to consider the abilities of future generations to meet their needs in developing countries, many of which struggle to meet their own existing needs today. Sustainability as a concept is viewed differently in this context. In Mongolia, where a third of the population live in poverty, there is a need to develop strategies that positively impact and improve the quality of life for the greatest number of people with the greatest possible efficiency. In countries like Mongolia, which face a lack of economic and technological resources it is important to design structures that can satisfy the specific conditions of those contexts. New infrastructure must be constructed to meet the challenges of today into the future, rather than repeating the mistakes of the past.[4] Working in close contact within communities allows designs to be achieved which are not an imposition of extraneous models, but a direct reflection of local traditions, material, building technologies and climate. By interpreting the past, it is possible to make informed decisions about the future. Perhaps in developing context, it is traditional, rather than industrial, techniques that can most efficiently increase the development of society.

Mongolia



WELCOME

TO THE SPARCEST PLACE ON EARTH

Landlocked in central Asia, between Russian Siberia and China, is Mongolia - a barren expanse of deserts and plains, lakes and mountains. Mongolia's three million inhabitants[1] occupy more than 1.5 million square kilometres of land - one of the least densely populated countries in the world. Mongolia is located on a continental plateau, with an average elevation of 1,580m, and slopes generally from its highest point in the Altai Mountains in the west, to the Gobi desert and 'steppe' plains in the country's south and east. Mongolias altitude leads to its cold and dry climate, with extremely cold winters and mild to warm summers. The country is characterised by clear skies and receives very little rainfall, most of which falls in the summer months.

The harsh climatic and geographic conditions in Mongolia have evolved a highly resistant and hardy people. The Mongolians have long been known for their nomadic lifestyles - the seasonal movement of cattle, 2 to 4 times per year, from one pasture to another has led the common people to consider livestock to be private property and land to be collective[2].
For centuries their livelihood has been, and remains to be, dependent on herding five types of animals - horses, cattle (including yaks), camels, sheep, and goats.[3] The animals satisfy almost all of the Mongolian family's basic needs. The diet of the average Mongolian consists of beef, mutton and goat meat, as well as a great variety of dairy products. Natural felt, made from processed sheep wool, is used to make clothing, bedding and insulation for traditional homes, while hair from other animals and their bones are used to produce musical instruments. The major form of transport is provided by horses, yak and camels.[4] The horse, which is used for herding, hunting, and sport, as well as travel, is the most important of these and plays an integral part in Mongolian culture and daily life. Mongolian children learn to ride as early as three years old, so it's no surprise that Mongolians are the best horsemen in the world.[3]

Tibetan Buddhism has been the dominant religion in the country since the 16th Century, when traditional shamanism was suppressed and marginalised after the conversion of the king, Altan Khan, to Buddhism. Some traditional shamantic practices, such as ovoo worshipping (pile of rocks), still remain a part of Buddhist liturgy.[5] Both Buddhism and shamanism were forbidden for more than 60 years in the the Mongolian People's Republic, but remained active with secret followings throughout the country. There is also a small but significant Muslim community in Mongolia (about 6 per cent of the population), of which mostly are ethnic Kazakhs living in the west of the country. Since the opening of the country's borders, Christian missionaries have arrived in Mongolia, creating some religious tensions and debate among the locals.[6] Nonetheless, the varied religious traditions of the country have led it to evolve into a fairly tolerant society.


'DZUD'
an extraordinarily harsh winter that deprives livestock of grazing
© Alessandro Grassani

CLIMATE

Mongolia is a country with an intense continental climate. Summers are warm, even hot, while winters are long, dry and freezing cold. Mongolia has the most typical continental climate of any country in the world, with extreme daily and annual variations in temperature.[1]

Climate forms an integral part of Mongolian life and is what has led to the development of both traditional building techniques and the nomadic way of life typical in the country. Intense weather hazards, such as severe cold and droughts, are common and the biggest challenge facing Mongolian herders. During the coldest months of winter herdsmen mitigate the effects of the climate and keep warm by moving their animals to a location sheltered from the elements, usually by a rock formation or mountains. Here they remain huddled close together with the animals until the harshest period has passed. In summer, the animals are free to roam the countryside, while the herdsmen and their families move to towns and cities.

The seasonal movement of animals has been practiced for centuries, however some extreme climatic events cannot be avoided. 'Dzud' is a specific and not uncommon phenomena that sometimes occurs during the winter-spring season in Mongolia. It is feared by the Mongolians as the temperature and lack of food leads to a great number of livestock deaths from starvation or cold. Given that animals are the most valuable possession of the nomadic Mongolian people, the dzud is devastating both economically as well as physically and psychologically. The economy of Mongolia is heavily dependent on pastoral farming. Therefore dzuds are capable of leading to serious economic crises and food security issues in the country. 2.4 million livestock were killed during the dzud season of 1999/2000, resulting in economic losses of $14.6 billion.[2]

Since Mongolia, like the rest of the world, is experiencing climate change, extreme events like dzud have the potential to increase in frequency and magnitude, further threatening the already weak economic and social stability of Mongolian families.


‘GER’
a circular tent of felt or skins used by nomads in Mongolia, Siberia, and Turkey.

THE VERNACULAR

Mongolians are a very proud and traditional people. The combination of cold climate and nomadic lifestyle has led to a vernacular style of architecture that considers three main characteristics - the simplicity of construction and deconstruction, adaptability and flexibility, and ease of transport.[1] As such many Mongolians, both in cities and rural areas, reside in circular tents called 'gers'. The ger, which literally means 'home' in Mongolian, is an integral part of the Mongolian way of life. The tents are extremely mobile, able to be assembled or dismantled in as little as 30 minutes and transported by several livestock, and provide sufficient insulation during even the coldest months of winter.

The ger was first mentioned in writing as many as 2500 years ago by Herodotus of Halicarnassus, who described the tent as a dwelling of the Scythians, a nomadic horse-riding nation in Central Asia. Extensive use of gers became prevalent with the expansion of the Mongol Empire under Genghis Khan in the 13th and 14th centuries[2] and existed for thousands of years, maintaining essentially the same structure and layout until today. Traditionally the door is oriented south, the mens place is in the west, while the east side is for the women. Opposite the entrance, at the northern side of the ger, is the location of the family altar. Also here is the 'tör,' or seat of honour3 - the most important place in the home and where guests are invited to sit. The stove, which is used for cooking and heating, is placed in the centre of the ger, its smoke escaping through a chimney in the 'toono' (opening) in the centre of the roof. The orientation of the ger allows the occupants to tell the time by the position of the sun entering through this toono. For the nomads, the ger is not only where they sleep, cook, eat and receive guests, but also a place to practice traditional rituals and marriage ceremonies.[3] Nowadays these traditions are no longer strictly upheld.

More than a third of Mongolia's three million people still live in gers.[4] In the capital Ulaanbaatar this number is even greater with more than half of the population living in ger neighbourhoods that surround the modern city. These sprawling suburbs are expanding in all of Mongolia's urban areas as ever more traditionally nomadic people settle in cities in search of more static and stable lives. The modern government, which considers these tent cities as a representation of a lack of development and poverty, no longer allows people to keep animals on their lots in the suburbs of Ulaanbaatar in an attempt to persuade people to move from the supposedly unhealthy gers into apartment blocks in the city. This attitude is shared by many of the country's rapidly growing middle class, which is stigmatising life in gers as 'poor' or 'uncivilised,' but for many, life in these neighbourhoods is a choice. Often, the quality of life in a ger is better than in an apartment, which may explain why government policies are not having any significant impact on the situation.

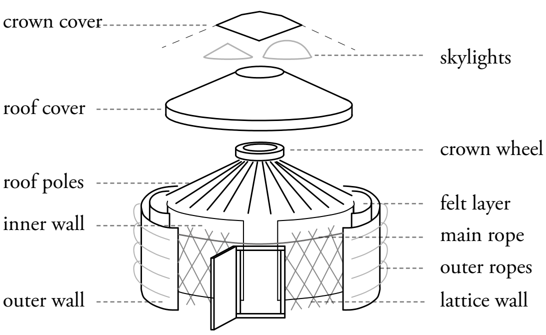
The biggest problem, however, are the inefficient coal and wood stoves used to heat the gers, which are the major cause of the pollution problem in Mongolia's cities.

BUILDING TECHNOLOGIES

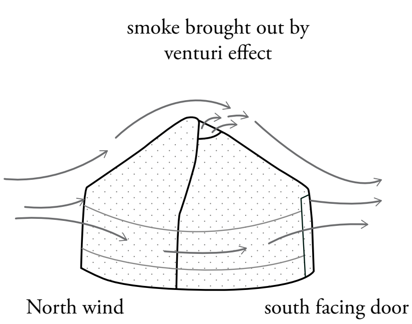
The choice of appropriate construction materials and technologies is directly related to the availability of skills and materials in a particular region,[1] which is why the ger is the most typical built form found in Mongolia. Its circular shape is perfectly suited for its function and context, providing a minimum surface area to floor area ratio with a minimal amount of materials used. The shape is optimal for heating efficiency, as it has 12% less surface area exposed to the outside compared to a rectangular envelope with the same area, and is less prone to storm damage as wind naturally flows around and over the ger.[2]

The ger is constructed from materials readily available in the Mongolian context using traditional techniques that have been practiced for centuries. A wooden lattice frame is covered in several layers of coarse wool felt attached with strings. The felt, which is typically hand-produced, has a thickness of 15-20mm. Three layers of natural felt provide sufficient insulation to withstand winter temperatures as low as -40^{o}C.[3] The frame is constructed in such a way that the weight of the roof is distributed equally on to the surrounding walls. Two or four central pillars are used to reinforce the central part of the ger.[4] Gers have no windows, so light enters through the *'toono'* and through the open door in summer. The disassembled parts of the ger can be transported by camel or yak to be rebuilt elsewhere as required.

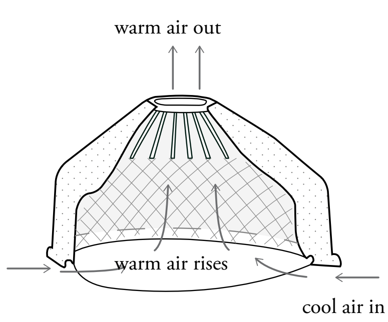
Although Mongolia has rich endowments of mineral resources, including copper, gold, uranium and coal,[5] it does not have much in terms of suitable building materials. Sun-dried mud bricks were historically widely used as a construction material in the country,[6] but their use has significantly decreased as concrete construction became more prevalent in the 20th century. Mongolia has no good quality natural stone, and cement production, which is based exclusively in the capital Ulaanbaatar, supplies only 30% of domestic demand, so most construction materials remain imported from China, Russia, Germany and Korea. Such a lack of local resources means that the cost of transport is increased, both economically and environmentally. As a result, low-tech materials, such as earth bag, adobe brick and straw bale construction, which can be produced locally and perform well in the local conditions, are gaining in popularity.



1. Structure of the ger



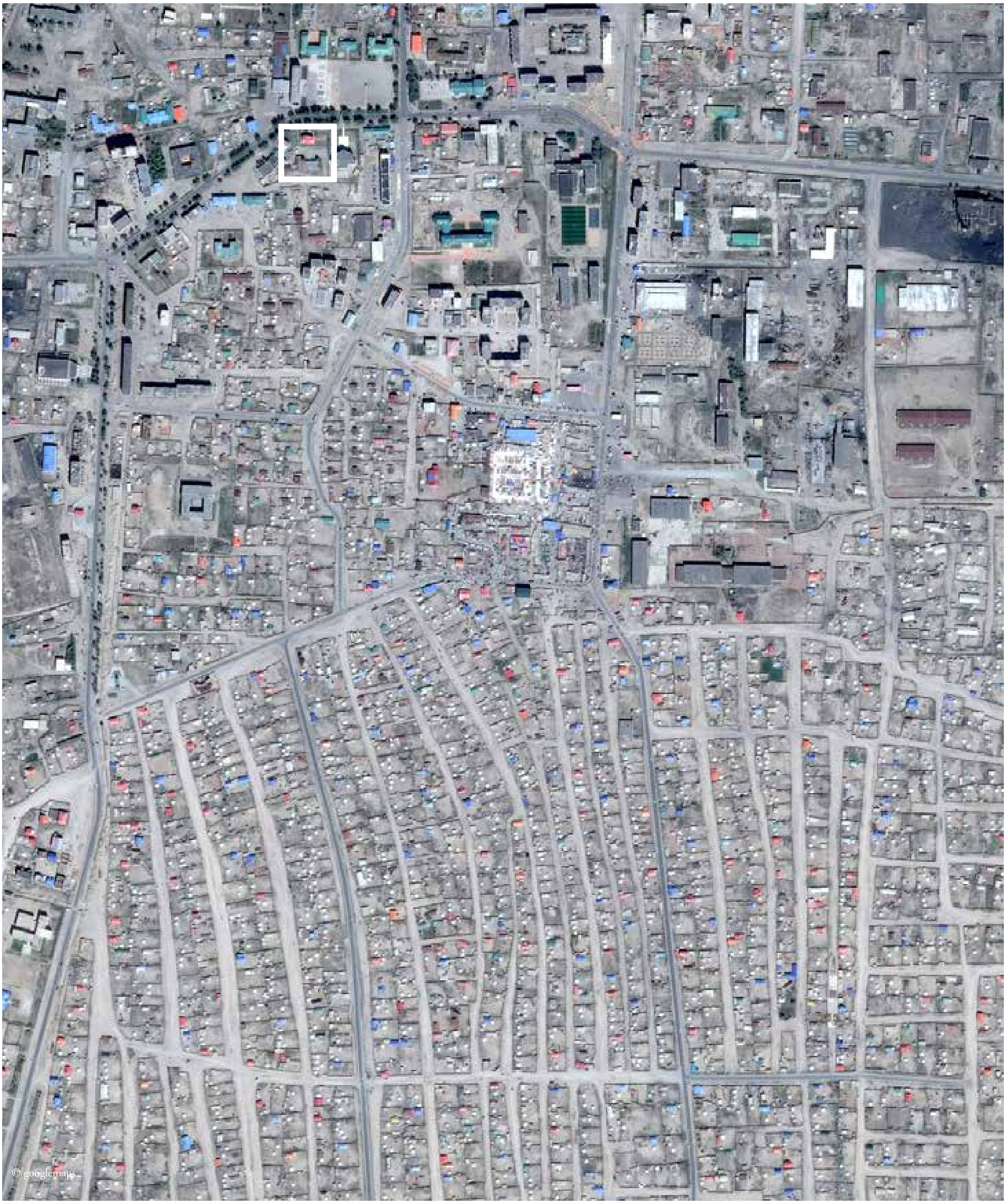
2. Wind movement around the ger

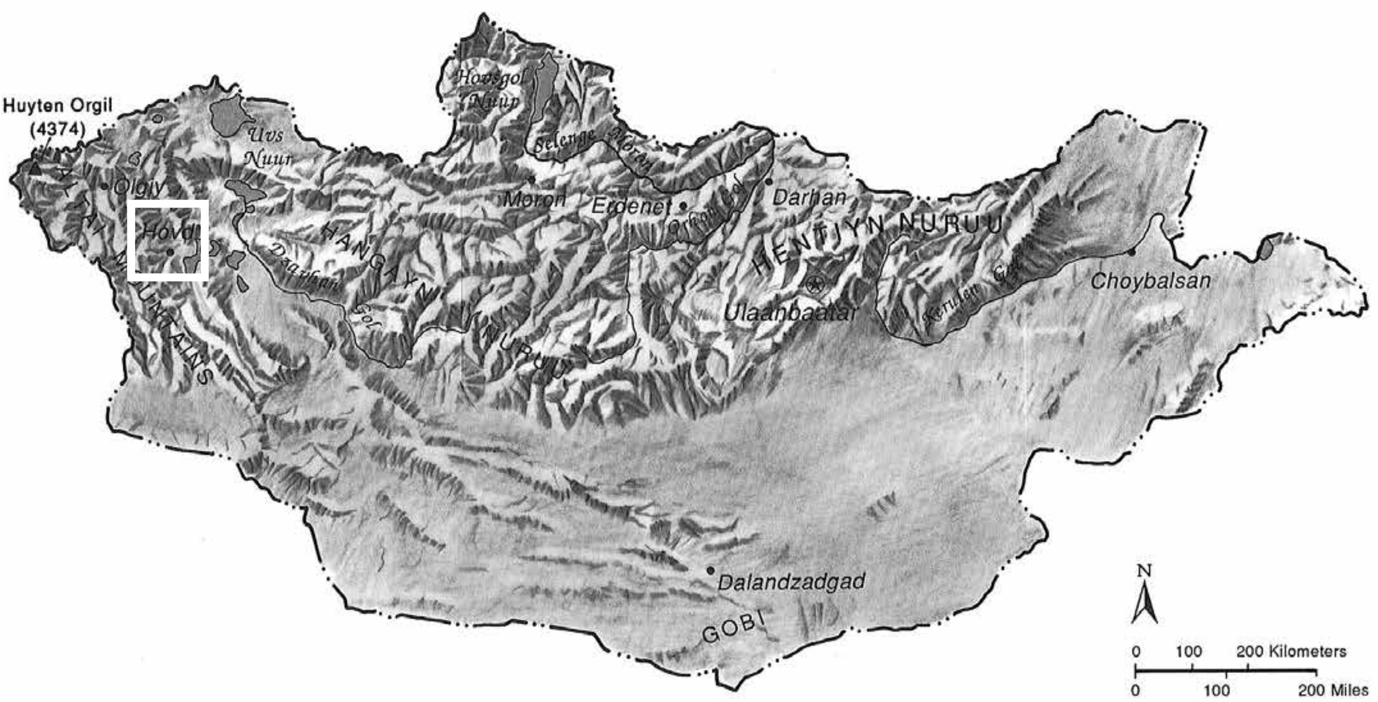


3. Passive ventilation in the ger

KHOVD

MONGOLIA'S WILD WILD WEST





The city

More than 1400 km from Mongolia's capital Ulaanbaatar, at the northern foothills of the Altai Mountains, lies the city of Khovd (or 'Hovd'), the major trading centre in the country's west and capital of Khovd Province. The city was founded in 1731 as a trade depot commercially linked to Peking[1] (Beijing) and its economy remains reliant on agriculture and trade to this day. Khovd is known for its harvest of tomatoes and watermelons, while other vegetables, including cabbage, beets, carrots, onions, and cucumbers, are also grown in the region. Like in the rest of Mongolia, many of Khovd's inhabitants are herders, moving their animals according to the seasons, and thus rely on transportable accomodation in the form of tents to sustain their nomadic way of life.

Almost 30 000 people call Khovd home, while the population of the province is 78 449. The region has a young population - 34% are children aged 0-15, 60.8% are working aged between 16-59 and only 5.2% are aged 60 or older. It is a multi-cultural community of more than 10 ethnic groups, including Khalkha, Zakhchin, Kazakh, Torguud, Olots, Altai Uriankhai, Dörvöd andMyangad people.[2] The growing and dynamic demographic situation in the city has put pressure on the existing education system and has facilitated a need for more schooling facilities, specifically an expansion to the overcrowded primary school.

1. Satellite image of Khovd

Regional centre of education, trade and culture

1. The site, existing school

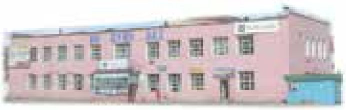
2. First School

3. Third School

4. Agricultural College

5. Second Kindergarten

6. Governor's Office



7. Red Market

8. Youth Centre

9. Theatre

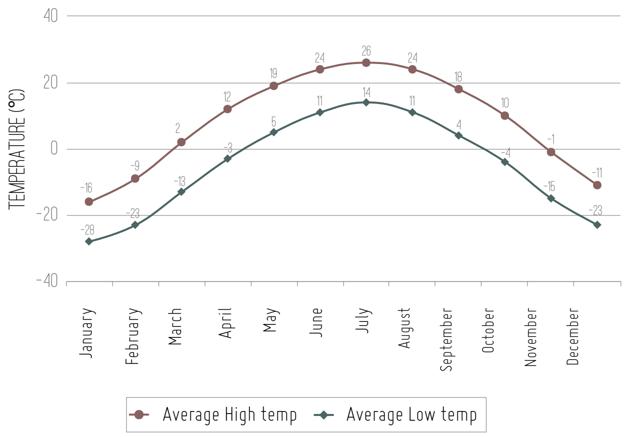
10. Khovd Museum

11. Khovd University

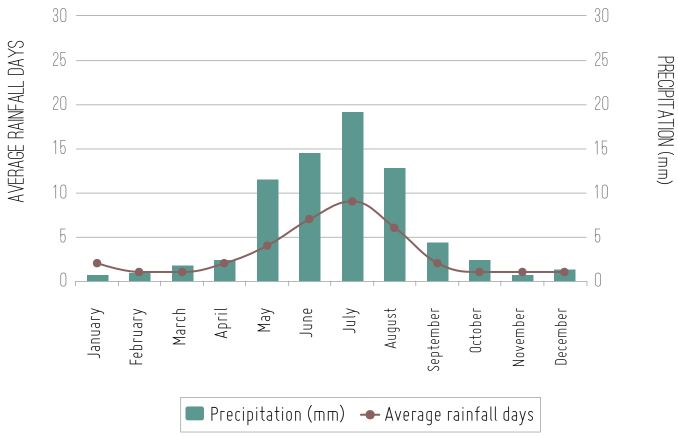
12. 'Winners'
(typical restaurant/bar)

13. Buyant Hotel
(typical hotel)

14. Big Market
15. School
16. First kindergarten
17. Ard Ayush Square
18. Police Station
19. Post Office
20. Mosque
21. Residential ger neighbourhoods



1. Average temperature graph (C°)

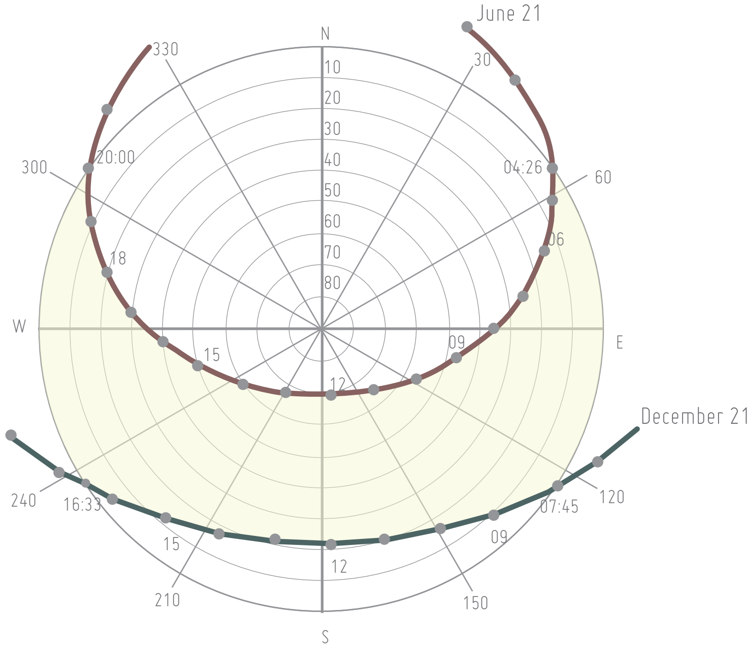


2. Average rainfall graph_ source: weatheronline.com

Temperature and precipitation

Situated at a height of 1400m above sea level, the climate of Khovd is characterised by warm summers and long, dry and very cold winters, like in much of the rest of the country.
The average temperature between October and March is below zero degrees, while in summer the daily high rarely exceeds 25°C. Only four months of the year experience an average temperature above 10°C. Precipitation is concentrated in the summer months, with a maximum of 20 mm, with almost no precipitations in the winter months.[1]

In the aimag of Khovd, the prevailing wind comes from west and northwest with an average annual wind speed of 1.6 m/s. According to statistical data, the highest wind speed recorded is 28 m/s in 1994.[2]



3. Khovd Sunpath

Sunlight

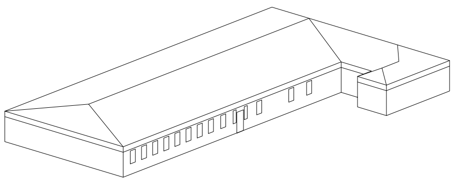
Mongolia's sunny days, of which there are more than 250 each year, have given it the name 'the land of the blue skies'.[1] The site's latitude, comparable to that of central France, means there is a great variation in the amount of daylight hours between the longest day in summer (15.5 hours) and shortest day in winter (less than 9 hours). The angle of the sun also varies significantly between the summer and winter months.

Understanding the solar patterns will greatly influence the design process as we seek to gain passive solar radiation, especially in the cold winter months. Achieving an appropriate amount of natural indoor light is important in a working environment such as a classroom, whilst avoiding any excessive openings in the buildings envelope, essential in such a cold climate.

The specific characteristics and climate of the area will be a major study in the design of the new building. They will be considered throughout the design process and influence the passive environmental strategies implemented in the building.

PROBLEM

The existing primary school building is occupied by 500 children in 8 classrooms. There are no indoor toilet or recreation facilities.



PHASING AND ADAPTABILITY

The new building is intended to alleviate these issues and meet the basic needs of the existing school by adding a multi function room, two classrooms and toilet facilities.

With an anticipated budget for the new building of $60 000, the evaluation criteria of the competition places a strong value on the adaptability and affordability of the project. To ensure maximum flexibility in realisation, it is proposed that the new rooms are added in three phases. To address the greatest priority of the project - overcrowding - at the earliest phase, the multi function hall is built first and initially divided to function as two classrooms. As subsequent classrooms are added, the hall becomes used for sport and recreation activities, both by students during the day, and the community outside of teaching hours.

