

Architecture of Healing:
A Humanitarian Environment for Children Affected by
Conflict in Sudan





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Architecture of Healing: A Humanitarian Environment for
Children Affected by Conflict in Sudan

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Adapted from photo by Fatima Alam, 2025

Abstract

In April 2023 Sudan plunged into a devastating conflict, resulting in a massive displacement which is considered the largest displacement crisis in the world. This conflict had disproportionately affected children and still is, through forced displacement, family separation, malnutrition, disrupted access to education, and severe exposure to violence. In response to these challenges, this thesis investigates the role of architecture in supporting the recovery and well-being of children affected by war through the design of a humanitarian residential and educational environment, supported by a healthcare unit.

The research begins by highlighting the statistics and facts of the Sudanese conflict on families, specially women and children, who are considered the most vulnerable groups in societies. Drawing from this context, the thesis argues that spatial and architectural design should provide the ground for healing processes. The study explores the medina as a historical urban model with spatial characteristics- such as inward-looking courtyards, shaded circulation routes, dense urban fabric, and hierarchical transitions between public and private spaces-, which offer valuable lessons for designing safe, socially supportive and climate-responsive environments for children in post-traumatic situation. It also has a strong relevance to the Sudanese urban context, which is considered an important factor for children to feel the familiarity within the lived-in context.

The research then investigates the physical contexts in which such an intervention could be implemented through a comparative analysis of representative climatic regions in Sudan. It investigates vernacular environmental design strategies used, building technologies, and locally available materials. Special attention is given to the passive cooling strategies, thermal mass, natural ventilation, courtyard systems, and climate-adapted construction techniques which contribute to create comfortable environment to occupants while reducing dependence on mechanical systems.

Finally, the research leads to a design proposal that re-interprets the spatial logic of the medina in a contemporary humanitarian frame. The final proposal aims to provide children affected by war a healing environment that helps in their psychological recovery, social belonging, and reconstruction of identity, through the integration of healing landscape, community-oriented spaces, climate-responsive strategies, and culturally rooted architectural principles. The thesis illustrates how vernacular knowledge and environmental design can inform resilient humanitarian architecture for the Sudanese context.

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Introduction

The armed conflict that erupted in Sudan in April 2023 has resulted in one of the world's largest displacement crises, with millions of people forced to flee their homes. Among those most severely affected are children, who have experienced displacement, family separation, interrupted education, inadequate healthcare, and prolonged exposure to violence. Beyond addressing immediate humanitarian needs, post-conflict recovery requires environments that support children's physical, psychological, and social wellbeing. Within this context, architecture has the potential to provide more than shelter by creating spaces that foster safety, healing, learning, and a renewed sense of belonging.

This thesis investigates the role of architecture in supporting children affected by war through the design of a humanitarian residential and educational community complemented by healthcare, recreational, and support facilities. The research explores how climate-responsive design and vernacular architectural principles can contribute to creating resilient environments that respond to both the environmental conditions of Sudan and the specific needs of children recovering from conflict.

Chapter 1 introduces the humanitarian context of Sudan, examining the impacts of the ongoing conflict on children and discussing the role of the built environment in supporting recovery and long-term wellbeing. It also establishes the research objectives, methodology, and design framework adopted throughout the study.

Chapter 2 investigates the theoretical foundations of the design proposal. It explores children's psychological, social, and environmental needs within residential care settings and examines the spatial qualities of the traditional Medina as a humanitarian urban model. Particular attention is given to its inward-looking organization, hierarchical public-to-private transitions, shaded circulation routes, and courtyard-based spatial structure, together with their relationship to the Sudanese (Hosh) which is the courtyard, as a culturally familiar architectural typology that promotes safety, social interaction, and environmental comfort.

Chapter 3 focuses on the environmental context of the Sudan through a comparative analysis of representative climatic regions. It examines climatic conditions, vernacular construction techniques, locally available materials, and passive environmental strategies, including courtyard systems, thermal mass, natural ventilation, roof design, vegetation, and wind catchers. These investigations establish the environmental principles that inform the architectural proposal and evaluate their applicability across different climatic contexts.