The design of the new facilities at the school are envisaged to become a precedent for other schools in the region. This is achieved by creating adaptable structures in scales that can be applied universally throughout Mongolia, with adjustments to accommodate specific sites, demographics or economic situations.

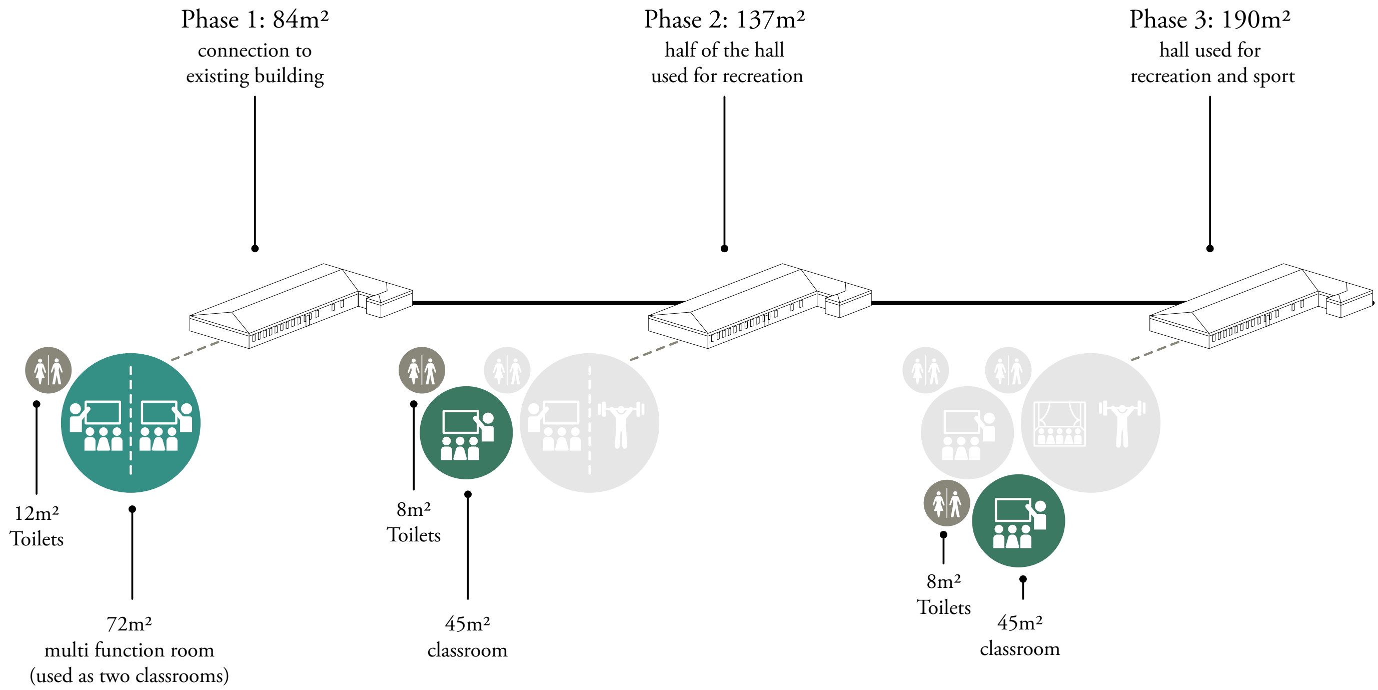
VISION

The project will propose a facility for 100 children at the existing primary school in Khovd, Mongolia and form the submission of our competition entry.

It will integrate function, structure and details with the universal need for education. The project will respond to the constraints of the site and extreme climate, considering lighting, ventilation, environmental conditions, materials, space, comfort, accessibility, adaptability and aesthetics.

A strong focus will be placed on the use of local materials and technologies in an attempt to promote an effective building culture in the city, develop a more relevant building typology in the region and respect the budget anticipated to realise the project.

The project will ultimately improve access to and quality of education in the city, forming a precedent for development of further schools in Mongolia.

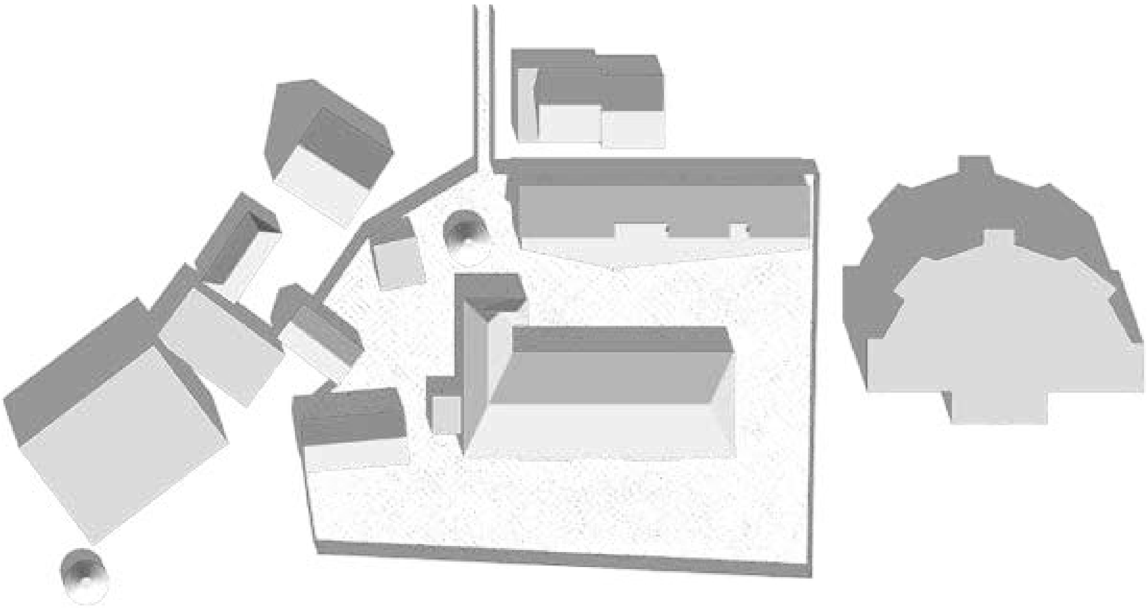


2

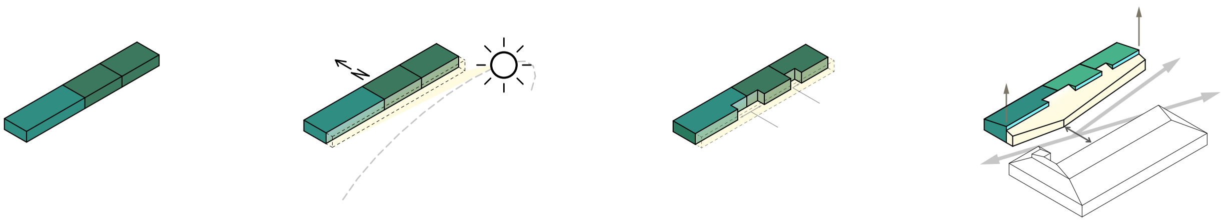
Cool School

COOL SCHOOL

The competition submission



1. Site plan



linear layout building

long south facade and sun space as heating strategy

circulation and indoor functional space

relation to the existing and solar gain

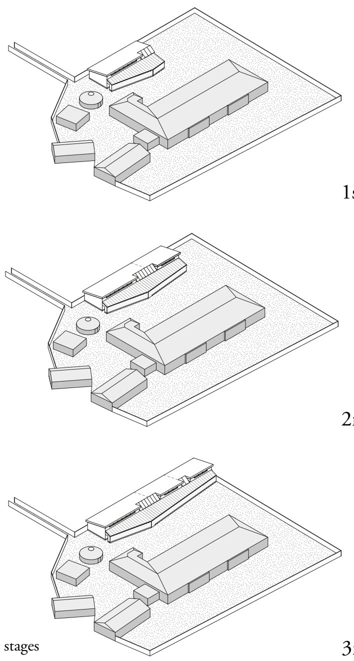
2. Design parameters

Site plan

The primary consideration in defining the layout of the site is solar access. The new building is located at the north eastern corner of the site so that it is oriented with a long south facing axis without compromising sunlight to the existing building. All of the existing structures on the site are maintained - to propose otherwise would be unreasonable given the project's tight budget.

A sunspace is attached to the south facade of the building and forms the passive heating principle of the building. The sunspace expands as additional phases of the building are realised.

The sunspace is distorted so that it becomes wider at the centre, creating a closer connection to the exisiting building and guiding a natural flow of people through the site.

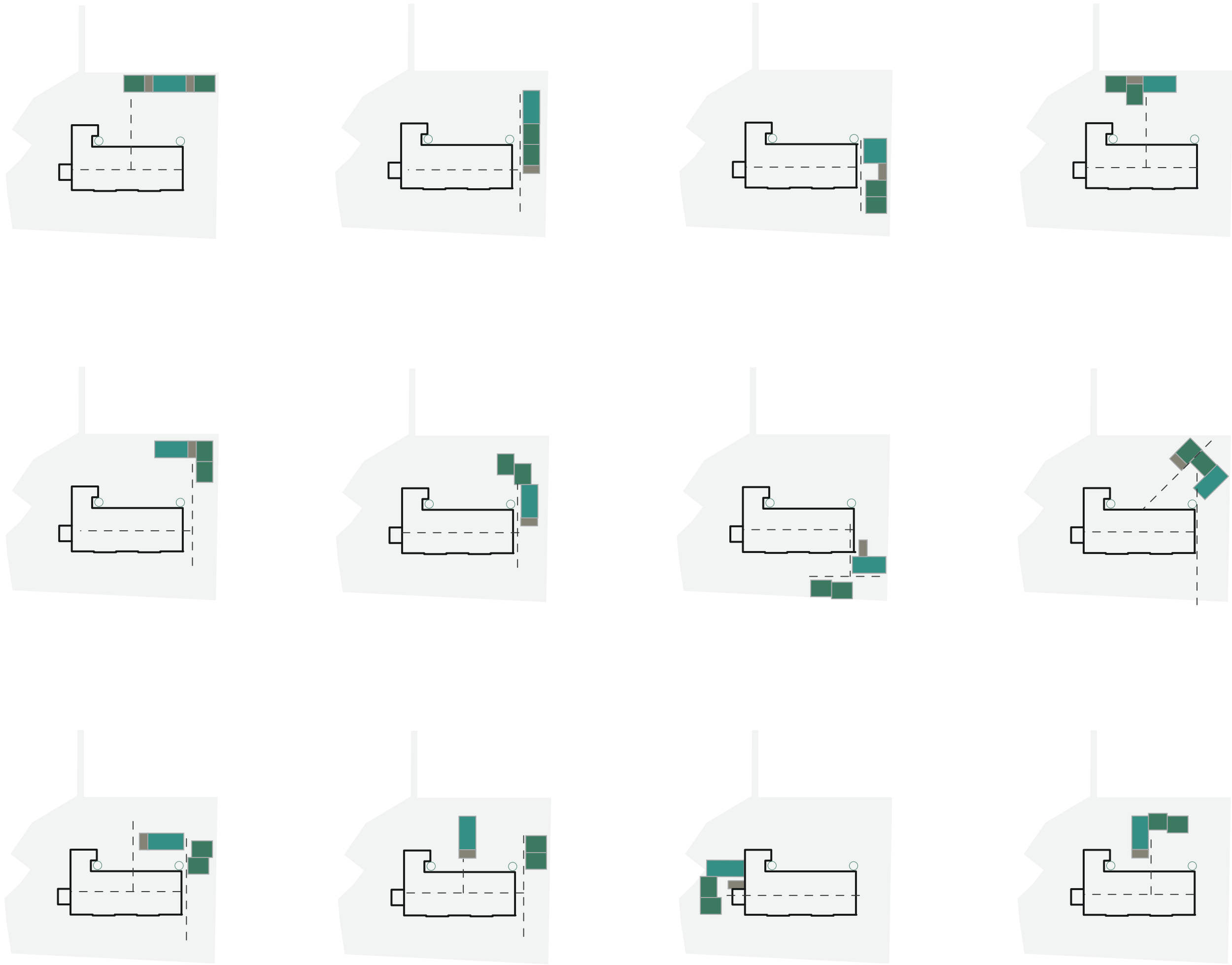


1st phase

2nd phase

3rd phase

3. Diagram of the phasing stages



4. Plan layout design process

Process

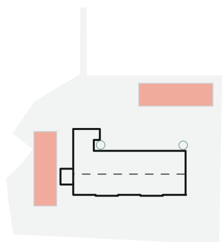
The primary consideration is the *connection* of new building to existing. Various possibilities are tested to determine whether this should be a physical connection and, if so, at what point it should connect.

A key factor in locating the new building is achieving good *sunlight* for all classrooms while maintaining sunlight to the existing building.

The two locations for the new building suggested by the competition brief are tried to determine the effects of other considerations on each.

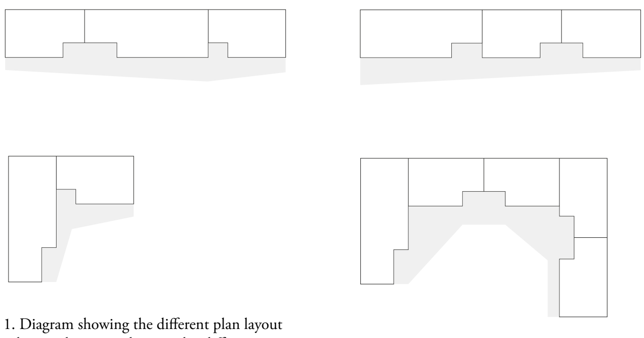
The *phasing* potential of each variant is recognised as a critical part of the project. The definition of *outdoor space* is seen as important factor in designing a new building and its relation to the existing one.

The two existing site *access* points are kept in mind and new potential access routes are identified for each option.



5. Suggested locations by the competition breif

1	Multifunction hall	75m²
2	Storage	3m²
3	Wardrobe	3m²
4	Restroom (accessible)	12m²
5	Restroom	8m²
6	Classroom	44m²
7	Sunspace	150m²
8	School veggie patch	
9	Gathering place Shared space for informal class Entrance hall	
10	Study area	
	Total heated area	209m²
	Total unheated area	150m²
	Total area	350m²

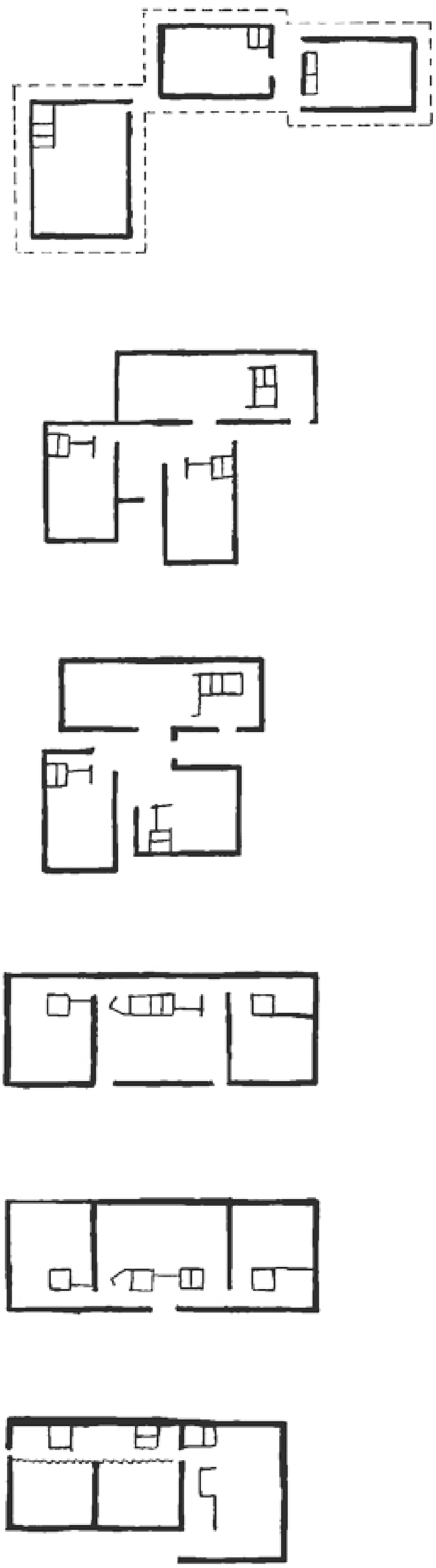


1. Diagram showing the different plan layout solution that can adapt to the different site conditions and the needs of the school

Plan

The multifunction hall and classrooms are designed as self-contained blocks, each with their own storage and cloak space, toilets and small gathering area before entering the room. Structurally disengaging each classroom 'block' from one another supports the potential expansion of the building in phases, as well as its potential to be adapted to any scale and context. The dimensions and layout of the service facilities in each block further reinforce this concept, as each can contain either two regular or one universally accessible toilet as required by specific needs.

The multi function room is located at the western end of the building, closest to the main entrance to the site. The classrooms are arranged linearly along an east-west axis to maintain a south facing orientation. A sunspace along the south facade of the building forms the circulation space between the rooms. The sunspace varies in width from its narrowest points at the ends to its widest point near the centre. The dynamic size of this space facilitates some additional functions outside of the rigid classroom environment, such as growing plants, playing and learning and studying.



Process

Various plan arrangements principles are tested to determine the potential for creating *variety* and *flexibility* in the *function* and *size* of interior spaces, both those functions specifically requested by the brief and any additional others, such as spaces for reading or recreation.

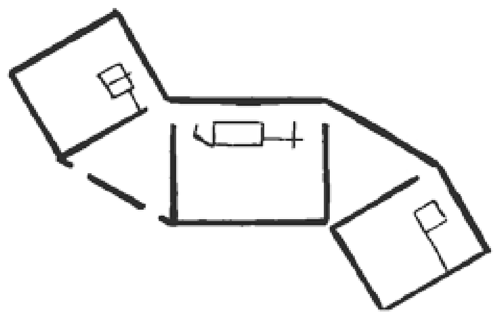
The possibility for *phased* construction is an ongoing consideration, including such factors as spatial and structural connections and material wastage in doubling of walls.

The orientation and layout of spaces is developed with *sun* potential in mind in the attempt to ensure equal daylight in the two classrooms. Another consideration is the scope for integrating *passive heating* strategies into the design.

Connections, both internal and to the existing building, are articulated to determine the most efficient use of space and to minimise the heated volume of the building.

Access from the existing building is considered, especially the access to the toilet facilities, which will be shared by students from the existing, to ensure classes are not distracted by entering children.

The possible internal arrangement of the classrooms is considered in terms of furniture, storage, access to toilets and daylight.



1. Sketches design process of the plan

Classroom

The classroom is the primary place of learning in a school. The layout of the room can be arranged to suit different teaching styles and learning activities. A pitched roof and ceiling creates a heightened sense of space in the otherwise compact floor area. The angle of the roof also integrates a row of operable south-facing clerestory windows that draw natural daylight deeper into the room and facilitate passive ventilation. A row of windows on the wall of the class establishes a visual connection between the class and the sunpace. To prevent distractions, the height of the windows is raised, so that a direct view to the activity of the sunspace can only be seen by a standing child, while the view for a sitting child is obstructed. Windows on the opposite wall allow views to the outside.

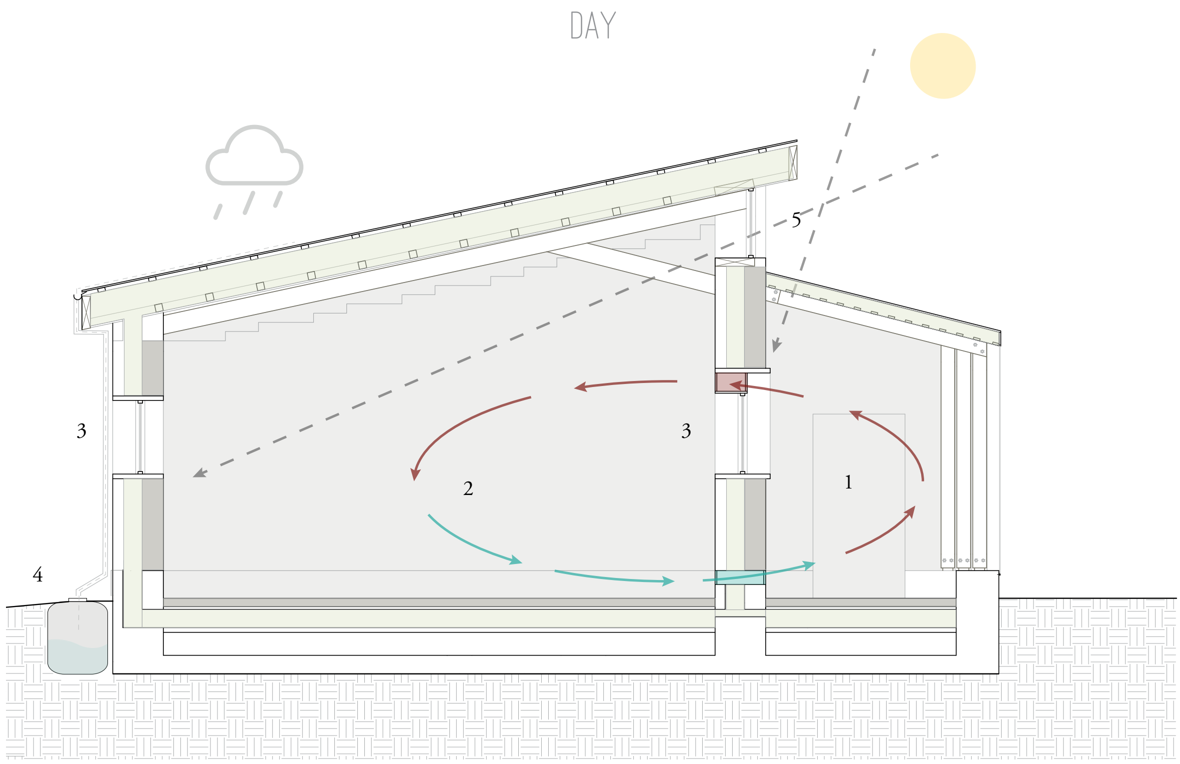
At the rear of each classroom is a storage nook that provides space for hanging winter jackets and storing books, school supplies and personal belongings.

Sunspace

More than just a circulation corridor, the sunspace is a universal place for recreation, collaboration, learning, meeting, playing, growing, reading.
A small amphitheatre in the central part of the linear space can be used for small meetings or larger gatherings.
The steps can also be used as a secondary and informal teaching space.
Some planter boxes are placed in the western end of the space so that plants can be grown all year round and students are exposed to issues of permaculture, food production and sustainability at an early age.
The narrower and quiter eastern end of the space is planned as a private study area that can be used by students between and after classes, as well as by teachers in preparing classes or working individually with students.

Sunspace

A further significant function of the sunspace is its use in passive solar heating. The large area of south-facing openings allows the space to heat up rapidly in Mongolia's cold but sunny climate. The warm air in the sunspace is circulated with the cooler adjoining rooms, reducing the need for additional heat sources. Adobe walls between the classrooms and sunspace store heat gained from direct sunlight during the day and release it slowly back into the space during the night to reduce daily temperature fluctuation. A heavy felt curtain is used to enclose and insulate the sunspace at night to minimise heat loss through the openings. Closing the curtain would be a task for the students who would, through the process, enhance their understanding of buildings as a climate screen.
To prevent overheating in the warmer months the sunspace is opened up to the outside and becomes an indoor/outdoor space.



1.sunspace

The vented wall allows for heating through convection and radiation. The sunspace forms the circulation and recreation areas, as well as a place to grow plants

2.air flow

The heat accumulated during the day in the sunspace is transferred to the class through the upper vents.
Cooler air is released back into the sunspace through the lower vents

3.windows

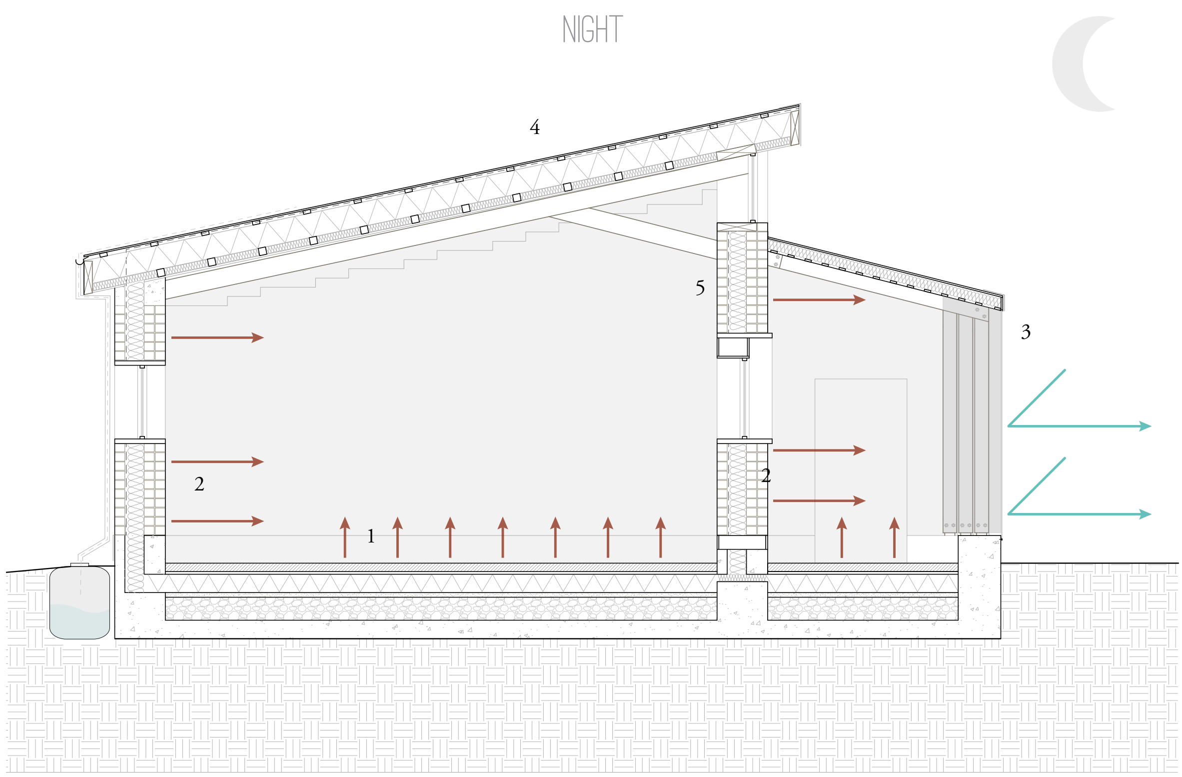
Double glazed windows with integrated vent when facing the sunspace

4.water

Rain water harvesting for use in garden

5.clerestory

Allow the winter sun to enter and heat the thermal mass.
The overhang of the roof shades against summer sun



1.floor

Adobe pavers on solid insulation with gravel fill
on concrete slab

2.thermal mass

The North, West and East walls of the class contain thermal mass (adobe brick 230mm), that prevents frosting in the room during the night by slowly releasing heat accumulated during the day

3.insulation

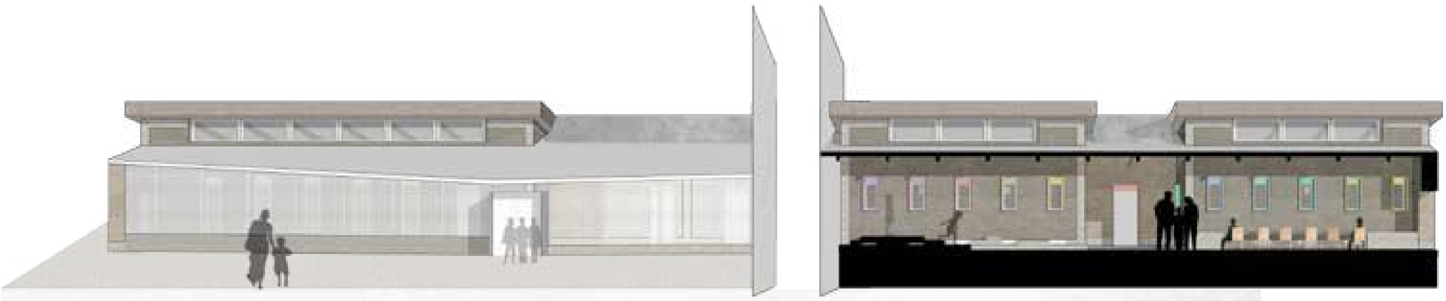
At night a heavy wool felt curtain insulates the sunspace

4.roof

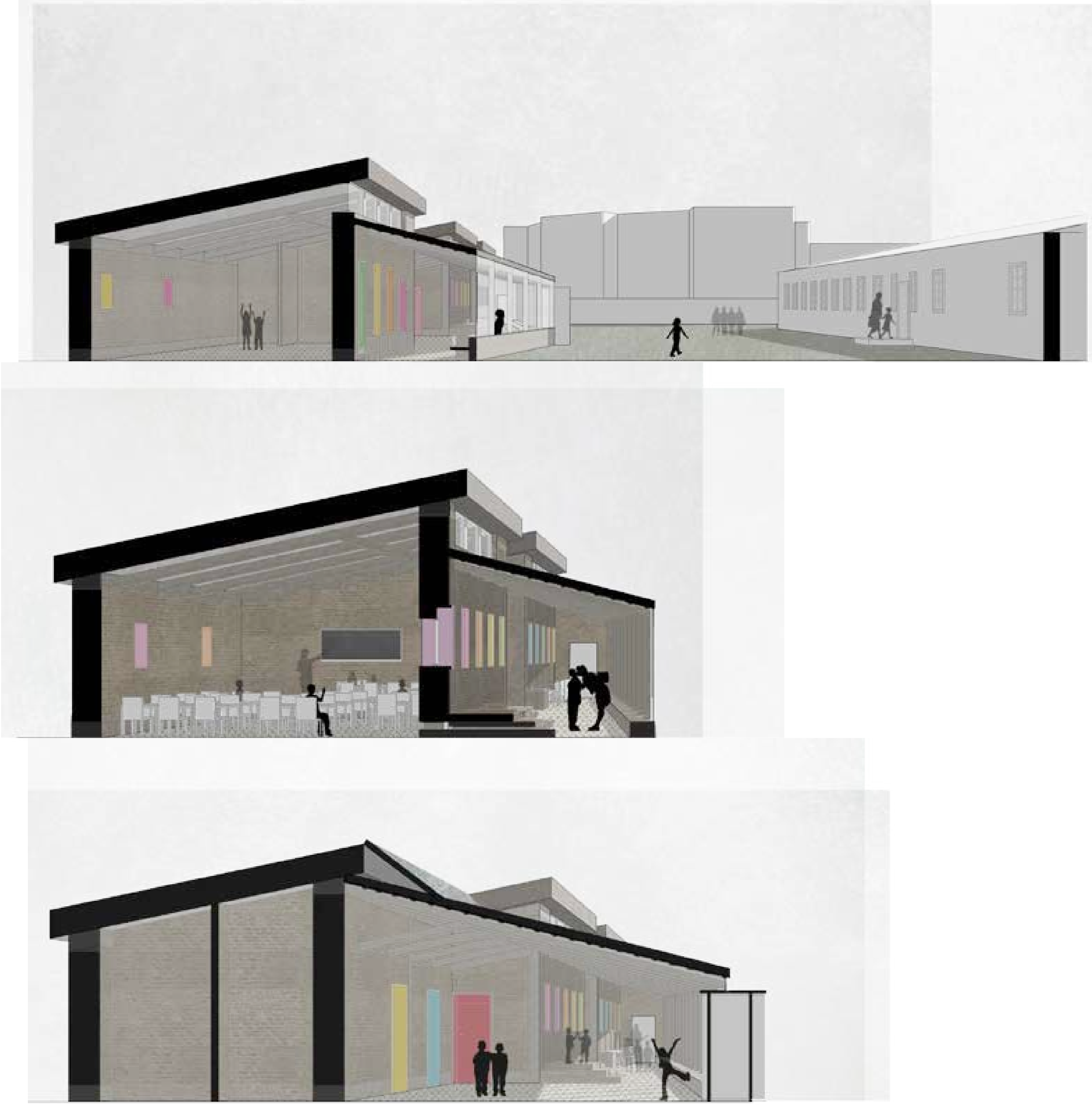
Metal sheeting on insulated timber framed roof

5.wall

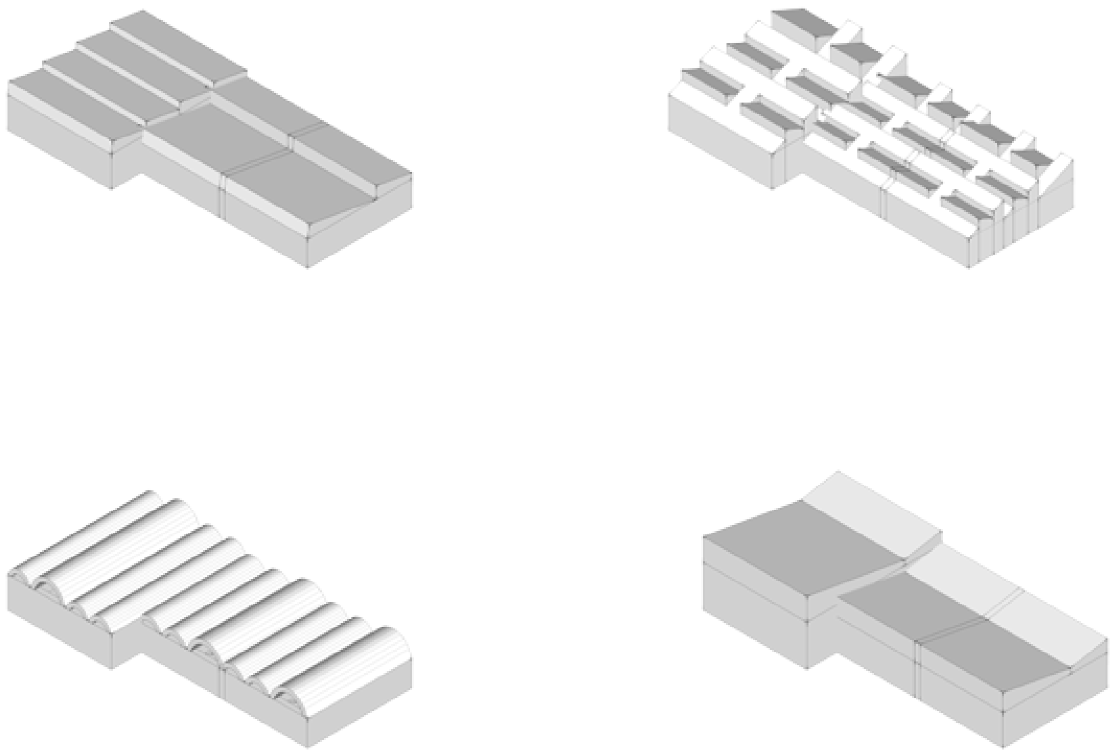
Natural wool felt
insulated double adobe brick cavity wall



1. Elevation and Section of the south facade towards the existing school building



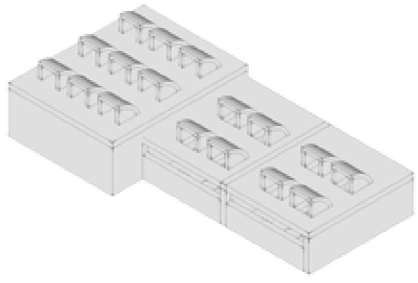
2-4. Perspective sections through the different spaces



5. Design process of volumes

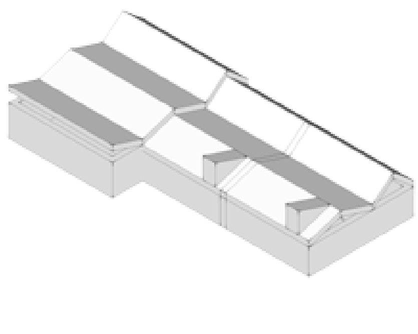
Process

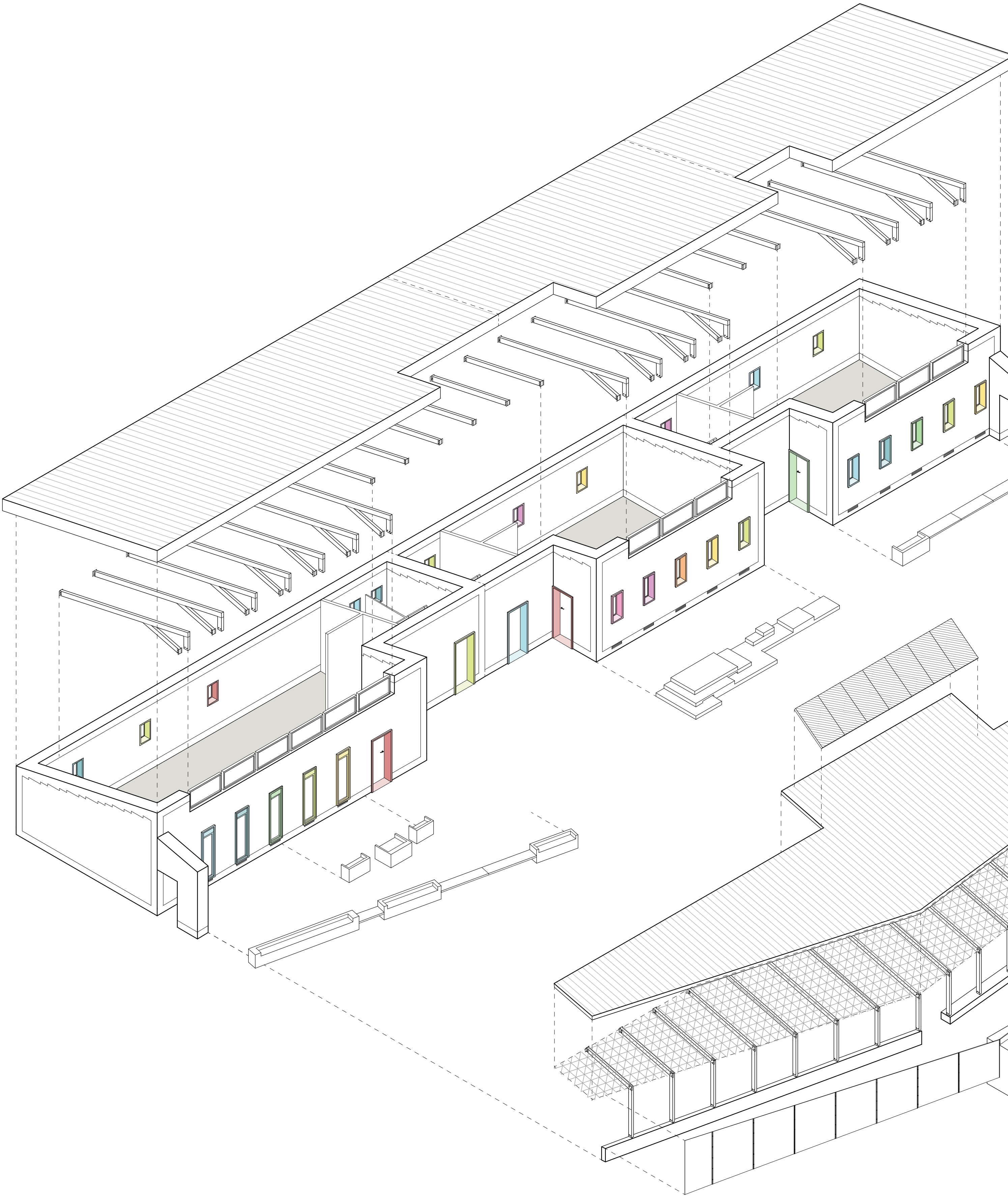
The volumes are considered with particular attention given to the potential for getting natural *light* into the rooms. The direction and place (depth, height) at which the light enters the space is also considered with regard to appropriate lighting in a learning environment.

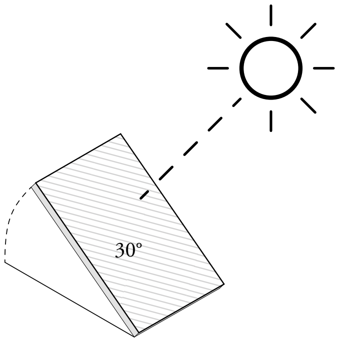


The concept of *phased* construction is kept in mind when designing the volumes. The way in which a new roof is joined to an existing roof is considered to ensure simplicity in detailing and construction.

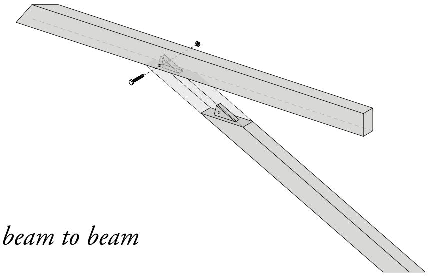
The *shape* of the volumes is intended to retain a humble character and expression that does not overpower or compete with the existing school building or surrounding city. The shape of the roof also directly affects the internal space and the occupants perception of it, so a relevant *scale* should be maintained.



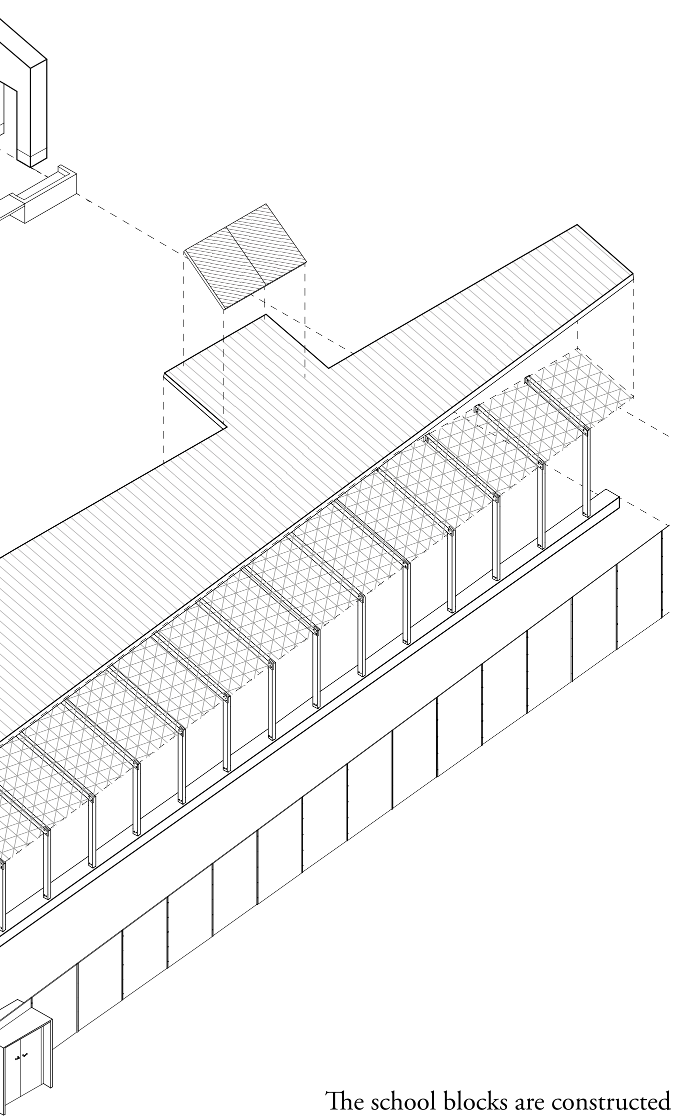




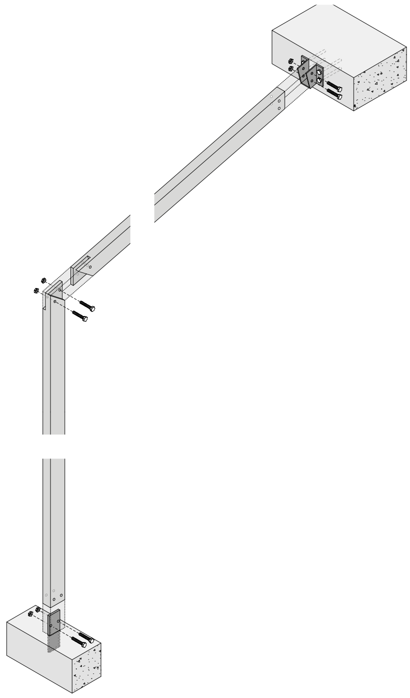
photovoltaic roof panel



beam to beam



beam to wall



column to beam

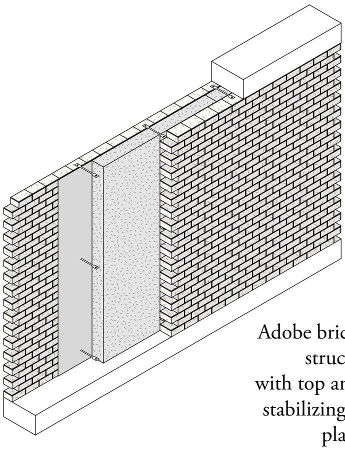
column to base

STRUCTURE

The school blocks are constructed from adobe brick walls, reinforced with concrete base and top plates. Simple timber beams are supported by timber struts in the longer spans of the classrooms. Columns of concrete at the corners of the brick walls articulate the phased construction system by emphasising the joint between the blocks. The sunspace contrasts the heavy construction of the school with its light timber structure and roof. The materials of the ger are replicated in the roof, with a timber lattice supporting natural wool felt insulation. Metal roofing is a more static interpretation of the canvas covering of the ger.

The columns of the sunspace are supported by steel plates which emerge from a concrete foundation, raising the column to accentuate its lightweight appearance. An interlocking timber joint is fastened with bolts at the junction between two timber members. At the meeting of beam and wall, the beam is supported by a steel shelf bolted to the concrete top plate of the wall.

Wall construction



Adobe brick bearing
structure
with top and bottom
stabilizing concrete
plate

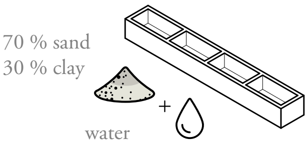
Adobe brick

produced on site
material collected on site
good sound insulation
high thermal mass properties
excellent fire and vermin resistance
only energy imput is human labour
after a lifetime they break back into earth

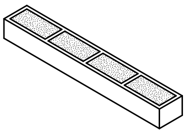
Natural wool felt insulation

locally produced
high thermal insulation
good moisture control
breathable
fire resistant

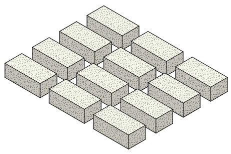
Adobe brick building process



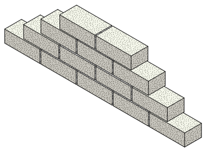
make the mould
for the brick in
timber or metal



pour the adobe
into the mould
and let it rest for
30 min

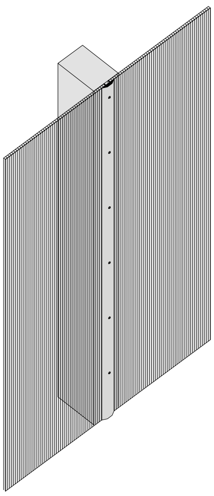


let the brick dry
in the sun for 3
days



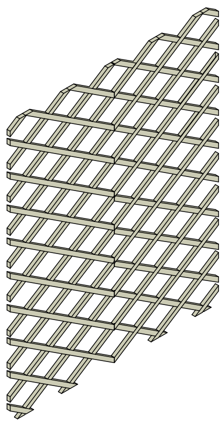
build the wall of
adobe brick with
mortar

Polycarbonate panel



2.5-5 $ m²
Cheap
high thermal insulation
good light transmission
great impact strength
light weight

Ceiling lattice



locally produced
rapid construction
flexible for different configurations

Process

A set of design parameters are initially defined to determine the most appropriate materials in terms of *sustainability, cost, aesthetics, constructibility,* and their *reference to city.*

Research is undertaken on suitable materials for the structure, insulation, facade and windows, floors and roof construction, with particular consideration to the *availability* of the material.

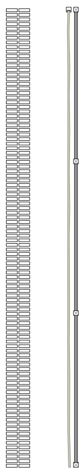
Particular effort is put into straw bale research, both as a structural material and as insulation. The lack of an established straw industry in Mongolia lessened the plausibility of the idea.

The possibility of using a traditional trombe or water wall is considered, but for practicality (requirement for significant human control) and space efficiency these ideas are discarded in favour of a sunspace with adobe brick thermal mass.