Building upon these findings, Chapter 4 presents the architectural design proposal. Inspired by the spatial logic of the Medina, the project combines residential units, educational facilities, healthcare services, staff and administrative/ security areas, and recreational spaces within an integrated community. The proposal reinterprets vernacular architectural principles through a contemporary humanitarian approach, creating adaptable courtyard-based residential clusters that promote environmental comfort, social cohesion, children's wellbeing, and opportunities for healing and recovery while remaining responsive to the diverse climatic conditions of Sudan.

Through this integrated approach, the thesis demonstrates how vernacular knowledge, passive environmental design, and child-centred spatial planning can inform resilient humanitarian architecture that is culturally grounded, environmentally responsive, and adaptable to different regions of Sudan.

CHAPTER 1.

CHILDREN OF CONFLICT: STATISTICAL AND SOCIAL REALITIES IN SUDAN



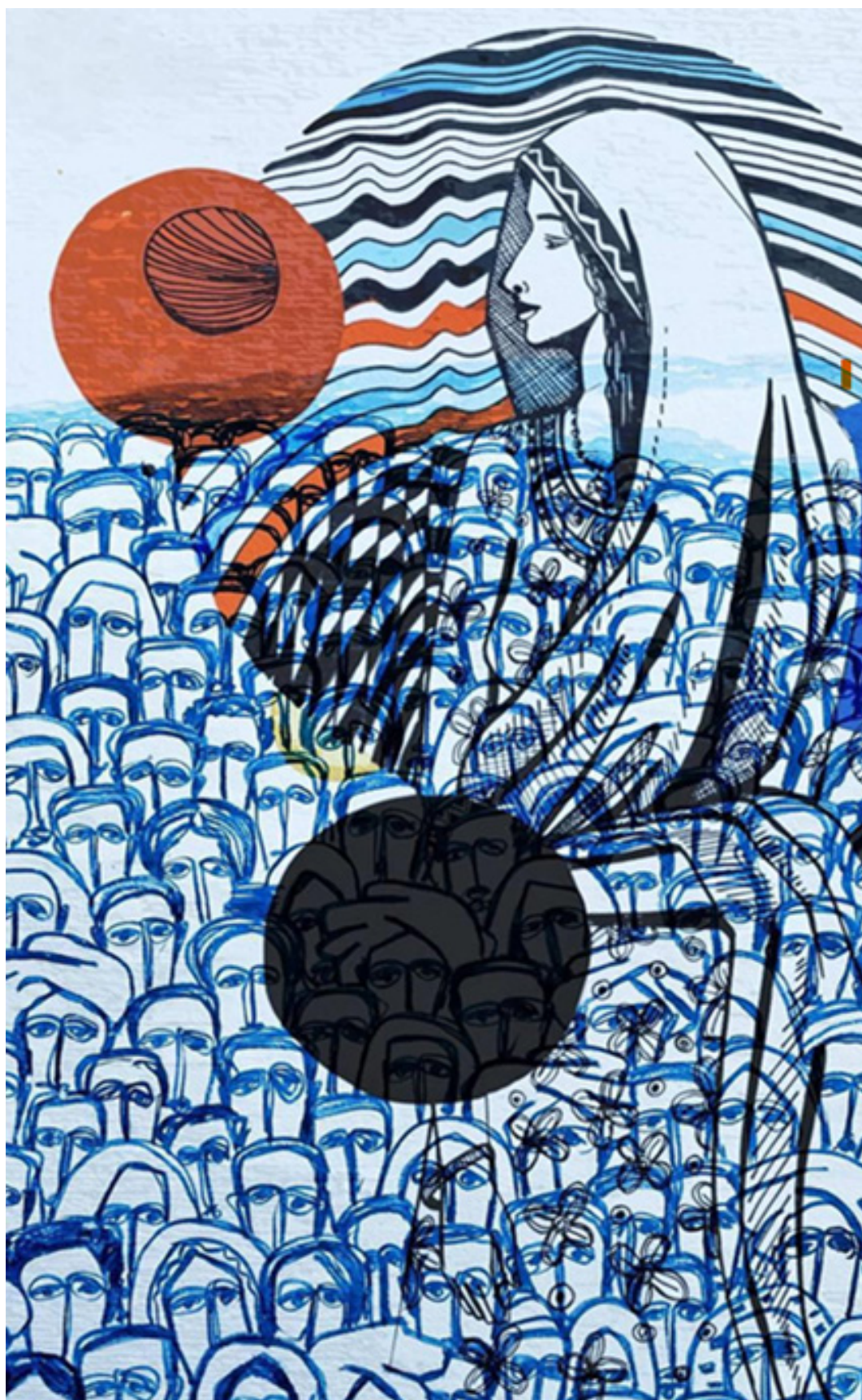


Figure 1, Talk about Sudan series. Artwork by Sudanese artist Galal Yousif Goly, 2023