Building materials

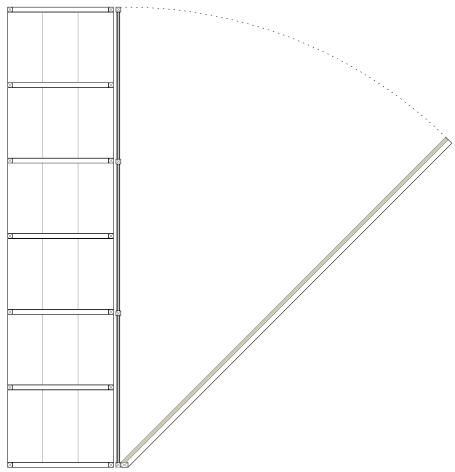
	Structure	Insulation	Traditional	Local
Concrete	✓	×	×	×
Timber	✓	✓	✓	✓
Steel	✓	×	×	×
Stone	✓	×	×	×
Rammed earth	✓	×	×	✓
Earth bags	✓	✓	×	✓
Straw bale	✓	✓	×	✓
Wool/felt	×	✓	✓	✓
Cellulose	×	✓	×	✓

Trombe wall

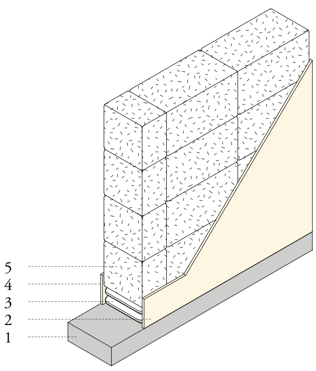


2 layers of brick
300 mm air gap
felt movable curtain (15mm)
double glaze (6-12-6)

Water wall

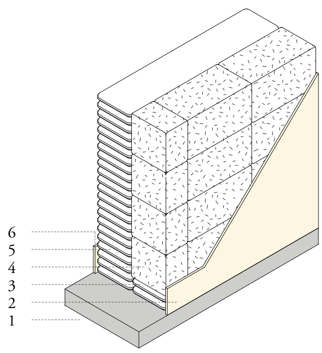


steel drum filled with water
20 mm air gap
double glaze (6-12-6)
felt insulation (25mm) with movable panel



Straw bale

1. Foundations above ground: 200mm; concrete with fly ash sourced from local power station
2. Earth-Clay render layer: 40mm; 3 part sand/2 part clay. before the last coat can be added a waterproof layer
3. Earthbag footers: 250mm; stop any moisture getting from the ground into the wall. Filled with earth or gravel stones
4. Straw bale: 900x500x500mm; structural and insulation function
5. Earth-clay render layer: 40mm; interior side. Can also be used timber panel or plasterboard

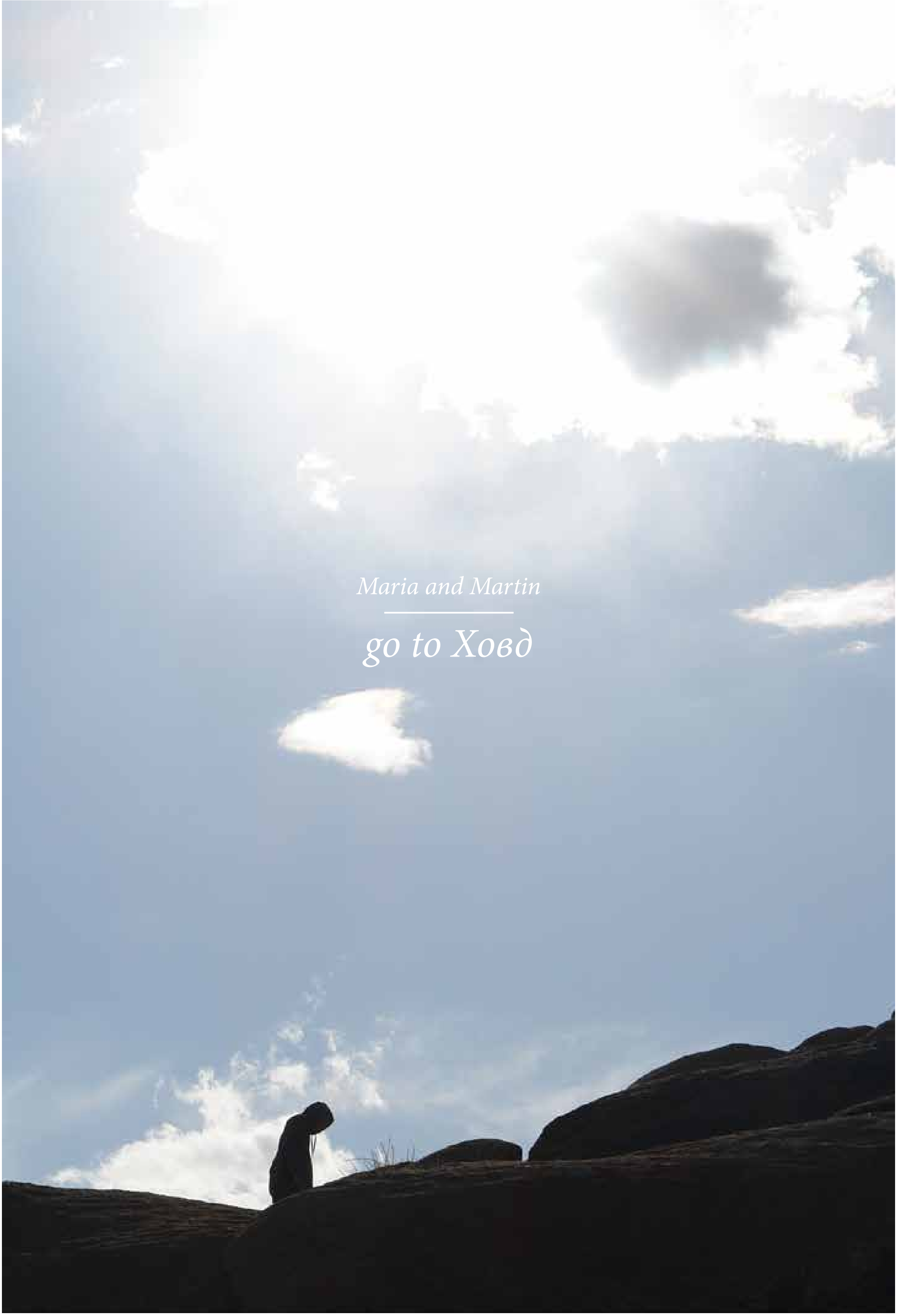


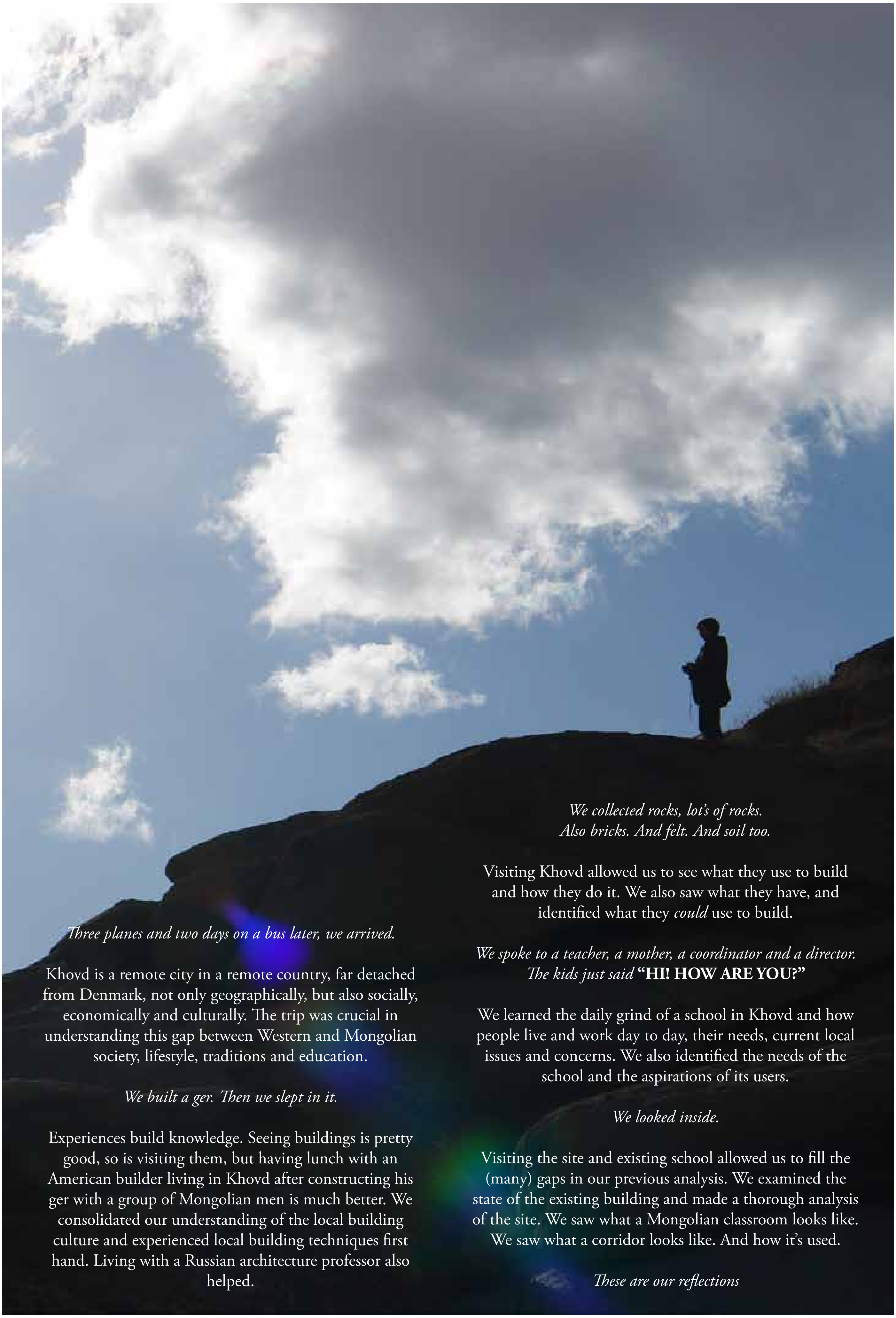
Earthbag and straw bale

1. Foundations above ground: 200mm; concrete with fly ash sourced from local power station
2. Earth-Clay render layer: 40mm; 3 part sand/2 part clay
3. Earthbag footers: 250mm; stop any moisture getting from the ground into the wall. Filled with earth or gravel stones
4. Straw bale: 900x500x500mm; insulation layer, positioned on the cold side
5. Earthbag structure: 250mm; tight together with metal wire between every layer. Ensure thermal mass
6. Earth-clay render layer: 40mm; interior side. Can also be used timber panel or plasterboard

3

Ховд


Maria and Martin
go to Ховд



Three planes and two days on a bus later, we arrived.

Khovd is a remote city in a remote country, far detached from Denmark, not only geographically, but also socially, economically and culturally. The trip was crucial in understanding this gap between Western and Mongolian society, lifestyle, traditions and education.

We built a ger. Then we slept in it.

Experiences build knowledge. Seeing buildings is pretty good, so is visiting them, but having lunch with an American builder living in Khovd after constructing his ger with a group of Mongolian men is much better. We consolidated our understanding of the local building culture and experienced local building techniques first hand. Living with a Russian architecture professor also helped.

We collected rocks, lot's of rocks.
Also bricks. And felt. And soil too.

Visiting Khovd allowed us to see what they use to build and how they do it. We also saw what they have, and identified what they *could* use to build.

We spoke to a teacher, a mother, a coordinator and a director.
The kids just said **"HI! HOW ARE YOU?"**

We learned the daily grind of a school in Khovd and how people live and work day to day, their needs, current local issues and concerns. We also identified the needs of the school and the aspirations of its users.

We looked inside.

Visiting the site and existing school allowed us to fill the (many) gaps in our previous analysis. We examined the state of the existing building and made a thorough analysis of the site. We saw what a Mongolian classroom looks like. We saw what a corridor looks like. And how it's used.

These are our reflections

Natural environment

Khovd city lies on the east bank of the Buyant River, which originates on the eastern slopes of the Central Mongolian Altai mountains. The city is located at an elevation of 1395m in a valley at the northern foothills of the mountain range. The city is completely flat, with steep and rocky mountainous terrain beginning 2-3km to the north and east of the centre and further away in the other directions. The mountains that surround Khovd provide picturesque views from the city centre with glimpses visible between the buildings and along the axis of streets in nearly all directions.

Almost the entire territory of Mongolia is within an arid or semi-arid zone that, combined with frequent cold winds, causes the land to stay 'without any plant cover around the year and stay almost barren.'[1] Apart from the trees lining the two main streets vegetation is virtually non existant in Khovd, with only small wooded areas concentrated in the 'Kazakh District' area along the river and on the northen edge of the city. The most common tree species in the region are larch, siberian pine or cedar and birch, however their distribution is sparce, which is partly attributed to the harsh climate and poor soil conditions, and partly to the lack of sustainability in its use, with Mongolians generally cutting down all available trees to use for heating in the winter months with little regard.

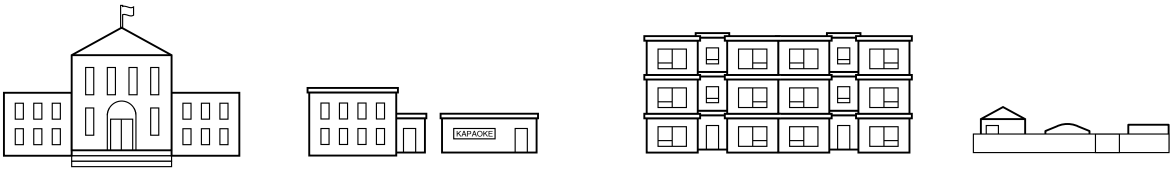
Sustainability

The concept of sustainability does not exist in Mongolia, least of all in Khovd. The city is more concerned about rapid development to meet its current needs than the needs of future generations. Although not justifiable, this mentality is understandable in a developing context, where mistakes of the past are still often being made. This is especially true of the building industry, which, with support of government policy, is constructing housing at a rapid pace to move people from nomadic lifestyles into 'modern' housing in cities. Environmental concerns are also lacking. This is evident in the delivery of all of the public services that exist in Khovd. District heating in the city is provided from burning coal. The sewage treatment system involves pumping the waste 'some distance' (we did not discover how far) outside the city and dumping it untreated into the landscape. The same is true for waste management. It is no surprise that water is unfit for drinking in the city.

The situation is not much different in unserviced areas. Toilets are simple pits in the ground. Household waste is also disposed of into these pits, filling them up even faster, which does not seem to be a big problem though as new pits are simply dug when the existing ones become full. There's no wood left, so animal dung and coal are the predominant fuels burned in stoves to heat gers, creating a concentrated level of pollution that settles in the valley of the city in the winter months.

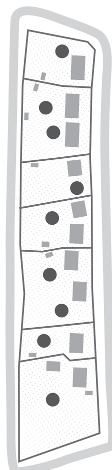
The critical shift away from this collective attitude and mentality requires the kind of generational change that can only come about from early and effective education. Currently, with no alternatives, even people with the best intentions have no other choice.

1. Khovd



Built environment

The urban structure and layout of Khovd is typical of Mongolian cities. The city centre is arranged around a central square defined by two main streets, the government building and several educational institutions. Beyond the square it is difficult to identify a coherent urban structure or feel any sense that planning of any kind exists in the city. Buildings in Khovd can loosely be categorised into four main groups - formal and informal public buildings and formal and informal residential buildings. The central part of the city is scattered with the formal variety of these socialist inspired architectural gems, the most notable of which are the government building, the theatre, the technical college, the university and several other (mostly) educational buildings. Formal residential buildings are also scattered around the central part of the city and new ones as tall as nine storeys are still being constructed. One even has a lift. Much smaller, informal public buildings, containing (mostly) 'pubs' and karaoke bars, maintain their little places between the larger buildings, squeezed into even the most unusual or unlikely sites. Any narrow passages left over inbetween are reserved for short-cutting through the city, a popular method for pedestrian movement from A to B.



2. Khashas in ger neighbourhood

In stark contrast, the suburban residential areas of the city, which surround and sprawl north and southwards from the centre, are characterised by small private plots of land known as *'khasha.'* Typically Mongolian khashas are enclosed by wooden or mud brick fences and contain a ger, toilets and a small storage building for wood or coal. In some cases, where several families live in the same khasha, more than one ger shares the plot.

3. Architectural expression of the city

Architectural expression and building culture

When it comes to architecture and construction, the Mongolians in Khovd adhere to a strict mindset of getting jobs done as cheaply and with as little effort required as possible. This attitude is inevitably joined by a shortage of skilled workmanship, a complete lack of concern for quality and little care for aesthetics. It is therefore not unusual to see buildings still under construction with crumbling facades or sidewalks only half a year old with cracked and crooked pavers. Couple this with the significant governmental corruption that exists and its no surprise to hear of examples such as the project to resurface the central square that ended in a half-paved-half-dirt square and several new cars for the municipality. The (lack of) skills and (lack of) availability of quality materials in Khovd must be kept in mind when designing a new structure in the city, as must the economic and social capabilities of the city.

Nonetheless, an eclectic style of architecture exists in Khovd and is worth mentioning. Exposed or plastered brick and concrete are the predominant building material in the central area, while mud and concrete blocks are common for both small buildings and fences in the suburban areas. Buildings are generally painted in pale colours - yellow, blue, pink, green and others - although this palette is very likely the effect of the sun on poor quality paints rather than the choice of an architect. Building roofs are mostly concrete (if flat) or covered in sheet metal, again with an interesting choice of colours - green, blue and red. Another notable feature of buildings in the city are the windows which display, at least from a western point of view, uncoventional and seemingly random divisions. There exists a large variety of ground surfaces in the city's public spaces, from dirt, to poured concrete, concrete tiles or pavers, to stone, and almost everything in between - a result of lack of planning or just a lack of regard.

Education in Khovd

With a third of the population aged under 15, it seems like every other building in Khovd is a kindergarten, youth centre or school and every other adult is a teacher. There are seven schools in the city, each of which has classes from primary up to secondary levels. Classrooms are full and, as Mongolia becomes ever more urbanised and the city expands, the education crisis in Khovd will only get worse.
Most schools are unchanged since they were built in the soviet era, a feature that is reflected in their physical conditions. Broken windows, missing floor tiles, busted or missing lights, cracked toilets (if they exist at all) and leaking roofs are not uncommon. Lack of maintenance is a major problem, although it is not clear if this is due to budgetary constraints or carelessness - likely a combination of both. Some schools are, of course, in better condition than others, and improvements and expansions are constantly being made. School numbers six and seven are newly built and school number one has a large new building currently under construction that is due to be completed in time for the next school year. The general state of schools in Khovd, however, is poor.

Typical facilities at schools include classrooms, a library, cafeteria, sports hall, performance hall, teachers study and some offices for administration. Most schools have both indoor and outdoor toilets and a caretaker/cloak room. Some schools also have a dormitory for students from the countryside, although this is far more common in small village schools around the province. Khovd city, by comparison, is a metropolis and students from rural areas generally stay with relatives in the city or in gers constructed for them by their parents.
The overwhelming impression of school facilities in Khovd is a lack of space. There's not enough classrooms so there can be up to 40 students in a class at one time. There's also no storage space, so books, bags, jackets, posters and absolutely everything else is cluttered around the room or hung on the walls, accentuating the crowded feeling of the spaces.

1. Typical school facilities

Tsast Altai school, the 4th school in Khovd, is the only school in the city that is split over two separate locations. 1200 secondary students attend classes in a building located on the northern border of the central square, while classes for *most* (for lack of space two classes are located at the secondary school building) of the 550 primary school children are held in a building located across the road and behind the commercial buildings south of the square. Although the distance between the two locations is only a little over 200 meters, they are separated by the city's busiest street and square. There is no sense of connectedness, neither physical nor visual.

The project is located on the primary school site of Tsast Altai, south of the square, next to the youth centre.
The main entrance to the site is via a narrow passage between the commercial buildings at the north of the site. A secondary entrance exists at the opposite corner of the site. There are two trees on the site, and two small and barren, yet fenced, garden areas in front of the school, either side of the entrance. Apart from a narrow concrete path that leads from the site entrance to a small, crumbling asphalt sqaure in front of the main door, the ground cover is dirt.

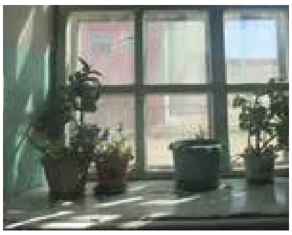
The existing school building has 8 classrooms, a library and two small offices. Other functions, such as the sports hall, small performance hall and tiny cafeteria, are located at, and shared with, the secondary school.
The building is in a very poor condition. There are holes in the floor, broken tiles and windows and no toilets. Small windows, with even smaller operable sections, account for north facing classrooms that are too dark and south facing ones that are too hot during summer. All are too small. The corridor, although dark and narrow, is well utilised with students congregating and playing in the space between classes.
Despite having absolutely no infrastructure designed for play, the site is also well utilised (this is only true for the area in front of the school - the sunny southern part of the site behind the school is reserved for the row of pit toilets and piles of rubbish). Wrestling on the two benches in front of the school seems to be a favourite activity for the boys, while the girls prefer skipping with ropes. After school hours the cooler kids show off their bike riding skills through and around the site. Outdoor activities are, of course, severely limited by climate.

1. Plan existing conditions

1	Main entrance of the existing school
2	Ger tent on the site
3	Storage building - neglected
4	Storage building - neglected
5	Outdoor toilet
6	Main entrance of the site
7	Secondary entrance of the site
8	Youth Development Centre (UNFPA)
9	Bank
10	Bank - under construction
11	Secondary school

Outside

Inside



Social Sciences Coordinator 1st school

The school has 1400 students, 74 teachers, 29 classes.
There is no dorm but we don't need one. Students from herdsman families live with their relatives or in ger built by the parents here in Khovd. The cafeteria is too small.
A new sports field has recently been built
We have many specialised classes and clubs, but no specialised rooms for them and no hall
Some classrooms are not used in the afternoon shift
The school is closed on weekends and during summer
The school is at capacity. We have a new building under construction which is nearly completed. The primary school students will move there from the next school year.
All of the teachers share one preparation room. It is too small and doesn't meet their needs
There is no storage space in the classrooms
We lack equipment in the gym

School Director Tsast Altai (secondary)

What we need most is a cafeteria, a small gym and a big hall for other activities. We have clubs for art, handcrafts, painting, sometimes planting, but no spaces for them. There is no library in this building, but there is in the primary school.
Most of the students live in the city, so we don't need a dormitory.
The teachers dont' have any space to work outside of classroom hours
During winter the students stay in the classroom all day. The rooms are very small, so they do nothing else besides sitting on chairs.
The (district) heating is ok in winter, but the lighting is very bad, and there is no ventilation, so in summer it's too hot and the air quality is poor inside.
The classrooms are about 6m x 7.5m for 35-40 students.
The corridor is 3m wide
We have 4 indoor toilets, but boys prefer to use the ones outside so that they can smoke.

Teacher
Tsast Altai (primary)

The classrooms have no storage space so theres nowhere to keep things. There is no space to hang winter jackets. There's also nowhere for children to wash their hands - there is no sink in the building.
There is very bad light in the classroom (chinese quality).
Ideally we should have no more than 20 students per class
We really need a teachers room as we cant stay in the school to prepare for the classes.
The gym hall of the secondary school building is too small, shared by too many kids and has no place for changing. We also have to bring them across the square to get there so we never go.
The south side of the site is not used because of the smell from the toilet and because boys urinate against the wall of the neglected storage building.

Tsagana: mother of
a student

There's no place to eat at the school so my oldest daughter cooks for the younger children when she is at home, because I'm at work during the day.
In winter the kids don't do anything besides stay in the class all day because there is no space. They never go to the gym because it's too far, too cold and they have nowhere to change clothes.
In summer it's too hot and there is no ventilation as the windows cannot be opened. Many are broken so in winter it's too cold
30/40 children per class is too many, sometimes they even have to bring their own chairs
The secondary school building of Tsast Altai has a playground. Here there is only dirt.

CONCLUSION

The trip to Khovd inspired the development of a meaningful understanding of the climate, culture, building traditions and capabilities and context of the city.
It allowed us to conceive a new vision for the project with reference to local needs and goals.
We developed a new building program that is both realistic and practical and uses architecture as a means of addressing the needs and concerns of the community in a holistic and integrated process.

We saw what a Mongolian school looks like, and what it aspires to be.
Now, we define a new interpretation of what it should be.

The city
A new school should be inclusive and able to engage and unite the diverse community of Khovd.

Climate
A new school should take advantage of its climatic condition, utilising the sun to mitigate the extreme cold

Built environment
A new school should integrate its site with the layout of the city and improve connections. It should also respect the economic and social capabilities of the city.

Architectural expression and building culture
A new school should associate with its context in terms of scale and expression and set a precedent for a contemporary use of traditional materials.
It should also consider the availability and quality of materials and skills in its design.

Natural environment
A new school should define an attractive and useable landscape in an arid context. It should diversify its heat sources to respect its natural surroundings

Sustainability
A new school should optimise its building envelope and windows to minimise energy use for heating and lighting. It should provide a platform for early exposure to, and education of, environmental issues.

Education
A new school should provide spaces that are large and diverse enough to meet their functional requirements. Its should be adaptable and expandable and require minimal maintenance.

Users
A new school should meet and exceed the needs and expectations of its users and be an extraordinary place to be. The use of spaces should be optimised.

Tsast Altai School
A new school should replace the building and its existing functions, creating diverse and practical spaces that are both attractive and comfortable. It should integrate essential new functions: toilets, a cafeteria, spaces for specialised activities and classes, a sports hall with changing rooms, space for teachers to prepare for classes and opportunities for both indoor and outdoor recreation.
It should articulate a more precise connection between the two school buildings.

VISION

We aim to grow cool school into a new building typology for education, that exceeds its functional requirements, respects its Mongolian context, takes advantage of its climatic condition, embraces the needs and aspirations of its users and is inclusive to the city.

4

New Tsast Altai School

1. Site Plan

Site plan

The existing buildings are replaced by a unified structure that defines the borders of the site and establishes a sheltered central inner schoolyard. Two strict learning axes are oriented east-west, advancing the cool school concept to optimise the orientation of classrooms towards south. These are contrasted and connected by two supporting axes, which converge and diverge from their loosely delineated north-south orientation to adjust to the site by meeting and separating from the surrounding buildings. The distinguishing feature of the site, its two trees, are retained and incorporated as defining features of the new schoolyard.
A new main entrance is created at the north east corner of the site, introducing a unified formal entrance from the street and square for both the school and the youth centre, creating a closer integration between these two buildings and establishing a more direct connecting axis to the secondary school building of the school. The existing main entrance to the site is retained, becoming a secondary entrance that facilitates greater flexibility in movement through the site.
The precise inner schoolyard is supplemented by two informal recreational zones that expand the limits of the site. A sports area to the south east of the building integrates with the youth centre and a bike trail to the south west connects the site to the city.