1.1. Socio-economic Impacts of the War on Children, Families and Communities

Since the beginning of the war in Sudan in April 2023, most of families have been affected in a harmful way, either by displacement, loss of livelihoods, family separation, or the destruction of their homes and communities leading to disrupting the social fabric and the economic stability of the communities, which are considered the main support system for children.

Multiple recent researches highlight the severe humanitarian consequences of the ongoing conflict on all families' members; particularly women and children who are considered the most vulnerable ones. As has been reported in recent mixed-method research examining the experiences of pregnant women and new mothers in conflict-affected areas of Khartoum State, that 86.6% of women -who had been interviewed- had no access to healthcare services (Miskeen, 2024).

Also, UNICEF (as cited in Hassan et al., 2025) reports an infant mortality rate of 51.5 deaths per 1,000 live births in Sudan, with figures expected to rise due to ongoing conflict and disruption of maternal health services. It has also been mentioned that more than 1.1 million pregnant women are currently in urgent need of medical care, as over 70% of health facilities in conflict-affected areas are no longer operational.

Alongside with fathers being conscripted, prisoned or killed, this led to sharply raising the numbers of vulnerable and orphaned children. Also, the displacement of extended families in different parts of the country- sometimes even outside the country- made taking care of these children even harder, creating the urgent need for institutional care facilities for orphaned children.

The economic systems in Sudan have collapsed under the strain of the war, which made families lose their sources of incomes, increasing child labour and recruitment by armed groups. These economic situations forced families to find solutions as making their children to join armed forces for the sake of protection, financial reward or even survival. Besides, the armed groups exploit the families who are in poverty to use their children- sons and daughters- to offer these families employment or means of transport (Hamoud, 2025).

Child labour occurs among different states in Sudan, in both rural and urban areas. Research shows that its prevalence varies by region and is linked to the economic level of the household. The highest levels are found in regions which are affected by conflict, displacement and economic instability; things that disrupt education and family livelihoods (Ajoud et al., 2024).

1.2. Data of families forcibly being displaced

The unexpected outbreak of conflict in April 2023 turned over the everyday lives of children. Fatuma, aged 13, recalled how her school day was interrupted: “in the middle of the exam, a teacher entered and asked us to put the papers away, she didn’t tell us why. She told us to go straight home and not to look around or linger in the streets”. By the time she reached home, her family was in state of panic, and since then they have been displaced six times, ending up in a camp in Kassala state (UNICEF/Forbes, 2025).



Figure 2, Illustration from “Fatima’s Story” depicting a Sudanese child and family fleeing conflict and arriving at a displacement camp. Source: Save the Children (illustration by Shiroug Idris).



Figure 3, Sudan- South Sudan border, where 3000 Sudanese refugees cross into South Sudan. Source: Photo by Ala Kheir (2023).

The number of forcibly displaced people since the outbreak of the armed conflict in Sudan in 2023 has reached approximately 10,946,900 people (UNHCR), as has been reported by the UN Refugee Agency, Sudan is the country with the largest number of forcibly displaced people in the world by the end of 2024 (Figure 4), with more than 11.5 million people being internally displaced within Sudan (Figure 5) (Figure 6), and over 2.7 million had fled to different neighbouring countries. This means that about one in five Sudanese – roughly 22% of the population – had been forcibly displaced by the end of 2024.