10 Classrooms

1 Workshop space

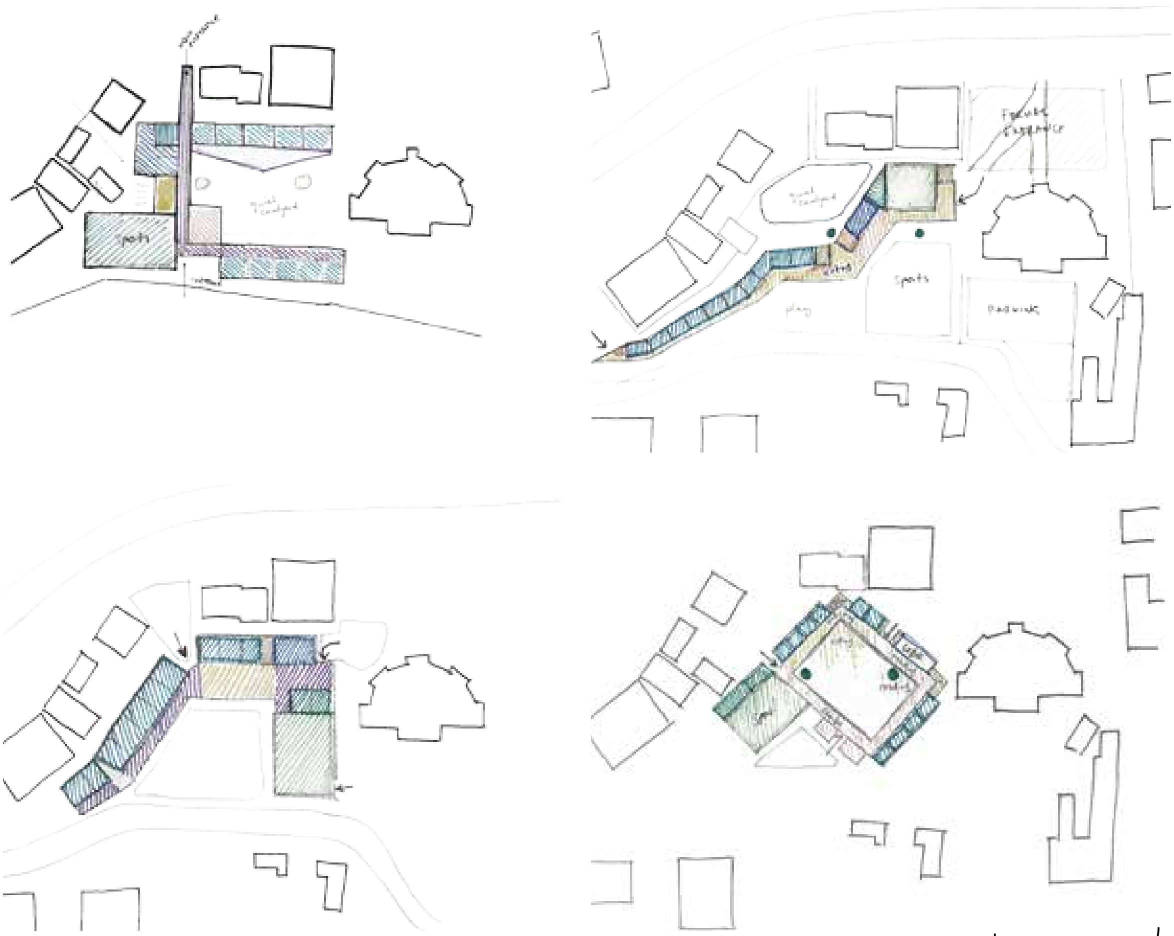
1 Teachers room with director’s office

8 Toilets

1 Canteen

1 Library

1 Multifunction hall



2. Site Plan process sketches

Process

The *reflections* from both Cool School and the research trip are integrated in all aspects of the design process for the new Tsast Altai school building.

Reaching the starting point - an empty site with the *existing building removed* - is a thoroughly considered and somewhat apprehensive decision taking into account the advantages and disadvantages of both options. The physical condition of the existing building make it unreasonable to suggest a refurbishment or reconstruction of the building, given an understanding of the constraints of the context and the priorities for users of the school.

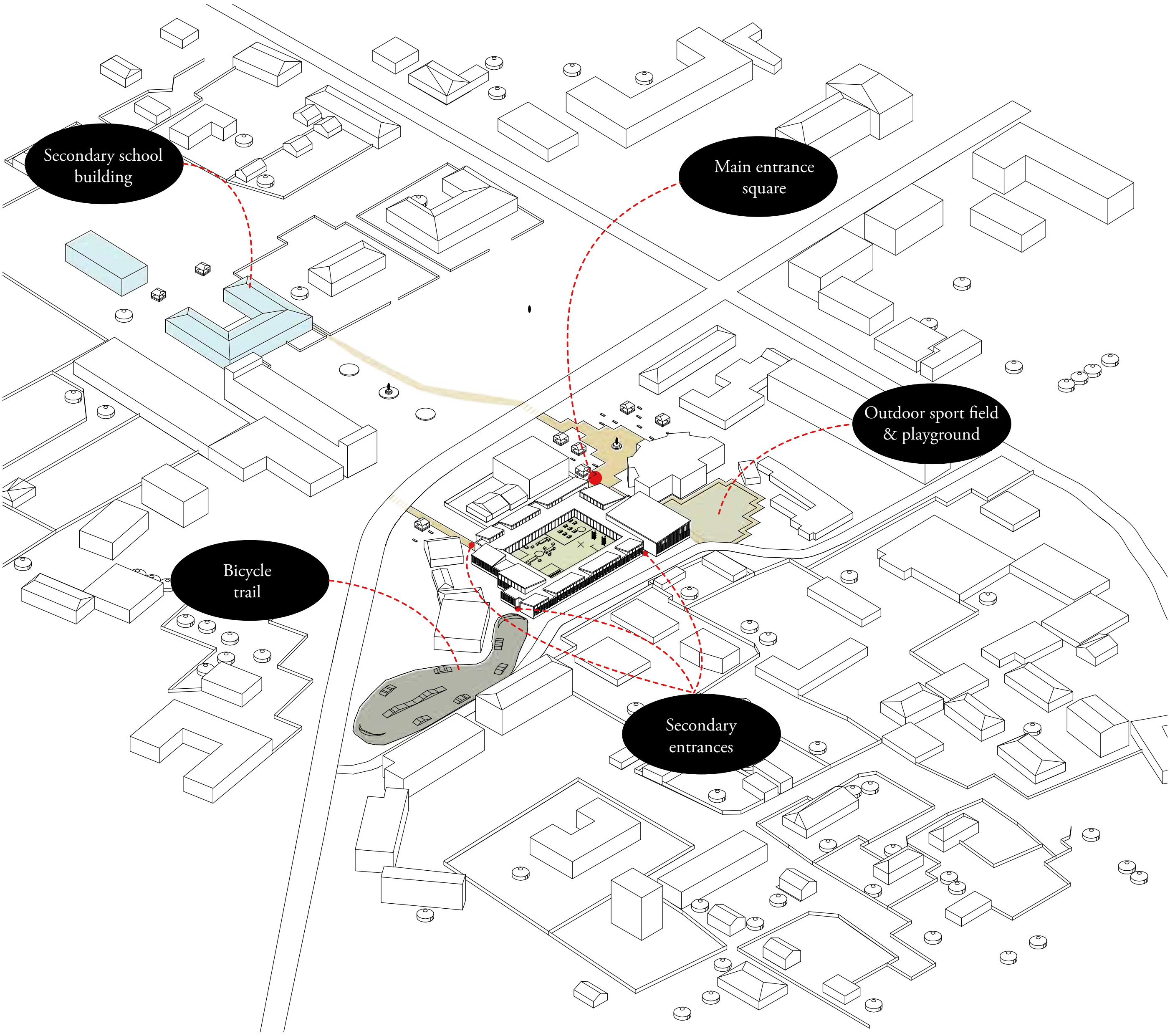
Early iterations attempt to extrapolate the unchanged cool school concept over the whole site to include the additional required functions.

A further *integration* with surrounding buildings and functions is attempted by treating *the site* as a whole and diminishing the rigidity of its boundaries. *Connectivity* with the secondary school building is considered in terms of views, access and shared functions, as is relation to the neighbouring youth centre.

The layout of the spaces remains heavily dependent on their potential for *solar gain*, especially the classrooms, which favour south facing orientations. The much larger room program also demands a more conscious arrangement to ensure sunlight also reaches outdoor spaces.

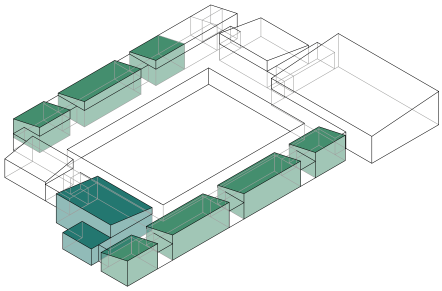
The larger room program also demands a more deliberate layout of spaces and functions in relation to one another, the entrances to the school, the physical and visual connection to the exterior.

With an empty site the *definition of space* becomes much more significant. Different site layouts are examined to determine the amount of *enclosure* that should be forged on the site. An effort is made to balance a sense of safety and shelter with openness to the city. The site is rationalised in an attempt to use it most efficiently.



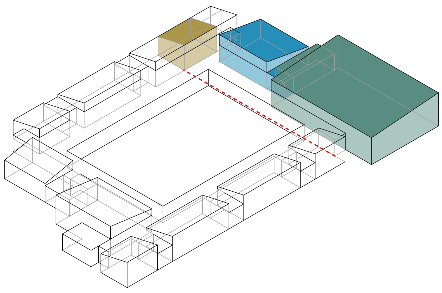
Relation to the city

Quadrilateral connectivity integrates the building wholly with its surroundings and supports the adaptability of the plan to other sites. Arrival is through a square shared with the youth centre, assimilating the functions of each to form a youth learning and development hub/precinct that opens up to the city. The entrance reinterprets the central square of Khovd, becoming an intimate place of gathering that cultivates a sense of community and pride of place which promotes and supports youth development in the city. The square aligns a more direct axis with the secondary school of Tsast Altai, while a childrens crossing further rationalises the connection between the two buildings.
The sports area and playground is sheltered from the main road in contrast to the bike trail that borders the street. Both recreational zones are located at the sunny south facing part of the site, so that the season for outdoor activities can be extended as long as possible.



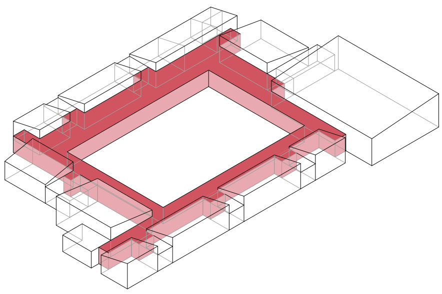
Learning facilities - 625m²

- Classroom (~22 students per class)
- Workshop



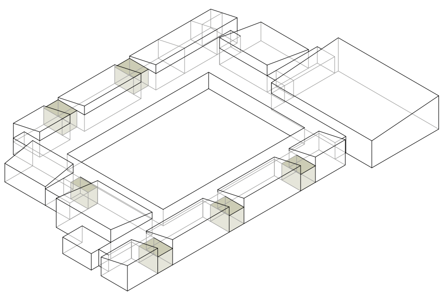
Public facilities - 695m²

- Sport Hall
- Library
- Canteen
- Ability to close the space for public use during weekend and summer



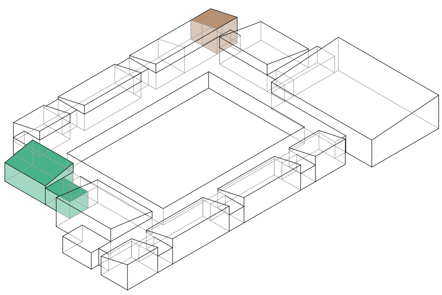
Sunspace - 815m²

- Circulation, study spaces, gathering area and dining hall



Restroom - 52m²

- Restroom



Staff facilities - 52m²

- Office
- Utility rooms

Refer to Appendix I for detailed numbers

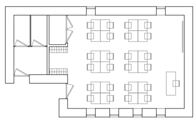
LEARNING

Classrooms

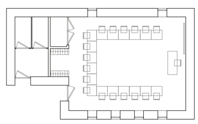
A diversity of learning spaces are defined to facilitate different styles of teaching and preferred methods of learning.

The classroom, as the core facility for learning, remains largely unchanged from the competition entry. All of the classrooms receive light from a row of south facing clerestory windows. Various classroom layouts can facilitate lecture, seminar, group or collective study arrangements. A storage shelves integrated into the windows of the internal partition wall supplementing the storage and cloak area at the back of the classroom.

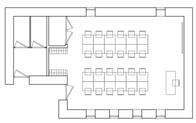
7500 x 6000



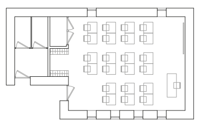
Group study
24 students



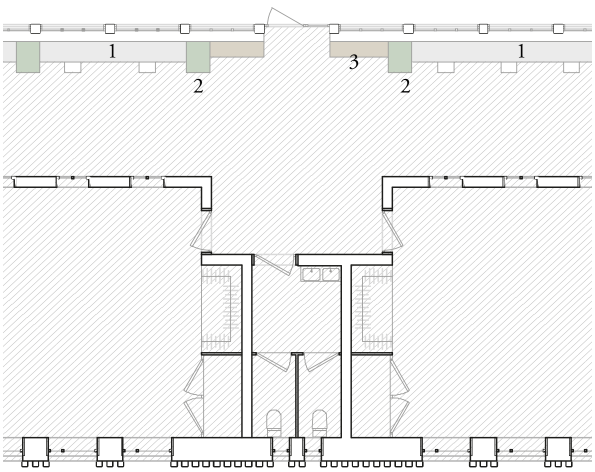
Seminar
18 students



Collective study 24 students



Formal lecture
22 students

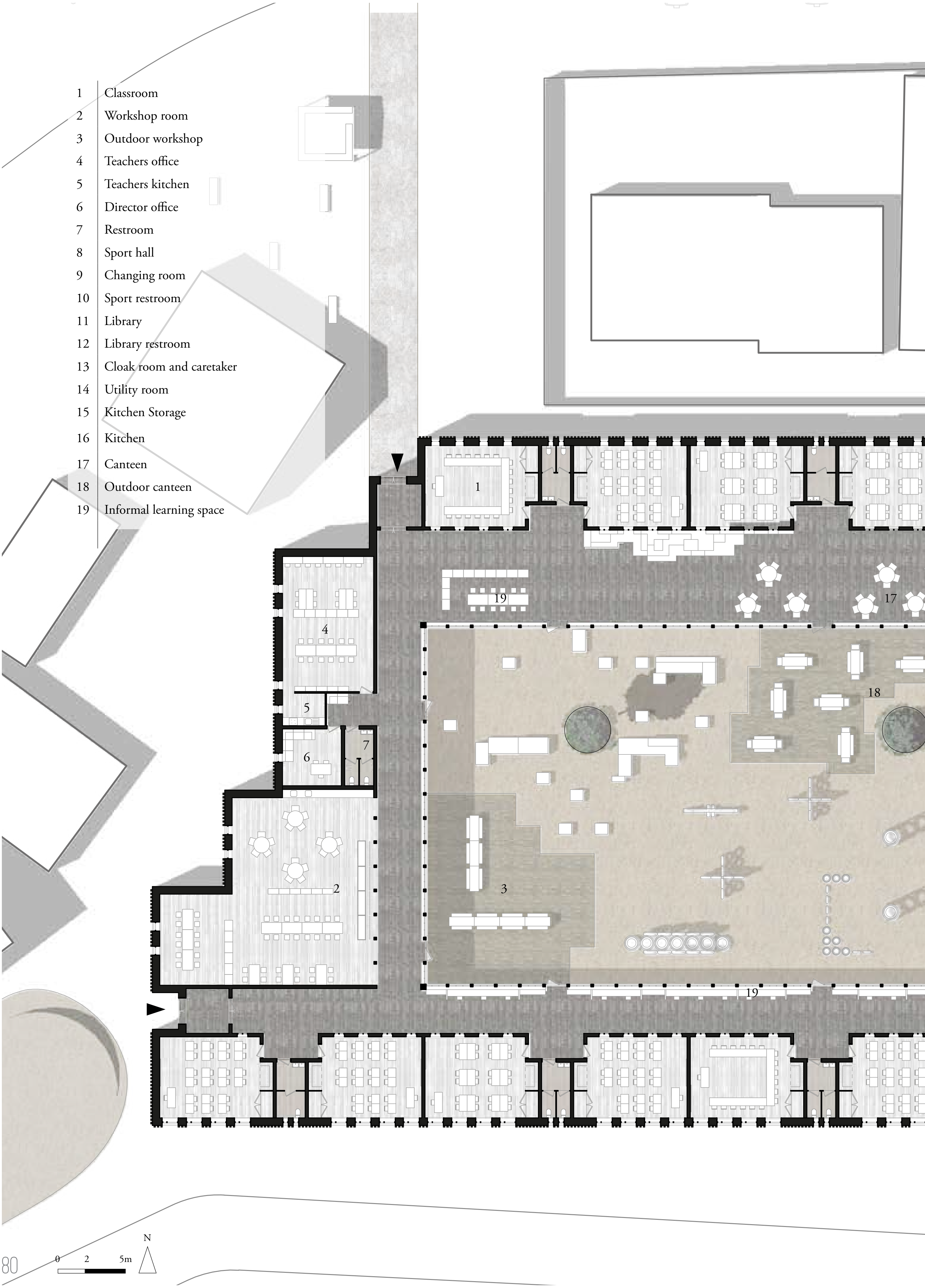


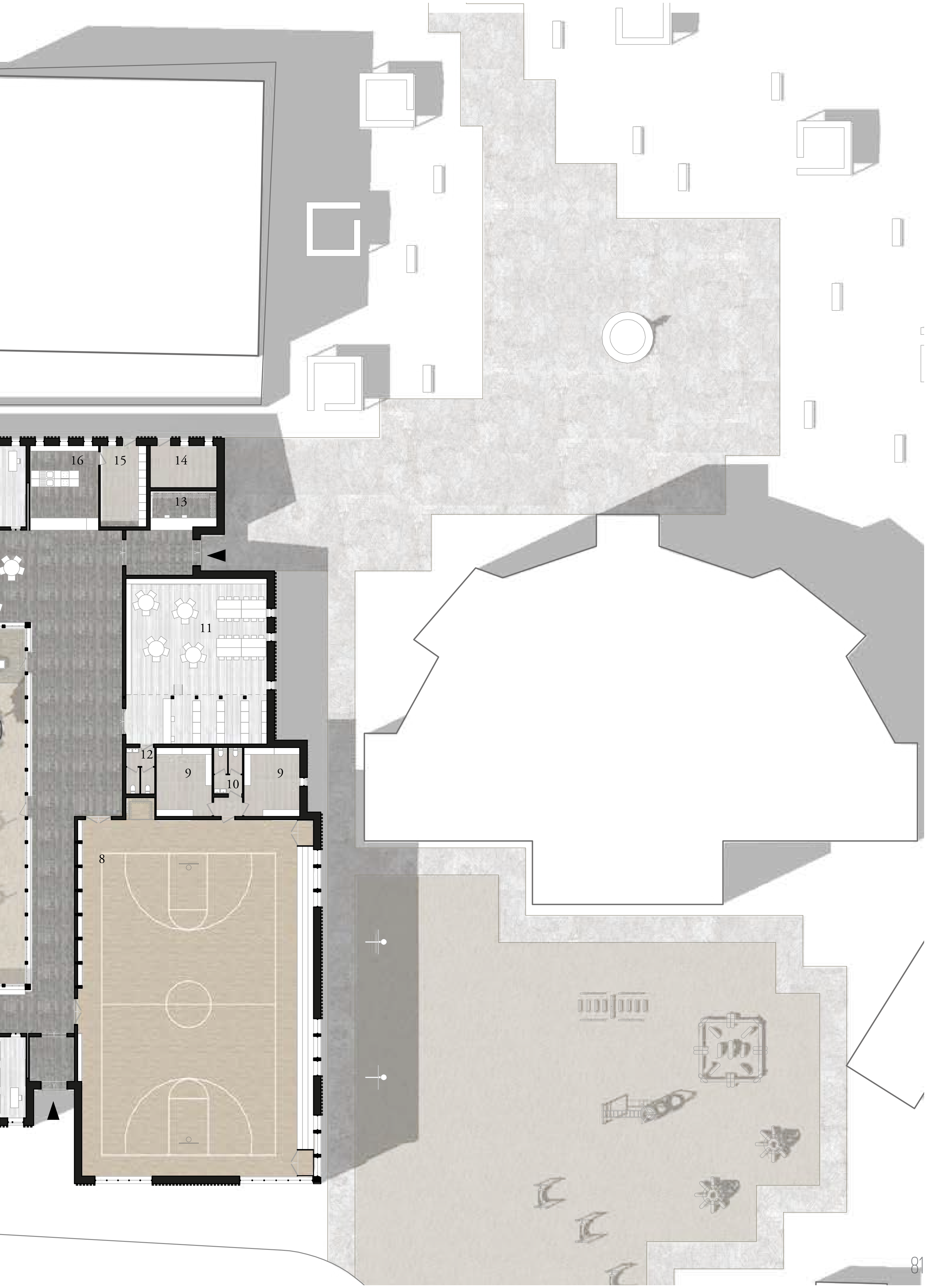
1 | Study desk
2 | Planter box
3 | Seating area
4 | Outdoor courtyard

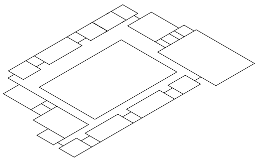
Informal study spaces

An area for private study is created in the smaller and less noisy southern axis of the school. Study benches are integrated into the exterior wall, which is raised to reduce the area of openings in the north facing facade. This orientation also illuminates the work spaces with a diffused natural light that allows a view over the courtyard but excludes glare. Individual study tables are complemented with longer benches that can be used by small groups of two or three children. Privacy is maintained with planter boxes that screen each of the workspaces from one other.

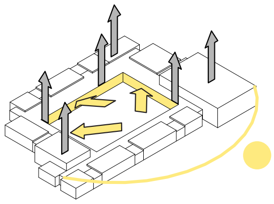
1. Classroom
2. Workshop room
3. Outdoor workshop
4. Teachers office
5. Teachers kitchen
6. Director office
7. Restroom
8. Sport hall
9. Changing room
10. Sport restroom
11. Library
12. Library restroom
13. Cloak room and caretaker
14. Utility room
15. Kitchen Storage
16. Kitchen
17. Canteen
18. Outdoor canteen
19. Informal learning space



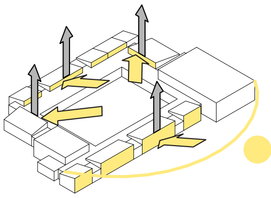

16
15
14
13
11
12
9
10
9
8



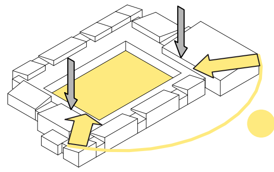
footprint



raise volume according to
room functions and daylight

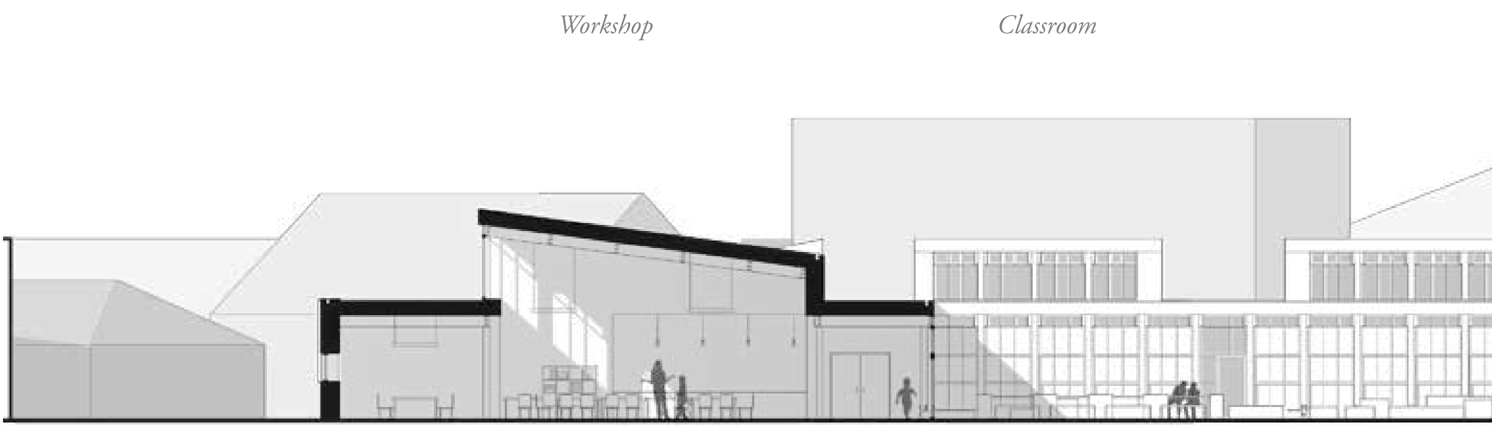


roof sloped for functions and
daylight



roof orientation to avoid
shade in the schoolyard

1. Short Section A-A'

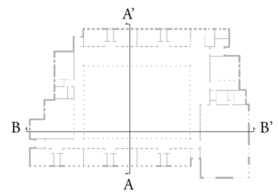


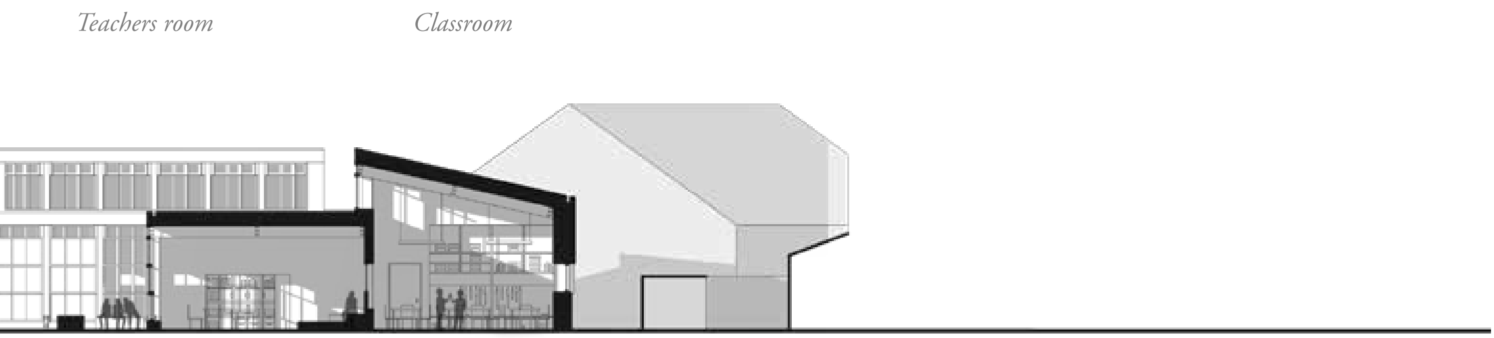
2. Long Section B-B'

0 2 5m

VOLUMES

The plan is extruded upwards to differing heights to meet the functional requirements of each room. The roofs of classrooms are sloped upwards in the southern direction to allow light into the rooms. (for daylight sudies refer to Appendix II).
Roofs of other rooms are pitched in a direction based on their use throughout the day - the teachers facilities are raised upwards in the east to draw in more light in the mornings when teachers are preparing for classes, while the library is raised up westwards, so that more light is gained for after school study and reading.
The larger volumes - workshop and sports hall are sloped downwards towards the inner schoolyard, to prevent overshadowing of this outdoor space during the day.



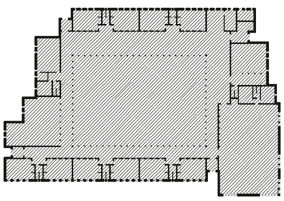


READING

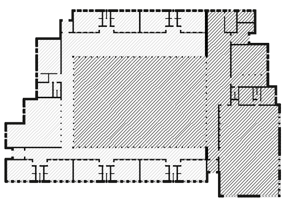
Library

Khovd does not have a public library, so the new school library embraces the people of the city and functions as a hub of knowledge for the entire community. To facilitate this practically, the sunspace is partitioned in two places with a sliding lattice screen that allows public access to the library, cafeteria and sports hall, as well as the schoolyard, but not to the rest of the building, even outside of school hours. (see ill.1-2)

The library's west facing clerestory windows draw in the afternoon and evening sun, creating a comfortable place for private and collective study after school. The brick feature wall, which makes reference to the history of the site by replicating the pattern of the frieze of the original building, separates the library from the sunspace, revealing the structure of the building and providing subtle glimpses of the trees in the inner school yard, without becoming a distraction.



1. Spatial use during the week



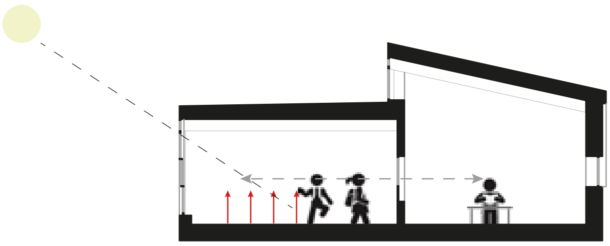
2. Spatial use during the weekend or schools vacation (public use)

Reading corner

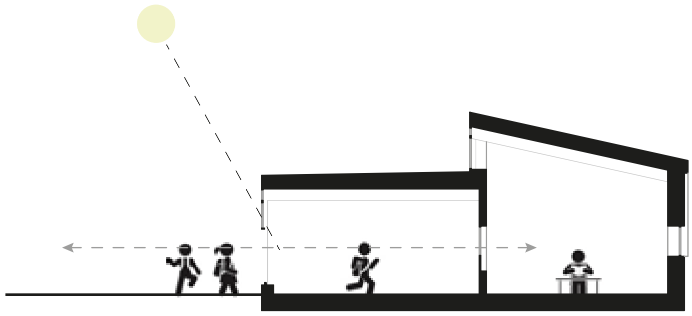
The volume of the library is utilised by a cosy children's reading space located on a mezzanine above the book shelf area. The mezzanine is filled with books, pillows, rugs and natural light.

WINTER	SUMMER

WINTER



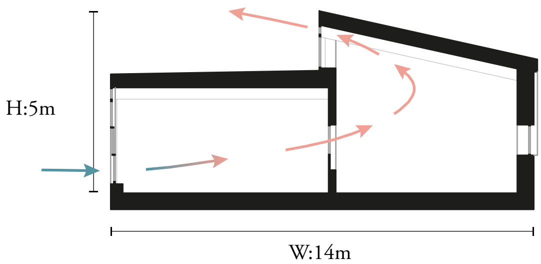
SUMMER

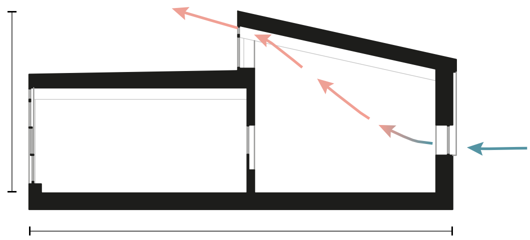


Climate and access

passive heating
thermal mass in the floor
heavily insulated roof
glazed south facade
circulation space supplements classroom
additional heating required from nov-march

access
connection to the outside
increased usable space
prevent distractions in the classroom

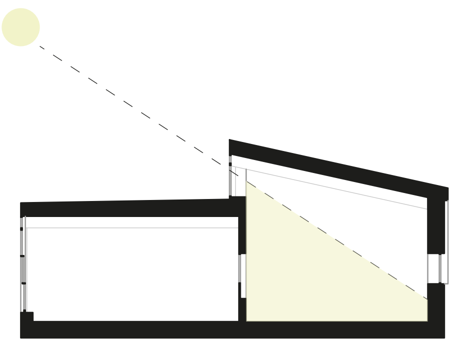


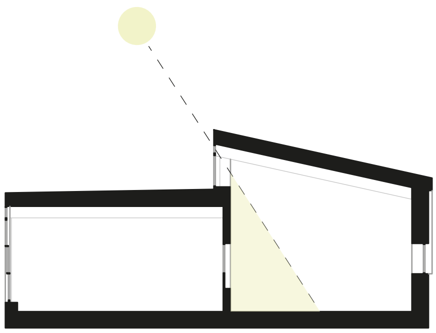


Air quality

natural ventilation
through the corridor and clerestory windows
single sided ventilation W≤ 2.5 H
cross ventilation W≤ 5 H

natural ventilation
through the north facing and clerestory windows
the sash windows (ill.1) of the south wing facade are opened during the day





Daylight

a good amount of natural daylight enters the classroom through the clerestory windows even during the winter months

the amount of light entering
the classroom is reduced during summer to avoid overheating

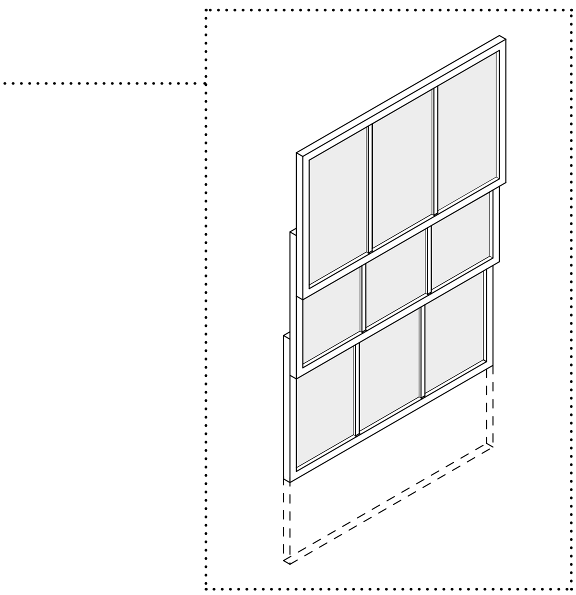
WINDOWS

The design of window openings in the building envelope focuses on the main requirements of indoor thermal comfort, as well as the visual and physical connection to the exterior space for study and daylight.
Therefore the focus for the design of the openings in the building envelope has been on these needs.

It is assumed that the school will be ventilated by natural means only since mechanical ventilations systems do not really exist in Khovd, except for maybe the hospital building. Furthermore, natural ventilation requires no energy input or any specialised skills in mainteinance that would be required in a mechanical system.

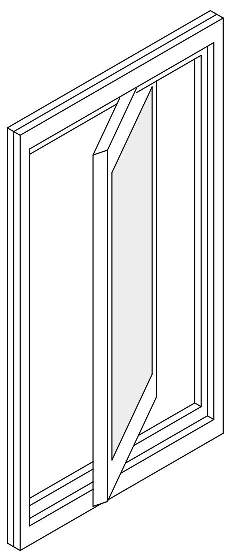
All of the rooms are designed with the potential for both cross and single-sided ventilation. The ventilation itself is assumed to be thermally driven as a result of a high difference of temperature between inside and outside. The operable window size is chosen in relation to the different type of ventilation.

Natural ventilation is assumed to be used both in winter and summer with two different strategies:
In winter the fresh cold air is introduced into the sunspace, where it warms up and is directed into the classroom where the space is heated to a higher temperature. The exhaust air is then expelled throught the clerestory windows. Preheating the incoming air in the sunspace reduces the energy demand for heating in the classroom.
In summer the fresh cold air is introduced directly through the classroom windows and is then expelled through the clerestory windows. The windows of the sunspace are open during summer to prevent overheating.



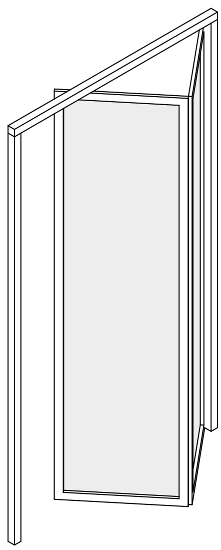
1. Triple hung sash window

Simple system, different level of opening, doesn't intrude into the adjoining spaces



2. Pivot window

Intrusive both in the courtyard and in the sunspace and exceedingly large pane of glass



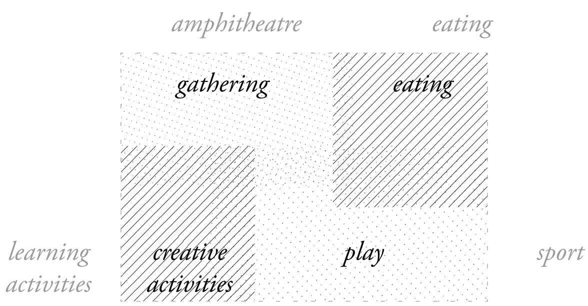
3. Folding window

Intrusive in sunspace - can be dangerous. Also exceedingly large panes of glass.

GATHERING

Sunspace amphitheatre

The sunspace is a multifunctional area that adds something more. More than just a circulation corridor, this is a place for playing, eating, running, meeting. A place for gathering. The amphitheatre is expanded so that it can function for larger groups of children or several smaller groups at the same time. The openable windows allow a direct connection to outside, creating an indoor/outdoor classroom in the warmer months. In the colder months the sunspace functions as a heat collector for the school.



Schoolyard

A sheltered, yet open, schoolyard is the focal point of the school. The strictly defined space is visible from every corner of the building and contrasts the cryptic and unspecific landscape surrounding the school and elsewhere in the city.
While the boundary of the yard is defined, its inner space remains flexible, with places diverse enough for climbing, skipping, wrestling, sitting, eating, reading, planting, and just about everything in between. Four distinct areas are established. The north east and south west portions of the yard have a solid ground surface with tables and seating to invite the eating and workshop activities of the interior outside. The rest of the yard retains a natural ground surface, with an area for growing plants in the sunny northern part and a tyre playground in the opposite corner. The four areas are not strictly delineated and activities can move seamlessly between them, limited only by the imagination of a child.
In the schoolyard low-tech solutions combine with this imagination to provide a canvas where lifelong memories of childhood can be forged.

Classroom

System	Description	Control	Schedule
Human load 25 pupils	100% 08-17 20% 17-18 50% 08-18	Standard Activity	Mon-Fri Sat-Sun
Venting	Basic air change rate: *2* TmpF/p/WindF: *1,9* Max Air Change: *5*	Venting Control SetP: *25°C* SetP: *800 Co_2-ppm* Factor: *1*	Jan-Dec Mon-Fri 08-18
Heating	MaxPow: *3kW* Fixed part: *0* Part to air: *0,5*	Day Set Point: *24°C* Night Set Point: *18°C*	Jan-Mar/Oct-Dec Mon-Sun 07-18 Jan-Mar/Oct-Dec Mon-Sun 19-06
Infiltration	70% 1-9 100% 10-18 70% 19-24	Basic air change rate: *0,13* TmpF/P/WindF: *0*	Jan-Dec Mon-Sun
Lighting	Task light:0,2kW General light: 2kW Level 2000 lux Type fluorescent Solar limit:2kw Exhaust part:0	Light control Factor:1 Lower limit:2kW Temp max: 25°C Solar limit: 2kW	Always

Hours /Year > 27°C	**Hours /Year > 26°C**	**Max Co_2- level(ppm)**
0	*0*	*397*
> 27°C max 25h/year	> 26°C max 100h/year	Co_2 level max 800 ppm

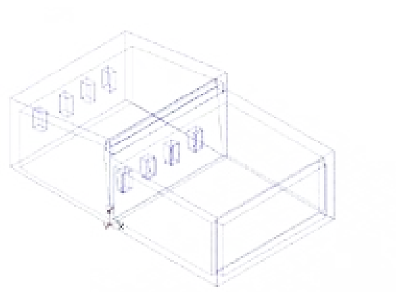
1. BSim systems definition

Sunspace

System	Description	Control	Schedule
Human load 25 pupils	15% 08-18	Standard Activity	Mon-Fri Sat-Sun
Venting	Basic air change rate: *2* TmpF/p/WindF: *44* Max Air Change: *10*	Venting Control SetP: *25°C* SetP: *800 Co_2-ppm* Factor: *1*	Jan-Dec Mon-Fri 08-18
Heating	MaxPow: *3kW* Fixed part: *0* Part to air: *0,5*	Day Set Point: *21°C* Night Set Point: *18°C*	Jan-Mar/Oct-Dec Mon-Sun 07-18 Jan-Mar/Oct-Dec Mon-Sun 19-06
Infiltration	70% 1-9 100% 10-18 70% 19-24	Basic air change rate: *0,13* TmpF/P/WindF: *0*	Jan-Dec Mon-Sun
Lighting	Task light:0,2kW General light: 2kW Level 2000 lux Type fluorescent Solar limit:2kw Exhaust part:0	Light control Factor:1 Lower limit:2kW Temp max: 25°C Solar limit: 2kW	Always

Hours /Year > 27°C	**Hours /Year > 26°C**	**Max Co_2- level(ppm)**
*48**	*145**	*372*
> 27°C max 25h/year	> 26°C max 100h/year	Co_2 level max 800 ppm

** They appear mainly in the month of July, when the school is closed*
Max Outdoor temperature: 30.5°C
Min Outdoor temperature: -40°C



2. Model of BSim simulation

Classroom		Sunspace	
Total		Total	
Heat demand:	*4674 kWh*	*Heat demand:*	*2538 kWh*
Sun radiation:	*1436 kWh*	*Sun radiation:*	*9100 kWh*
Average		Average	
Temperatures:	*22.5°C*	*Temperatures:*	*20°C*
Air Change:	*$2h^{-1}$*	*Air Change:*	*$2h^{-1}$*

Total heat demand: *70 kWh/m²*

3. BSim final results

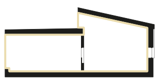
INDOOR ENVIRONMENT

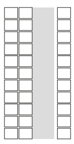
The project focuses on reaching a balance between heating demand and energy consumption and good indoor climate, a major challenge in extreme cold contexts such as Mongolia.
The most effective way of reaching this balance is to utilise the climatic conditions to the advantage of the building. In a place where the sun shines for most of the year, the cold can be offset by harnessing the energy of the sun through passive solar strategies. Besides optimising the building orientation to maximise solar gains, suitable strategies to mitigate the cold include a highly insulated and tight building envelope that minimises thermal bridges, choosing appropriate materials, such as low u-value windows and thermally massive materials that can retain heat for long periods of time.

Simulations with BSim were made in order to ensure that a good indoor environment is achieved in the classrooms and sunspace. The north wing has been chosen for the simulation (ill.2). Here the sunspace is deepest and the north facade of the classroom is exposed to the external environment, therefore affecting more the heating and venting requirements.
It is seen that a relevant factor for indoor thermal comfort is the combination of ventilation and heating system during the winter months. Therefore the focus will be on improvement by regulating these factors.
During the cold months the thermostat in the classroom is set at 24°C with a basic air change rate of 2/h.
In the corridor space the thermostat is set at 21°C with the same air change rate (ill.1).

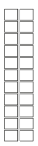
The focus of the project was not to design a Zero Energy building, rather to reach a reasonable energy expenditure in the developing context of the site. Since no relevant Mongolian building standards have been found, iterations have been compared against European standards. Although the final results are slightly short of reaching European standards (ill.3), they display a vast improvement on the current condition, which is reflected in the school operating budget - after staff wages, heating costs are the biggest expense. Furthermore, the climatic condition in Mongolia and temperature range is more extreme than in Denmark, so it would be unreasonable to expect to reach the same energy consumption.

envelope

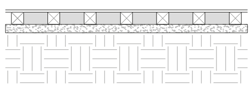




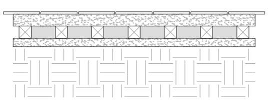
heavy wall, 550 mm
U-value: 0,150 W/m²K



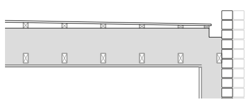
light wall, 240mm
U-value: 0,408 W/m²K



Classroom floor, 210mm
U-value: 0,30 W/m²K

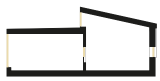


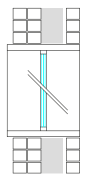
Circulation floor, 330mm
U-value: 0,28 W/m²K



Roof, 420mm
U-value: 0,12 W/m²K

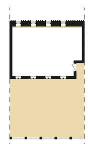
openings





Window
U-value: 0,83 W/m²K

thermal mass

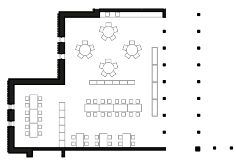


Thermal mass forms an integral part of the sustainable strategy of the school.
It functions by minimising the daily temperature variation inside the rooms by storing and releasing heat. In the sunspace (except that of the north facing south wing) and classrooms, heavy floors and walls accumulate solar heat during the day and release it slowly back into the rooms during the night, thereby preventing the temperature from dropping too low during the night.
(For detailed iterations of material choices refer to appendix IV).

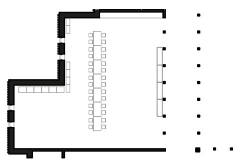
COLLABORATION

Workshop

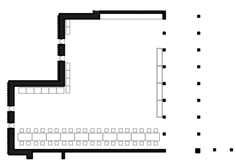
Art, handcraft, sewing, painting, sculpture, drama, gardening, music, games, cooking, film making, poetry, reading, writing, knitting and more... the workshop is a multi functional space for every kind of club. Movable shelving provides storage that can divide the room into several distinct zones or be moved to the perimeters of the room to form a large open space for exhibitions or large-scale performances.
A direct connection to the schoolyard allows the workshop to merge with the outdoor space so that activities can also continue outside.



1. Workshop divided in 3 spaces



2. Workshop as single room



2. Workshop as open space for special event

Sunspace meeting area

A casual activity area is located at north west end of the sunspace. This is a place for informal meetings between both students and teachers, as well as gathering of smaller club groups.


1- Brick wall


2- Natural wool felt


3- Painted timber floor board


4- Dark slate stone


5- Brick floor


6- Local stone


7- Metal roof sheeting


8- Concrete


9- Wood window painted envelope


10- Glulam timber


11- Steel wood connection


12- Painted tyres

MATERIALITY

The choice of every material in the new school is thoroughly considered and consciously deliberate. Particular attention and thought is dedicated to the major concerns: material availability, simplicity of detailing and construction, reference and use in context - both current and vernacular, functionality and practicality and the ability of the material to enhance the spatial experience within the building through composition, colour, texture, smell and, of course, aesthetics.

Locally sourced stone slate lines the floor of the circulation sunspace. The solid and heavy nature of the slate anchors the building in the site and references the geology of the region. Slate is a practical choice as it is highly durable, important in a circulation space that experiences a heavy movement of people, and resists frost and cold weather. Although a dark slate is chosen to maximise its ability to absorb heat from the sun and optimise its thermal mass functionality, the inherent variability in the colour of slate adds to the practicality of its use as dirt and stains are less visible. A different local stone is used externally in the paved parts of the school yard, the colour of which matches that of the surrounding ground, blurring the definition between the different areas of the yard and maintaining a homogeneous appearance of the space.

A clear distinction is created in the learning spaces of the school - the classrooms, library, workshop and teachers study - where timber boards are used on the floors. The floorboards are painted white, a contemporary interpretation of the colourfully painted timber floors that typify public buildings in Mongolia that also heightens the hierarchical perception of transition in space between the hard and dark slate of the sunspace and the soft and light timber of the inner rooms. Timber flooring, as a softer, more absorptive material, is also acoustically a more sensible choice for a classroom.

The walls of the school are constructed from brick. Brick is a material of human scale, with tactility and visual robustness, and the dominant expressive material in the school. Brick assuredly declares the solidity and permanence of the school through every wall. It is a commonly used material in Khovd, so the school reflects the texture and colour of the city through a contemporary interpretation of its use to express the facade. Strips of bricks are extruded outwards from every facade with openings, enhancing the linearity of the building elevation by emphasising the horizontal lines of the bottom of its openings and the top of the sunspace parapet. Furthermore the strips conceal the window frames to protect them from the harsh external weather and provide some limited shading to the windows. A further consideration in choosing bricks in such a cold and dusty context is their long life span and that they require little, if any, maintenance. The practical features of brick also make it a suitable flooring material, used in the service spaces - toilets, kitchen, utility - of the school.

A concrete foundation supports the building and is visible as a base around the edge of the school yard. This rigid perimeter maintains the perception of the strict rectangular definition of the yard even when the windows are open and confidently marks the transition from inside to outside. The height of the base is also perfect for a child to sit.
A glulam timber structure rises from the heavy concrete and brick base of the school. The columns and beams are deliberately exposed everywhere in the building, composing a contradictory atmosphere of space and lightness throughout the otherwise solid structure. The use of wood in the structure refers to both its vernacular and current use in roof structures in Mongolia, and relates to the timber window frames and doors used throughout the school. Glulam is also a more environmentally responsible structural material, requiring less energy to produce than concrete or steel. Connections are detailed with simple joints and basic steel plates, to minimise complexity in construction.
Another material with a strong association to vernacular architecture is the sheep wool used to insulate the school. Although visually hidden, the choice of insulation material is critical in such a cold climate. Natural wool felt, similar to that used in gers, is chosen for the walls, while loose wool is used in the roof and floor. Wool is used for its exceptional thermal properties, wide availability, low cost and traditional significance.

The roof of the school is made from sheet metal, a common roofing material in Khovd that resists damage from cold and sun.

One final element is introduced into the school: tyres. Tyres are commonly used as barriers, garden beds and decoration around the city - often they are formed into swan-shaped sculptures. Recycled tyres, a waste material, will become the primary playground facility, with places for climbing, swinging, rocking and crawling.