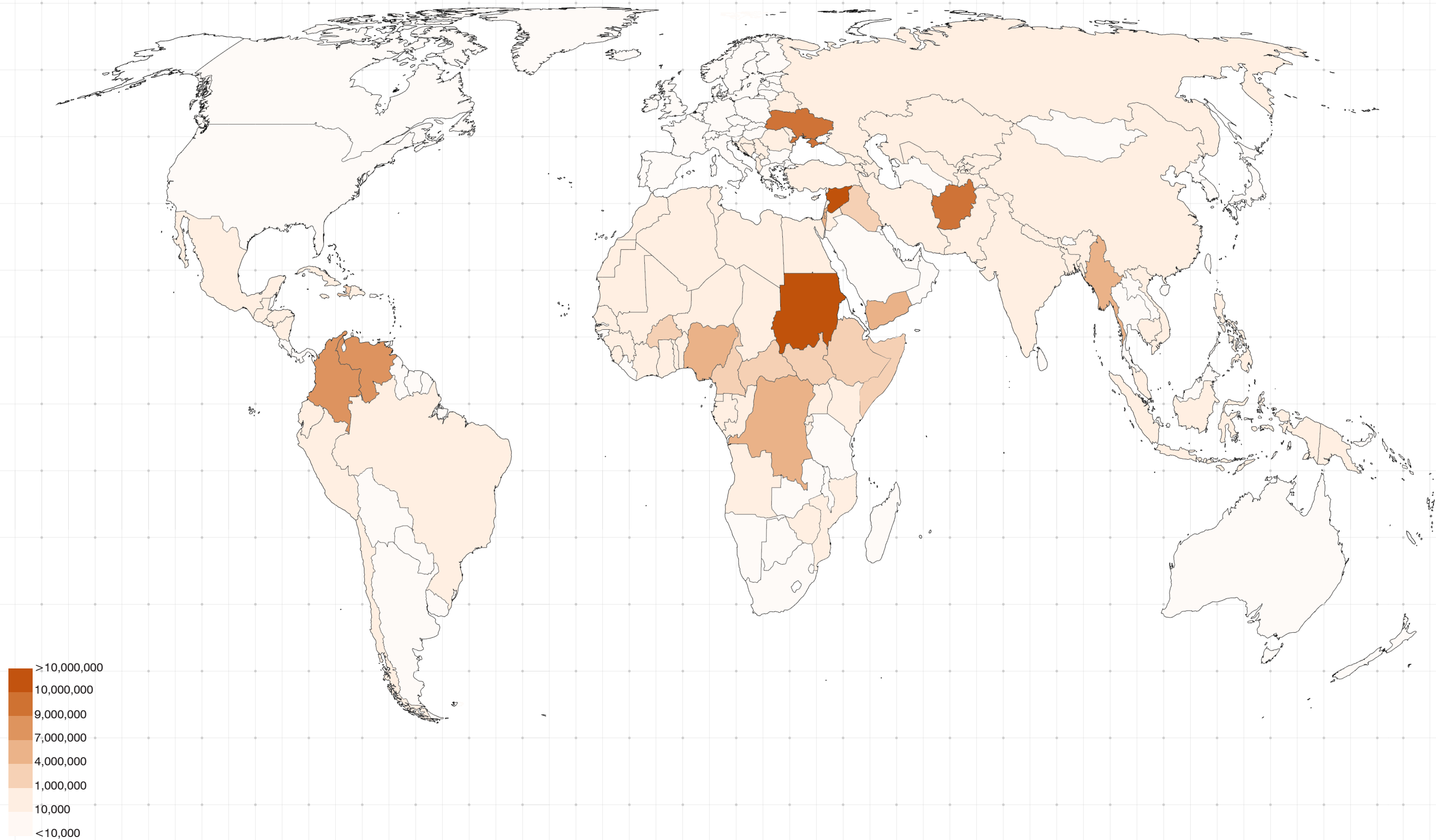


Figure 4, Forcibly displaced people worldwide. UNHCR, 2025

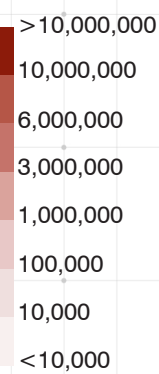
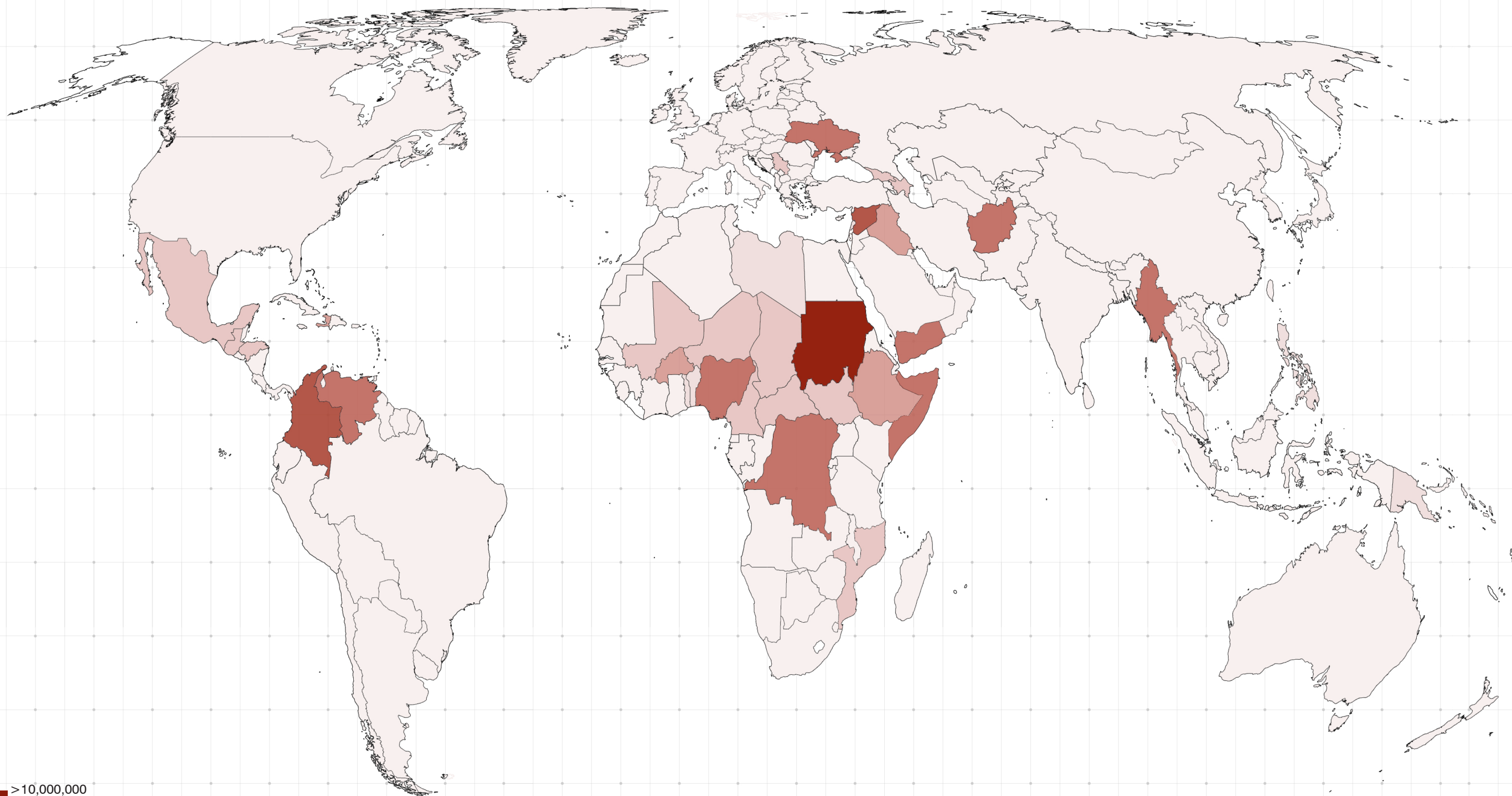