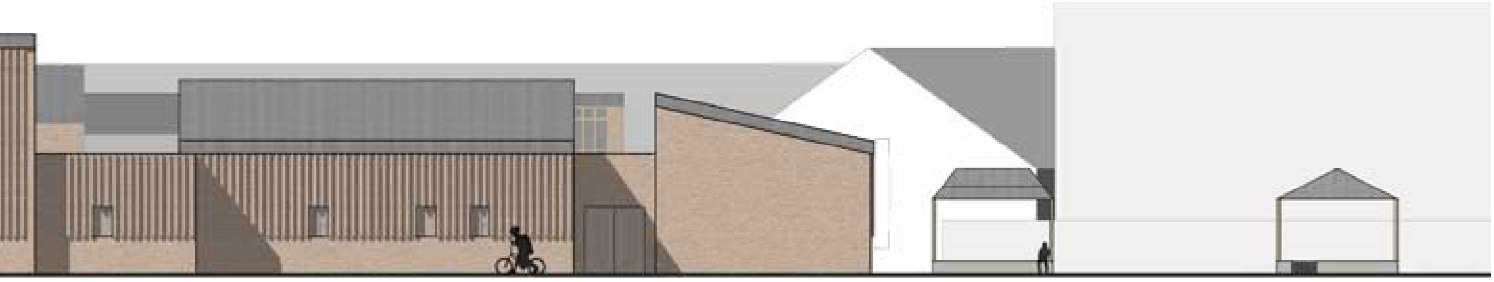
1. East elevation

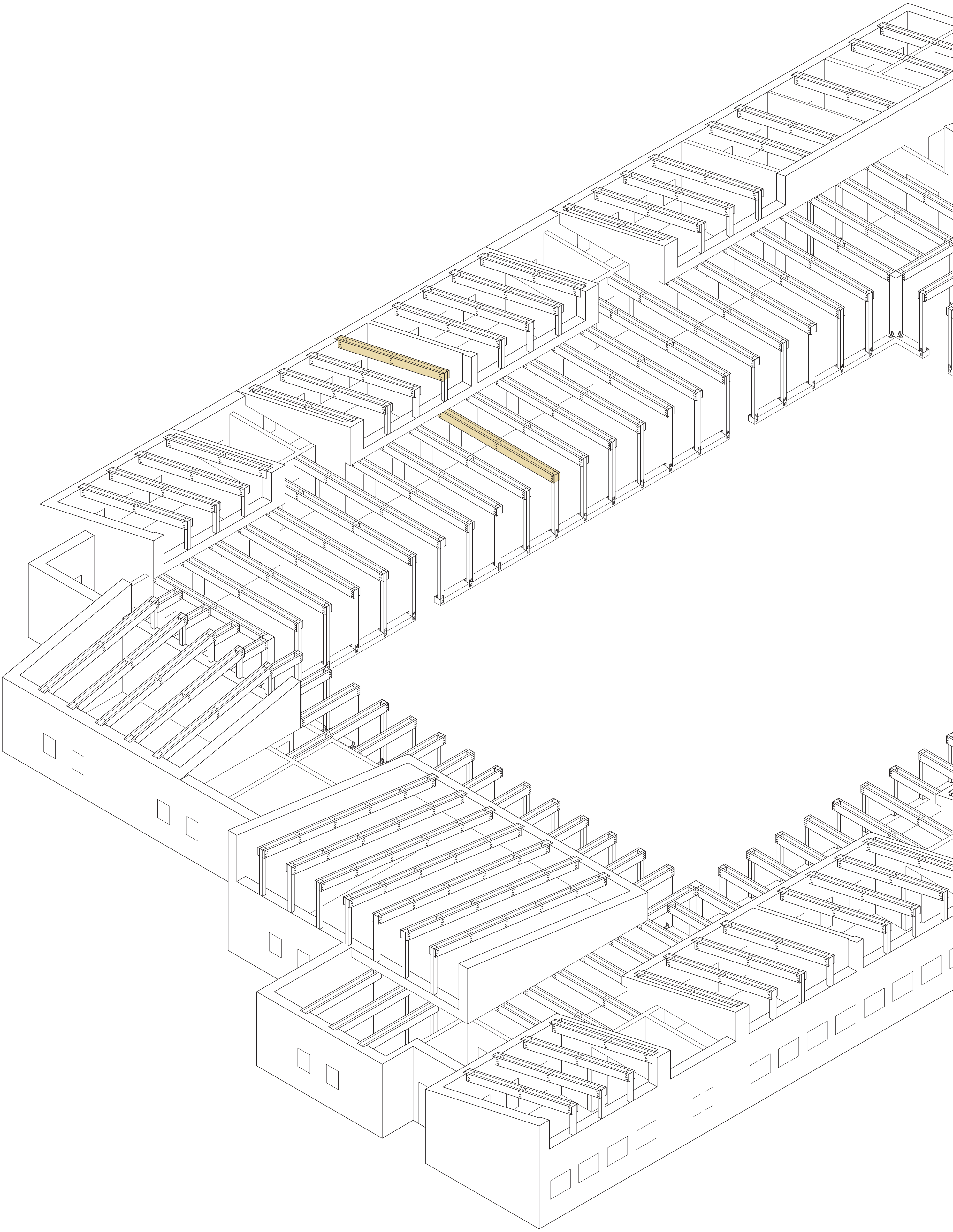
2. South elevation

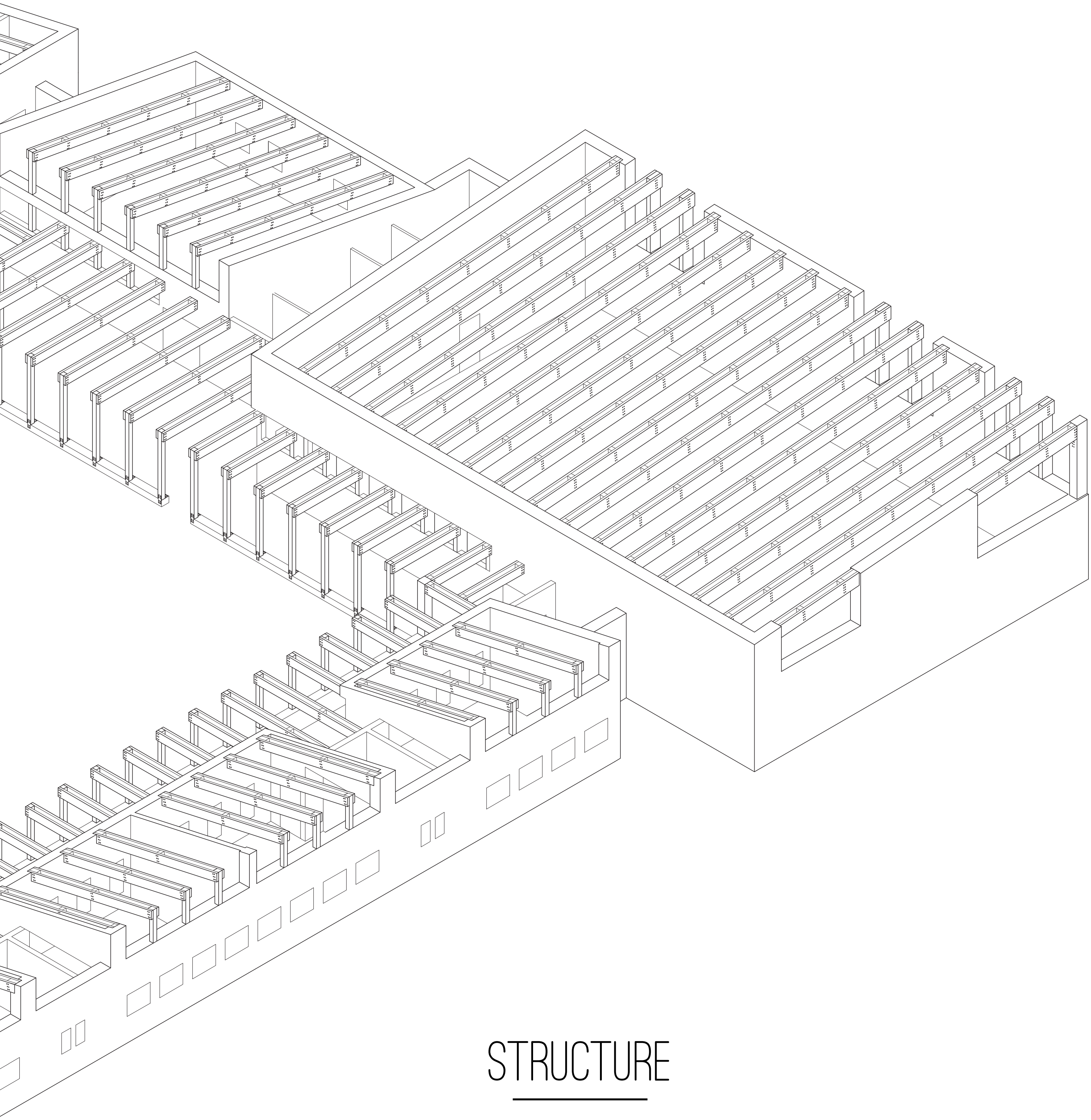
3. North elevation

4. West elevation

0 2 5m







STRUCTURE

The structural principle of the school is based on a series of timber beams supported by timber columns and load-bearing brick walls. The roofs of various rooms are pitched in one direction to maximise internal light and minimise overshadowing of the central schoolyard. The sunspace is covered by a flat roof with the same post and beam structure.

GL28c Glue laminated timber beams can be manufactured in the large dimensions required by the spans in the building and are therefore proposed for the primary beam. To reduce the size (and cost) of individual members, the beams are designed as two elements split by the width of the columns that support them. The principle is continued throughout the building and allows a greater expression of the structure in the facade elevations. The space between the beams also allows for the simple and practical visual concealment of technical elements, such as cables and lights, that provides for easy access for maintenance.

The secondary structure consists of C24 softwood joists, sourced as locally as possible - likely from neighbouring Russia or China. C24 timber is chosen as it is one of the 'most commonly available' timbers worldwide[1], which means wider availability and lower costs.

The structure of the north wing classroom and sunspace (as shown in the image) is analysed in further detail as these elements are the most commonly occurring in the building. The longest span of the sunspace is found here.

Dimensioning the members

The classrooms with adjoining circulation space are the most common structural typology in the building, so the primary roof beams and secondary joists here are detailed and dimensioned. The north wing is calculated as the circulation space has the longest span here.

The natural loads arising from climatic conditions, namely snow, wind and sand, are calculated, as is the dead load arising from the self-weight of the roof itself. For load calculations refer to appendix V.

Applying the calculated loads to the roof beams allows the deformation of different beam cross-sections to be defined in Karamba. The allowable vertical displacement is typically 1/600 to 1/400 (ASCE 7-88).

Several iterations of member cross sections are tested to determine the required dimensions of the members, outlined below. Iterations are done of the sunspace structure, as the span is slightly longer than that of the classroom.

Primary beams

A 1/400 displacement in the primary beams of 7 metre span is equal to

$$disp_{max} = 7.0 \ / \ 400 = 0.0175 \text{ m}$$

		Width (cm)		
		10	15	20
Depth (cm)	30	0.043	0.03	0.023
	35	0.028	0.019	0.015
	40	0.019	0.013	**0.011**

A beam cross section of 40cm x 20cm is chosen for the primary beams.

Secondary joists

A 1/400 displacement in the secondary joists of 1.78 metre span is equal to

$$disp_{max} = 1.78 \ / \ 400 = 0.0045 \text{ m}$$

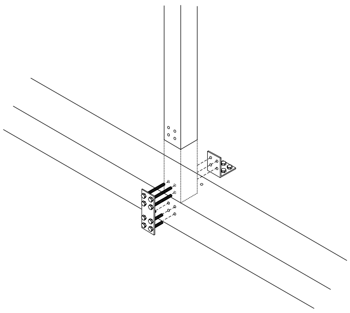
		Width (cm)		
		2	5	10
Depth (cm)	5	0.0399	0.016	0.0081
	10	0.0054	**0.0022**	0.0011
	15	0.0018	0.0007	0.0004

A beam cross section of 10cm x 5cm is chosen for the secondary joists.

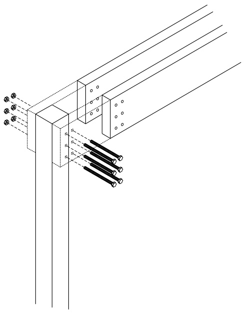
Connections

Connections between members are designed for simplicity of construction. The two parts of the beam are bolted with a timber spacing element in between. The beams are bolted to the columns, which are fixed to the concrete base with basic steel plates. These types of joints are proposed as they do not require a high level of precision in manufacture or assembly.

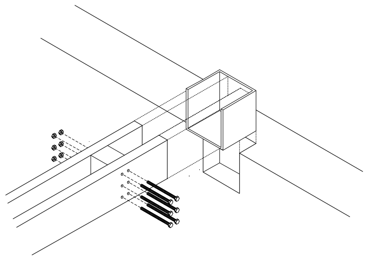
column to base



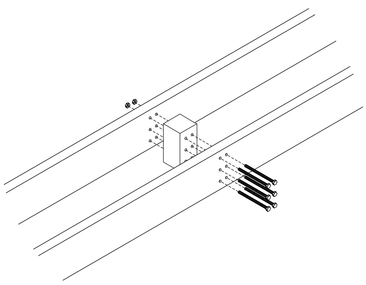
column to beam



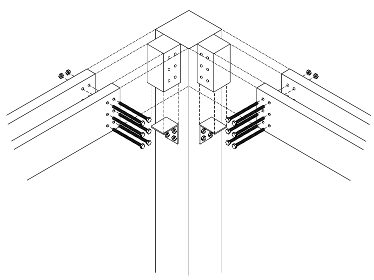
beam to wall

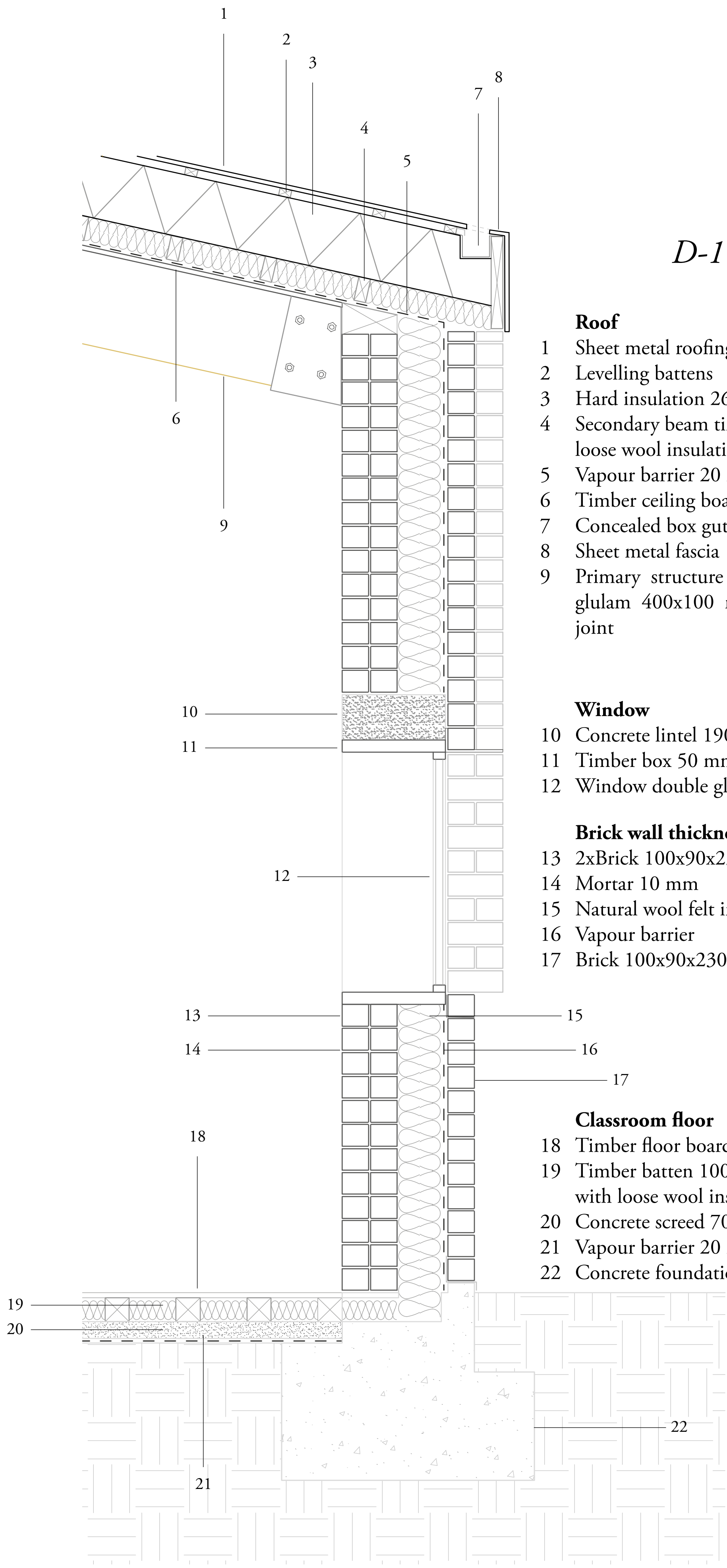


beam



corner column





D-1

Roof

1 Sheet metal roofing 18 mm
2 Levelling battens
3 Hard insulation 260 mm
4 Secondary beam timber C24 100x50 mm with loose wool insulation in between
5 Vapour barrier 20 mm
6 Timber ceiling board 20 mm
7 Concealed box gutter
8 Sheet metal fascia
9 Primary structure with double timber beam glulam 400x100 mm with metal steel plate joint

Window

10 Concrete lintel 190 mm
11 Timber box 50 mm
12 Window double glazed 12-4-12 with air gap

Brick wall thickness 550 mm

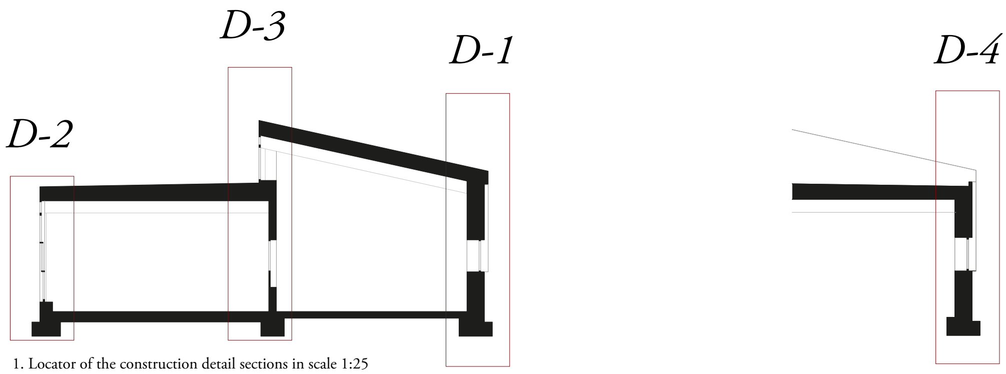
13 2xBrick 100x90x230 mm
14 Mortar 10 mm
15 Natural wool felt insulation 180mm
16 Vapour barrier
17 Brick 100x90x230 mm

Classroom floor

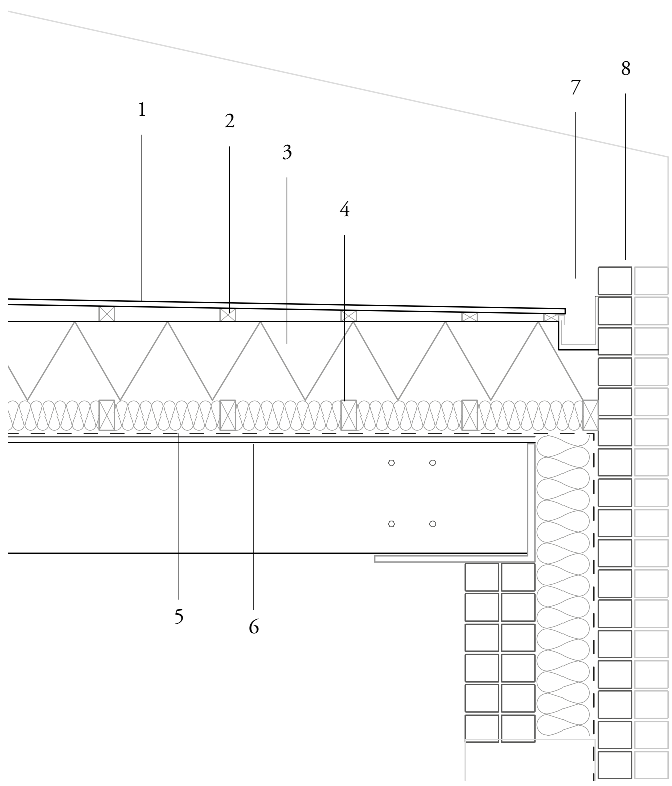
18 Timber floor boards 20 mm
19 Timber batten 100x100
with loose wool insulation in between
20 Concrete screed 70 mm
21 Vapour barrier 20 mm
22 Concrete foundation

DETAIL

The detailing of building elements gives an overview of the construction of the building and clarifies the expression of the extruding brick facade.
The two types of roof to wall connections are shown: the pitched with a concealed gutter and the flat which is framed by a parapet.



1. Locator of the construction detail sections in scale 1:25

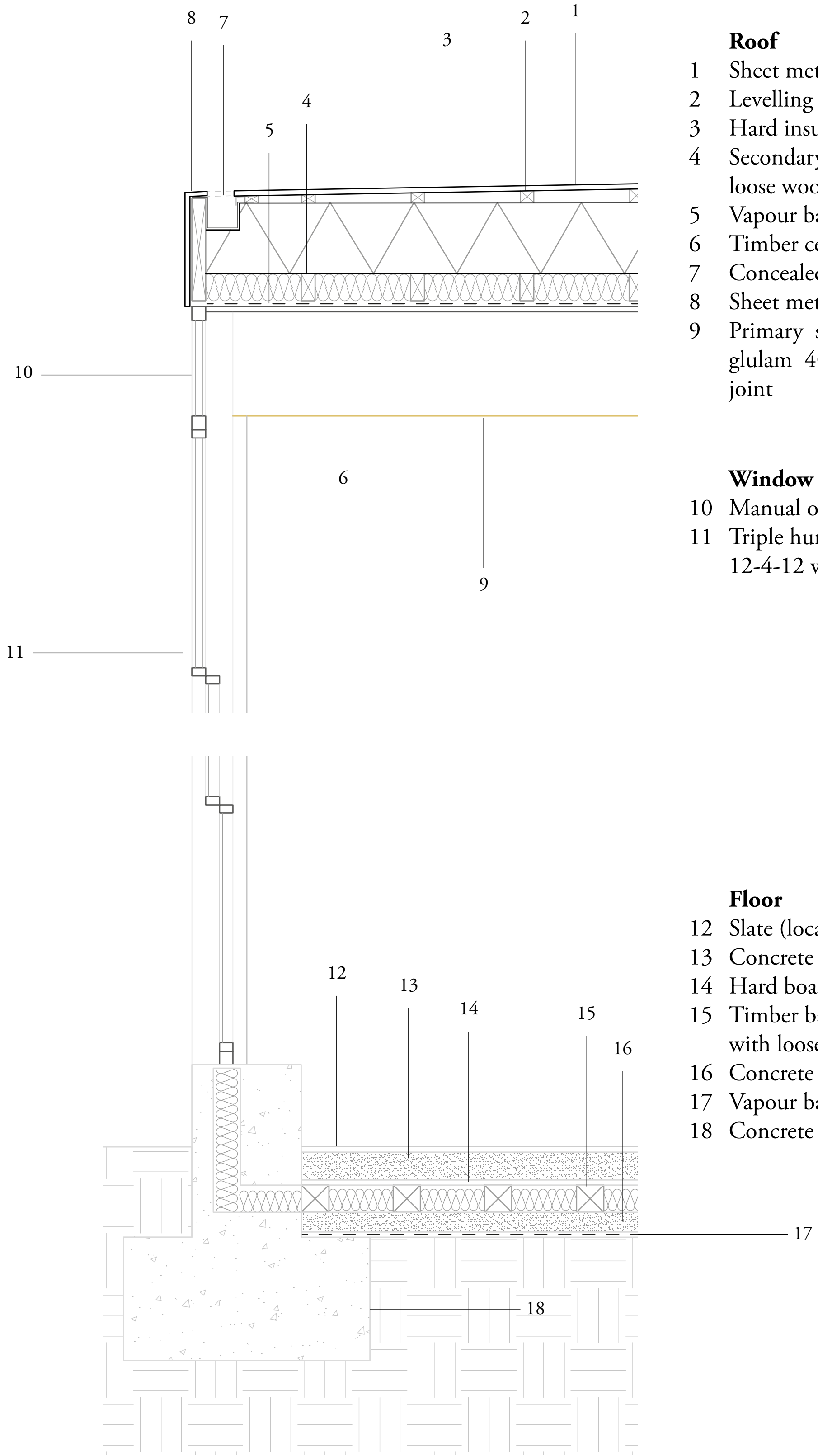


D-4

Roof

1 Sheet metal roofing 18 mm
2 Levelling battens (1% inclination)
3 Hard insulation 260 mm
4 Secondary beam timber C24 100x50 mm with loose wool insulation in between
5 Vapour barrier 20 mm
6 Timber ceiling board 20 mm
7 Concealed box gutter gutter
8 Brick parapet

D-2



Roof

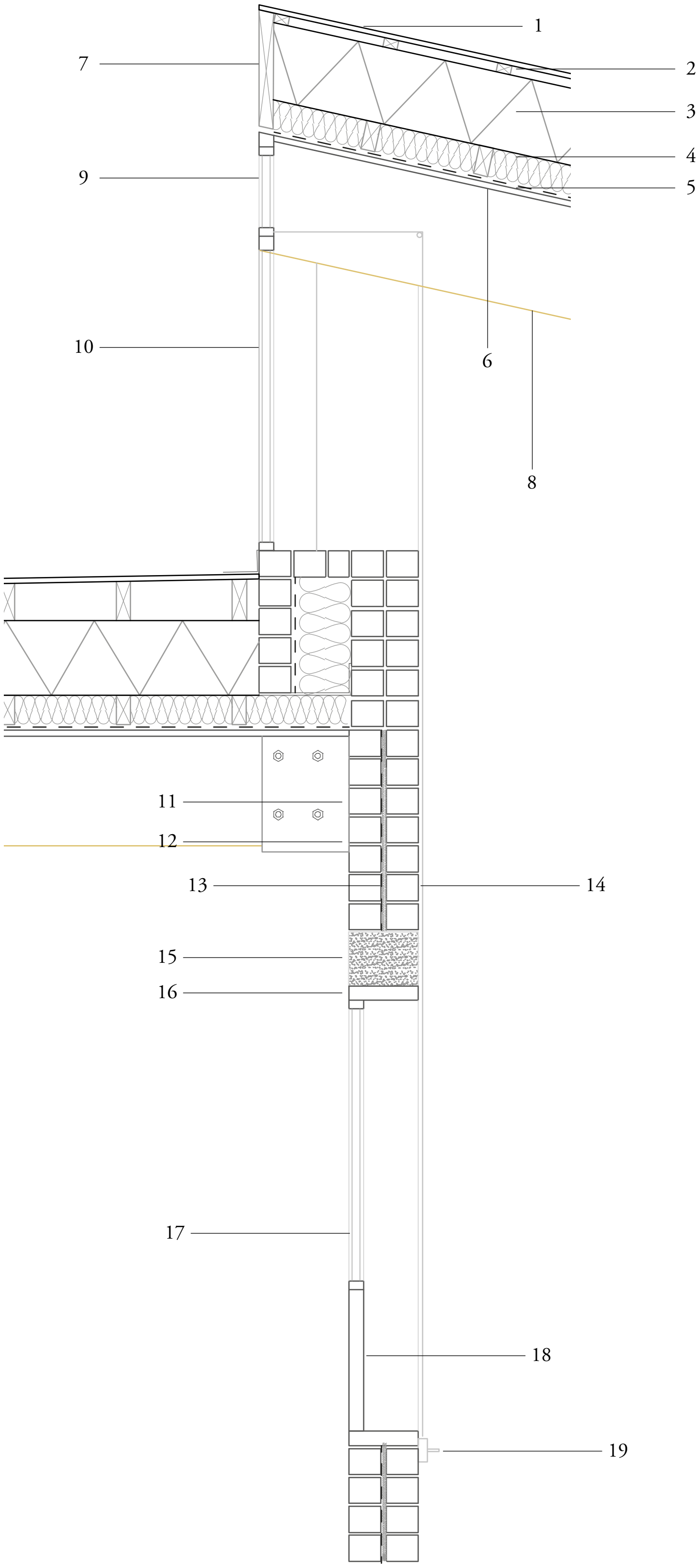
1 Sheet metal roofing 18 mm
2 Levelling battens (1% inclination)
3 Hard insulation 260 mm
4 Secondary beam timber C24 100x50 mm with loose wool insulation in between
5 Vapour barrier 20 mm
6 Timber ceiling board 20 mm
7 Concealed box gutter
8 Sheet metal fascia
9 Primary structure with double timber beam glulam 400x100 mm with metal steel plate joint

Window

10 Manual operable vent
11 Triple hung sash window double glazed 12-4-12 with air gap

Floor

12 Slate (local) stone flooring 20 mm
13 Concrete screed 100 mm
14 Hard board 20 mm
15 Timber batten 100x100 with loose wool insulation in between
16 Concrete screed 70 mm
17 Vapour barrier 20 mm
18 Concrete foundation



D-3

Roof

1 Sheet metal roofing 18 mm
2 Levelling battens
3 Hard insulation 260 mm
4 Secondary beam timber C24 100x50 mm with loose wool insulation in between
5 Vapour barrier 20 mm
6 Timber ceiling board 20 mm
7 Sheet metal fascia
8 Primary structure with double timber beam glulam 400x100 mm with metal steel plate joint

Clerestory windows

9 Venting opening with manual operating system
10 Clerestory window Double glazed 12-4-12 mm

Brick wall thickness 240 mm

11 Brick 100x90x230 mm
12 Mortar 10 mm
13 Vapour barrier with natural wool felt sound insulation 20 mm
14 Brick 100x90x230 mm

Window

15 Concrete lintel 190 mm
16 Timber box 50 mm
17 Window double glazed 12-4-12 with air gap
18 Integrated storage shelves
19 Handle to operate the clerestory vents

5

The end

CONCLUSION

Cool School combines the use of local materials and building technologies with passive solar design strategies that harness the energy of the sun for heating in the cold climate of Mongolia.