Figure 5, Internally displaced people (IDPs) worldwide. UNHCR, 2025

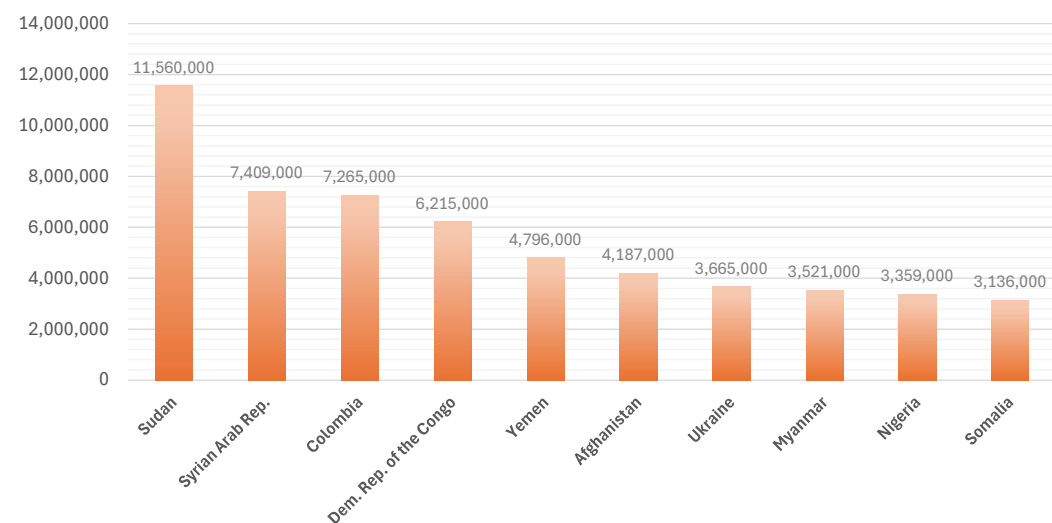


Figure 6, Internally displaced people (IDPs) worldwide by country of origin, UNHCR, 2024

1.3. Data of children who has been displaced, violated and abused

“Children continue to pay the highest price for a crisis not of their making- increasingly with their lives.”

UNICEF

Globally, the total number of children who has been displaced by conflict and violence by the end of 2024 has rose up to 48.8 million, being driven from home to different places around the world. As the displacement occurs suddenly and without preparation unlike the voluntary migration, this makes the situation even harder for the families and especially the children.

Displacement has increased the risk of trauma, exploitation and neglect because of the sudden loss of the children’s family support system, home and other essential services like education and healthcare. In Sudan, the percentage of children who have been displaced is larger than that of adults (Figure 8), which gives a direct indicator for the mass number of children who are facing this catastrophe.



Figure 7, Chad. Sudanese refugee students and their teacher take refuge from the punishing sun in the shade of a tree in Metche, a refugee site in a remote region of eastern Chad that is home to some 50,000 Sudanese refugees. Source: UNHCR/ Nicolò Flippo Rosso.

Children represent nearly one third of the total number of populations in the world, there are approximately 2.3 billion children worldwide. As has been reported by the end of 2024, an estimated 33.8 million children- around 1.5% of all children globally- have been internally displaced worldwide, with 57% of them living in African countries, primarily in Sudan and the Democratic Republic of Congo due to ongoing conflicts (UNICEF).

The fact that more than half of the world’s internally displaced children - which are 19.3 million child- are concentrated in a single continent underscores the urgent need for this catastrophe to be a global attention and to take coordinated action.

Normally when children being displaced within the country, they often face serious risks while searching for safety. Sudan recorded the largest number globally, with almost 5.4 million internally displaced children, estimated as 1 in every 6 displaced children (Figure 9).

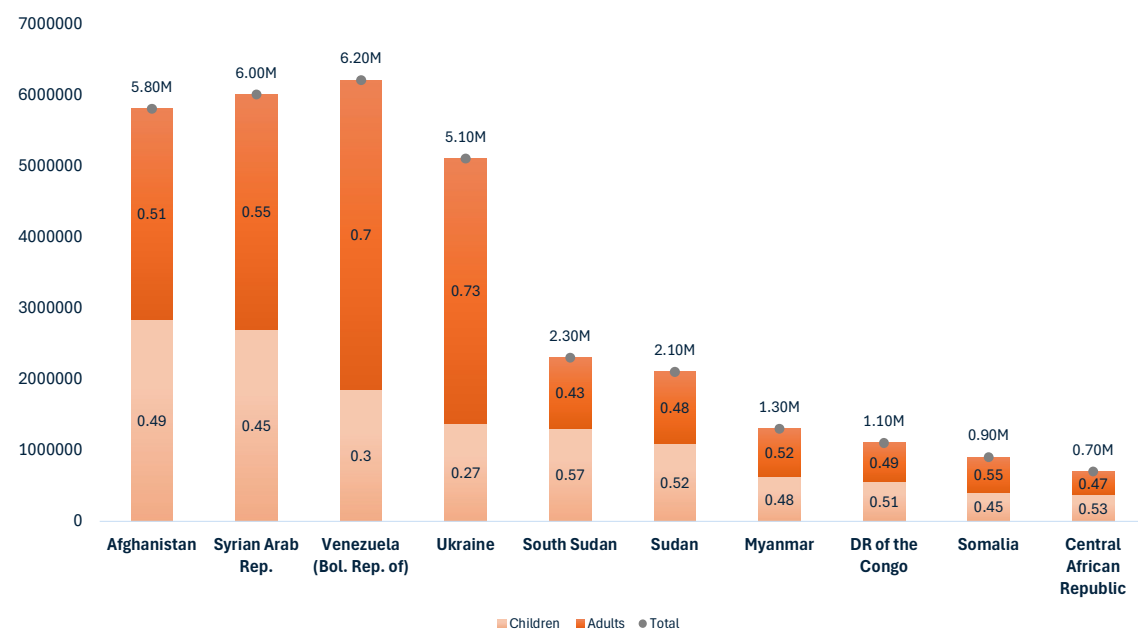


Figure 8, Number of refugees by age and country of origin. UNICEF, 2025

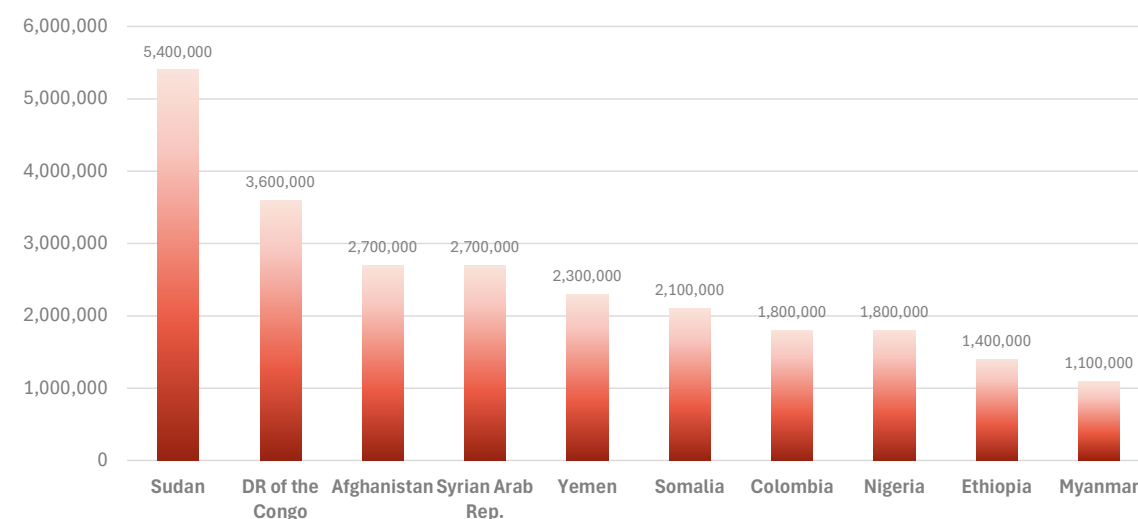


Figure 9, Largest internally displaced child populations by country. UNICEF, 2025

1.3.1. Psychological effects of war on children

“Life here is difficult. Leaving Khartoum made me very sad,” said Areeg, an 11-year-old who fled Khartoum, she added **“I love to draw. I can put all my emotions into the drawings.”**

“I tried to forget the pain, but I couldn’t,” said Waad, 10 years old, **“The pain of loss grows for my siblings and me. Everyone here tries to help us, but it’s unbearable.”**

“How much more will I lose?” Mohamed, 10 years old.

(UNICEF Sudan, 2024)

Children who have been displaced have expressed deep emotional distress and loss. These testimonies highlight both the psychological toll of displacement, and the coping mechanisms children adopt amid crisis (UNICEF, 2025).