Our proposal is a building that responds to the problems faced by the existing school by creating an improved learning environment that aspires to initiate a transformation in Mongolian school design. Through its adaptable integration of learning and support activities in one building the design embraces the community with its multi-functional spaces, friendly environmental impact and accessible cost of construction.

REFERENCE LIST

Page 11 1-5. Dahl, T. 2008, Climate and Architecture, The Royal Danish Academy of Fine Arts, School of Architecture Publishers, Copenhagen

Page 12-13 1-4. Dahl, T. 2008, Climate and Architecture, The Royal Danish Academy of Fine Arts, School of Architecture Publishers, Copenhagen

Page 15
1. UNESCO International Bureau of Education, 2013. http://www.ibe.unesco.org/fileadmin/user_upload/Publications/Institutional_Docs/IBE_brochure_2013_eng.pdf
2. Council of global education, 2014. http://www.globaleducation.org/2.htm
3. Moeller humanities textbook. http://www.collegeenglishbooks.com/two-models-of-teaching-learning.html
4. Waldorf Method, 2012. http://www.whywaldorfworks.org/02_w_education/
5. Christian Schittich, 2013. Detail Magazine - Building for children

Pages 16-17
1. Carl Sterner, 2013. http://carlsterner.com/design/2003_cincinnati_waldorf_school.shtml
2. Dutch design, 2011. http://2011.sfudutchdesign.ca/2011/20th-century-architecture-in-amsterdam
3. World data on education 2011, http://unesdoc.unesco.org/images/0021/002113/211308e.pdf
4. UNEP, 2013. www.unep.org/wed/2013/docs/SWITCH_PSC_Needs_Analysis_Report_Final.pdf
5. Kindergarten in Tokyo, 2008. Detail Magazine 3rd Ed.

Page 19
1. Arch+ 211/212 Lepik Andres: Think Global, Build social!
2. Small Scale, Big Change: New Architectures of Social Engagement by Andres Lepik. The Museum of Modern Art, 2010
3. Brundtland Rapporten, 2004. www.bu.dk
4. A+U Arup

Page 21
1. National Statistical Office of Mongolia, 2015. http://en.nso.mn/
2. Encyclopedia Britannica, 2015. http://global.britannica.com/EBchecked/topic/389335/Mongolia/27420/Ethnography-and-early-tribal-history
3. American Museum of Natural History, 2015. http://www.amnh.org/explore/science-bulletins/bio/documentaries/the-last-wild-horse-the-return-of-takhi-to-mongolia/article-the-horse-in-mongolian-culture
4. http://english.voyage-mongolie.com/general-information-about-mongolia/nomads-and-tradition-in-mongolia/nomadism-in-mongolia
5. http://www.magnificentmongolia.com/mongolia/culture.html
6. http://www.mongolian-ways.com/culture.htm

Page 23
1. Weather Online, 2015. http://www.weatheronline.co.uk/reports/climate/Mongolia.htm
2. National Agency for Meteorological, Hydrology and Environment Monitoring of Mongolia

Page 25
1. Evasion-mongolie, 2015. http://www.evasion-mongolie.com/en/mongolia-home/mongolian-architecture
2. Yurt Info 2015, http://www.yurtinfo.org/yurtstory-the-history-of-yurts-ancient-and-modern
3. Elmira Köçümkulkïzï and Daniel Waugh 2001, https://depts.washington.edu/silkroad/culture/dwellings/dwellings.html
4. Shuying Lin, Architecture in Design, 2011. http://www.architectureindevelopment.org/project.php?id=34

Page 27
1. Ashok Kumar, Rajni Lakhani, Prof. S.K.Bhattacharyya and Sapna Ghai, Low Cost Construction Technology for Cold Climate:Case Study Ladakh Region, 2012. http://www.scribd.com/doc/129869829/Low-Cost-Construction-Technology-for-Cold-Climate-Case-Study-Ladakh-Region#scribd
2. Jeff Kapron, Yurtinfo, 2015. http://www.yurtinfo.org
3. Yurts Direct, 2015. http://www.yurtsdirect.com/catalogue_felt_choices.html
4. Evasion-mongolie, 2015. http://www.evasion-mongolie.com/en/mongolia-home/mongolian-architecture
5. UNEP, 2013. www.unep.org/wed/2013/docs/SWITCH_PSC_Needs_Analysis_Report_Final.pdf
6. Tibet Heritage Fund, 2015. http://www.tibetheritagefund.org/pages/projects/mongolia/mongolian-architecture.php?lang=EN

Page 29 1. Encyclopedia Britannica, 2015. http://global.britannica.com/EBchecked/topic/273328/Hovd
2. Government of Khovd Province, 2015. http://www.khovd.gov.mn/

Pages 32-33 1. Weather Online, 2015. http://www.weatheronline.co.uk/reports/climate/Mongolia.htm
2. Khovd province climate change issue, 2012, http://www.icc.mn/aimag/Khovd/?q=node/5044

Page 58 1. Ministry of Environment, Nature and Tourism, Mongolia, 2009. Mongolia Assessment Report on Climate Change 2009

ILLUSTRATION LIST

Illustration numbers not listed below are illustrations created by the group members, either as diagram, pictures or drawings.

Page 10 1. Flickr: 40457697@N05, 2011, https://www.flickr.com/photos/40457697@N05/6383891379/

Page 16 1. Carl S. Sterner, 2003, http://carlsterner.com/design/2003_cincinnati_waldorf_school.shtml
2. The Scottish Government, 2007, http://www.gov.scot/Publications/2007/12/14115428/5
4. Open Building.com, http://openbuildings.com/buildings/fuji-kindergarten-profile-2425/media

Page 22 1. Alessandro Grassani, 2014, http://www.artslife.com/wp-content/uploads/2014/06/007.jpg

Pages 29 1. thoughtyoumayask, http://www.photius.com/images/mn02_01a.jpg

Page 52 1. CG texture, http://www.cgtextures.com/getfile.php/BrickOldRounded0100_1_M.jpg?id=40465&s=m&PHPSESSID=4ei40isau0ovmvaf2c6lli7f52

2. Sheepwhool insulation.com, http://ie.sheepwoolinsulation.com/images/about_range.jpg

Page 64 1. Blogspot, http://4.bp.blogspot.com/-5f8hDI62HIE/TdU22odOJlI/AAAAAAAAAEU/tG5i4r7IC_Y/s1600/TsAGAE.png

Page 94 1. CG texture, http://www.cgtextures.com/getfile.php/BrickSmallBrown0176_2_S.jpg?id=57741&s=s&PHPSESSID=1is8o1f368l4ccv3spfqatj0p6

5. CG texture, http://www.cgtextures.com/getfile.php/BrickSmallNew0092_9_S.jpg?id=55895&s=s&PHPSESSID=1is8o1f368l4ccv3spfqatj0p6

6. CG texture, http://www.cgtextures.com/getfile.php/BrickOldMixedSize0030_1_S.jpg?id=38119&s=s&PHPSESSID=ehmsa5tmusf4l4hhl1koo9h8d2

7. CG texture, http://www.cgtextures.com/getfile.php/RooftilesMetal0063_1_L.jpg?id=107202&s=l&PHPSESSID=20bk2nq76ndf4v2najp16ug9o3

8.CG texture, http://www.cgtextures.com/getfile.php/ConcreteBunker0162_1_S.jpg?id=60527&s=s&PHPSESSID=4ei40isau0ovmvaf2c6lli7f52

9. Egoin, 2013, http://ad009cdnb.archdaily.net/wp-content/uploads/2014/01/52a61c3ae8e44ec62300013a_new-building-for-nursery-and-kindergarten-in-zaldibar-hiribarren-gonzalez-estudio-urgari_zaldibar_exterior_038-1000x666.jpg

10. Rosboro, http://www.rosboro.com/userfiles/gallery/Rosboro-Custom-Glulam-08.jpg

11.ahisgett, http://construction.about.com/od/Wood-And-Plastics/a/Bolts-Glulam-Steel-Bolts-Connections.htm

12. Backpackerina, 2012, https://backpackerina.files.wordpress.com/2012/07/dscf0379.jpg

6

Appendix

APPENDIX I

SPATIAL PROGRAMME

Indoor functions

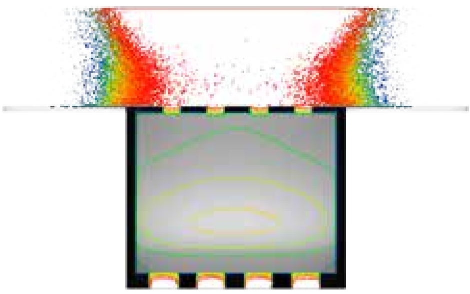
Functions	Shared with public	Window orientation	Clerestory windows	Connection with the courtyard	Area (m²)	Total (m²)
Classroom (25 pupils)		S	S		48	480
Workshop		W	W-S	■	145	145
Storage					34	34
Teachers room		W	E-S		84	84
Director office		W			21	21
Library		E	W	■	140	140
Sport hall		S-E	W-E	■	600	600
Change room					21	42
Toilet		N-S			8.8	61.6
Kitchen and storage		N	S		52	52
Canteen		N-S		■	135	135
Informal study space		S		■	173	173
Care taker		N			30	30
Total (m²)						2058.6

Outdoor functions

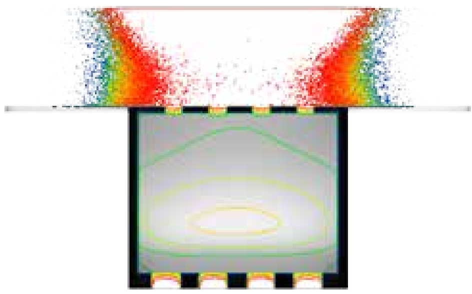
Enclosed courtyard					1000	1000
Total (m²)						1000

South Wing

Summer

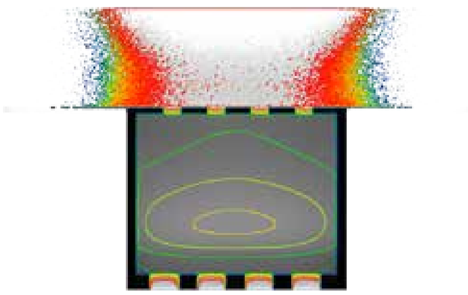


1. *June 21-11am_* average 5%

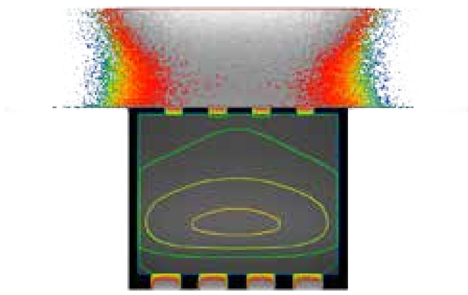


2. *June 21-15pm_* average 4%

Winter



3. *December 21-11am_*average 4%



4. *December 21-15pm_*average 4%

APPENDIX II

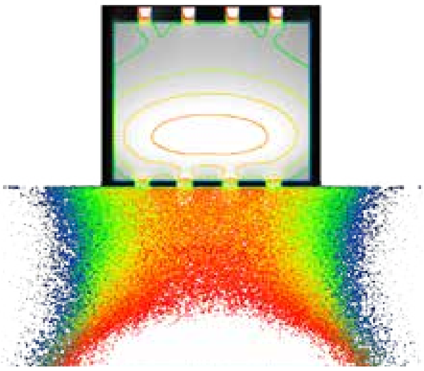
DAYLIGHT

The light study was carried out for a test class in the north and one in the south wing with the adjacent circulation space.
With adjustment to the window size according to the orientation and needs and further introduction of clerestory windows, the daylight levels reached are good.
Interiors with an average daylight factor of 5% or more are considered to be daylit rooms and will not normally require electric lighting.

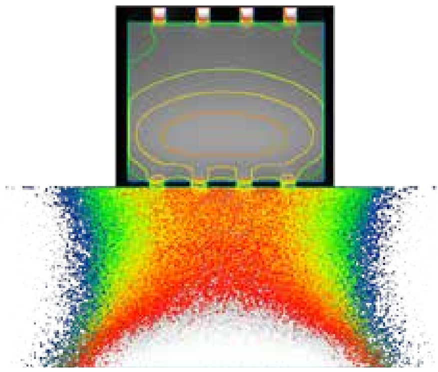
Daylight factor (DF%)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0

North Wing

Summer

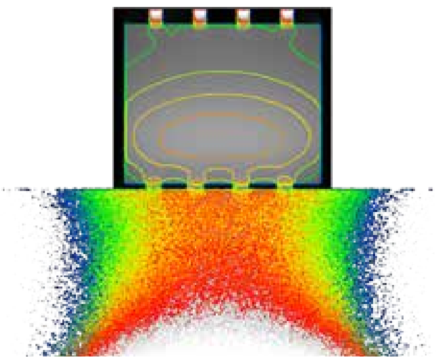


5. *June 21-11am*_average 5,5%

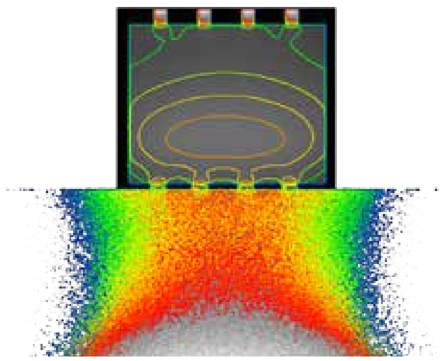


6. *June 21-15pm*_average 5,8&

Winter



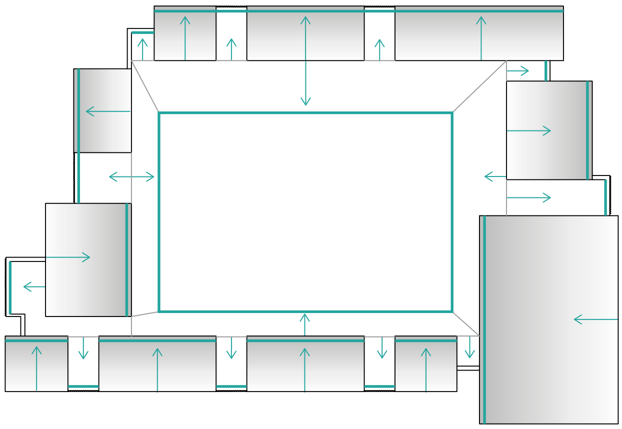
7. *December 21-11am*_average 5%



8. *December 21-15pm*_average 5%

APPENDIX III

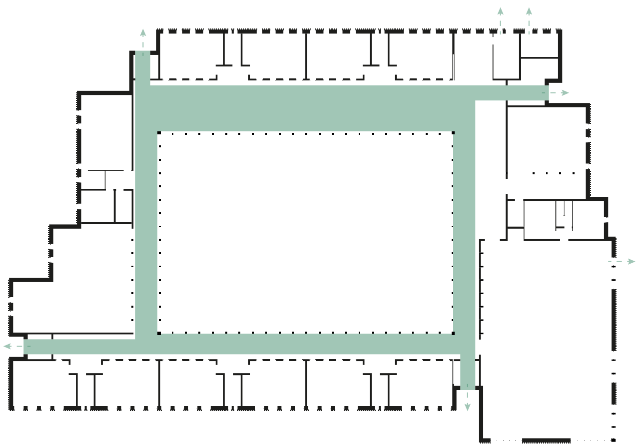
DRAINAGE



drainage flow

gutters

FIRE ESCAPE



fire escape

exit route

APPENDIX IV

MATERIAL CHOICES AND INDOOR ENVIRONMENT

As mentioned in the introduction, the development of the school design has been an iterative process, containing several loops, where ideas where improved several times, in order to reach good indoor environment both for the classrooms and the sunspace.
The following tables show the different systems, control and materials chosen during the process, and how these choices were effecting the indoor environment.
For final control system refer to ill.1 page 90 (BSim systems definition)

classroom

	1	2	**3**	**4**
	Venting		**Window U-value 0.83 W/m²K**	**Insulation**
Set Point	400ppm	800ppm	800ppm	800ppm
Set Temp	23 °C	23°C	23°C	23°C
Results				
Heating demand	10138	10000	6074	5900
CO2	420	432	427	430
H>27	16	15	13	13
H>26	39	33	33	32
H<15	0	0	0	0

sunspace

	Venting		**Window U-value 0.83 W/m²K**	**Insulation**
Set Point	400ppm	800ppm	800ppm	800ppm
Set Temp	20 °C	20°C	20°C	20°C
Results				
Heating demand	8816	6940	3853	2983
CO2	358	389	371	372
H>27	91	79	70	69
H>26	178	153	149	148
H<15	0	0	0	0

1- First iteration

2- The heating demand slightly decrease in the classroom, but has a substantial breakdown in the sunspace

3- The heating demand is almost half of the precendent simulation in both the spaces and is slightly decreased the amount of hours>26

Original windows:
standard double glazed window
U-value: 2.7 W/m²K

Improved windows
double glazed with air gap
filled with argon
U-value: 0.83 W/m²K

4- The roof insulation is increased from 260 mm to 360 mm.
Furthermore a new control is given to the heating system:
Heat Cntrl is set OFF in September and April because the passive solar is assumed enough to heat during the day

In April are registered 3H<15, therefore for the Cntr is set to OFF only in September, since the heating demand is decreased.

Floor classroom	Heating demand
Sand lime brick	4374
Timber boards	4674
Floor sunspace	
Sand lime brick	2550
Timber boards	2624
Slate stone	2538

5- Since most of the thermal mass is located in the floors, have been tested different materials before taking decision.
Even if with brick as floor material in the classroom, the heating demand was slightly lower, for the architectural expression and design character, we decided to have timber floor boards for the class and dark slate stone for the sunspace.

APPENDIX V

STRUCTURE CALCULATION

Snow load

Although the low precipitation values in Khovd suggest snowfall in the city is sparce, heavy snowfall can occur during dzud seasons and should therefore be considered when dimensioning the structure. The Eurocode 1 (BS EN 1991-1-3:2003) equation for determining snow load on the roof is:

$$s = \mu_i * C_e * C_t * s_k$$

Where:

The snow load shape coefficient (μ_i) is defined by the shape of the structure. A monopitch roof with an angle between 0º and 30º has a coefficient of 0.8 (table 5.2).

The exposure coefficient (C_e) of the site is defined in table 5.1. The topography of a site with no significant removal of snow by wind because of terrain, other buildings or trees is considered normal, so an exposure coefficient of 1.0 is used.

A thermal coefficient (C_t) of 1.0 is defined as the roof does not have a high thermal transmittance.

The characteristic value of snow load on the ground (s_k) of 1.0 is taken from the Danish National Annex (DS/EN 1991-1-3 DK NA:2012). The Danish load is used due to a lack of accessible data for snow load on the ground in Mongolia. This results in a conservative estimate, as greater snow fall is expected in Denmark than in Khovd.

The snow load on the roof is defined as:

s = 0.8 * 1.0 * 1.0 * 1.0 = **0.8kN/m2**

The snow load affecting the primary beams and secondary joists is calculated by multiplying the snow load on the roof by the area of roof affecting the member below, which is derived from the spacing of the beams multiplied by their span and is equal to 12.46m^2 for the primary beams and 1.25m^2 for the secondary joists.

The snow load affecting the primary beams is calculated as:

9.97 kN

The snow load affecting the secondary joists is calculated as:

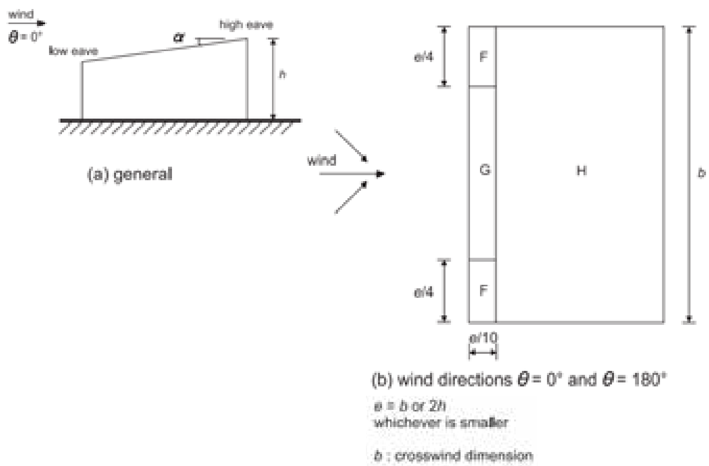
1 kN

Wind load

Wind is a variable load affecting the structure both horizontally and vertically. The vertical suction created on the roof beam is considered here. The prevailing winds in Khovd are northerly, so this direction is considered. The full calculation of wind actions is included in the spreadsheet 'Cool School_Structure' in the attached CD. Only the basic values are stated here.

Basic wind velocity (vb) 28 m/s
Mean wind velocity (vm) 16.97 m/s
Turbulence intensity (lv) 0.36
Peak velocity pressure (qp) 0.6276 kN/m2

The action of wind on the roof surface is calculated to determine the wind load on the roof beam. The monopitch roof is divided into sections according to figure 7.7 in Eurocode 1 (BS EN 1991-1-4:2005). The external pressure coefficients of the roof sections are calculated for zones of 0º (northerly wind), according to table 7.3a.



The loads on the sections are calculated as:

Zone F **-0.565 kN/m2**
Zone G **-0.502 kN/m2**
Zone H **-0.188 kN/m2**

The biggest load (Zone F) is multiiplied by the roof area affecting the structure below to determine the load on the beams and joists.

The wind action affecting the primary beams is calculated as:

-0.7 kN

The wind action affecting the secondary joists is calculated as:

-0.07 kN

Sand load

Increased desertification in Khovd Province - a result of reduced rainfall leading to reduced soil moisture, as well as increased damage to topsoil, vegetation and agriculture by livestock - has led to a steady increase in the average annual number of sand storms occurring in the region during the past decades[1]. Therefore, the load of sand accumulating on the roof during and after a sand storm should also be considered.

The sand load on the roof is derived by the following expression:

$$q_{sand} = A * D * \rho_{sand} * g_{gravity}$$

Where:

A is the area of the roof affected by the sand.
D is the depth of sand accumulating on the roof, which here, for lack of data, is assumed to be 0.05m, beyond which the sand should be removed.
ρ is the density of sand 1442kg/m^3 (Source: Engineering Toolbox[2])
g is the factor of gravity 9.8 m/s^2

The sand load affecting the primary beams is calculated as:

8.81 kN

The sand load affecting the secondary joists is calculated as:

0.88 kN

Dead loads

The dead load of the structure is its permanent self-weight. The weight of the primary beams and secondary joists being considered is calculated automatically when applying a gravity load in Karamba. Such calculation takes into consideration changes of member dimesnios that can be factored in progressively during design development.

The densities of the other elements in the roof structure are required to calculate their impact on the beams below. The following densities are defined:

Structural plywood 10.4kg/m^2 (Source: rfcafe[1])
Natural wool felt 22 kg/m^3 (Source: Sheep Wool Insulation[2])
Sheet metal roofing 6.22 kg/m^2 (Source: Hornsey Steels[3])

The density of each element is multiplied by the factor of gravity (g) 9.8 m/s^2 and the area of roof affecting the beam below to determine the load of the secondary structure and roof on the beam below.

The loads of individual elements on the primary beams are:

Plywood 1.27 kN
Felt insulation 0.86 kN
Sheet roofing 0.076 kN

With an overall dead load (excluding self weight of the beam) of:

2.89 kN

The loads of individual elements on the secondary joists are:

Plywood 0.13 kN
Felt insulation 0.086 kN
Sheet roofing 0.076 kN

With an overall dead load (excluding self weight of the joist) of:

0.289 kN