The conflict of course has its psychological effect on children, who have been exposed to severe violence, making them struggle with fear, detachment and aggression. As in recent research conducted in Sudan about these effects, which included participants who has been displaced during the war, it revealed that children aged between 6 to 18 years old are suffering from high levels of emotional distress. The mental health assessment is showing that 68% of the children frequently felt sad, 73% felt anxious and 29% had diagnosed conditions (PTSD, depression) (Awad et al., 2024).

The displacement, loss of homes and replacing stable settlements with camps, made the children more vulnerable and they lost the sense of belonging and identity once embedded in Sudanese communities. Awad et al., (2024) demonstrate the positive relationship between children’s well-being and presence of school and family support system, suggesting that interventions for displaced children must include spaces that support emotional recovery and stability.

1.3.2. Sexual Violence Against Children

Sexual violence has become one of the deliberate tactics of the war, especially with children among the most vulnerable victims. UNICEF (2024) reports that most reported cases of sexual violence (raping) have happened to girls, even for children as young as one year old during the ongoing war. Meanwhile boys are facing distinct challenges related to underreporting, preventing them from seeking help.

This use of sexual violence as weapon has caused deep psychological and physical trauma to displaced people, which underscores the urgent need for safe and protected environments that prioritise psychological healing for these children.

1.3.3. Recruitment and Use of Children by Armed Groups



Figure 10, Sudan's child rape and sexual violence crisis. Source: UNICEF 2025

Siobhan Mullally, the UN special rapporteur on trafficking in persons said, "The recruitment of children by armed groups for any form of exploitation – including in combat roles – is a gross violation of human rights, a serious crime, and a violation of international humanitarian law," (Kenny, 2023)

The children in Sudan are also being used by armed forces and groups for recruitment reasons since the beginning of the war, exposing them to severe danger and depriving them of their childhood.

According to the United Nations reports (2024) there has been more than 277 cases of children recruitment which have been verified between 2022 and 2023, even though the real numbers are way higher, as security limitations continue to delay data collection.

The armed groups are taking advantage of this situation as most of these children came from poor families, where lack of education, displacement and family separation leave them vulnerable to exploitation.

1.3.4. Disability affecting children

When families face attacks in their communities and they must flee, children with disabilities face life threatening risks that others do not usually face. Hamamatou, a 13 years old girl from southwestern Central African Republic who had polio and needed assistance to walk, recalled how her brother carried her on his back while armed fighters attacked their community. When he became exhausted, she told him,

"Souleymane, put me down and save yourself,"

hoping he might return if he survived. However, she did not see him again. Nujeen, a disability rights activist from Syria, shared her experience as a child with disability in 2019 when their town was attacked saying,

"Every day, I feared that I could be the reason that my family was one or two seconds too late."
(Ćerimović, 2022).

As Ćerimović (2022) explains that in such moments, children with disabilities may be left behind as families are forced to take split-second decisions between fleeing with those who can escape easily or staying to support their disabled children.

The research also adds that, while armed conflict has its negative effects in all children's mental health, its impact is aggravated for children with disabilities, who may fear abandonment, worrying about putting their families at risk, and face chronic barriers to education, mental health care, and social stigma.

These risks are reflected as well in another research, noting that:

"Disability among displaced persons should be considered as a risk factor for increase in psychopathological disorders and is closely related to poverty"
(Sanhori et al., 2022, p. 9).

Sanhori et al. (2022) found that disability incidence among internally displaced persons (IDPs) in central Sudan increased over time and was strongly associated with psychological distress, poverty, low education, and rural residency. Within this population, young people and males were particularly at risk to both increased disability and mental health challenges.

Another community-based study in Khartoum state found that nearly half (48.4%) of the sampled population of individuals with physical disability, were children under the age 10, with amputations (30.8%) and cerebral palsy (30.3%) being the most common conditions identified (Abdelnour et al., 2023). Abdelnour et al., (2023) added that although many participants had the ability to access physiotherapy services and were satisfied with the care, yet major obstacles persisted; mostly financial constraints (70.5%) and transportation difficulties (42.7%). Together, these findings demonstrate that even in non-conflict periods, disabled children in Sudan face high frequency impairment and systemic obstacles to care; conditions which are likely to be severely aggravated by the ongoing conflict and mass displacement.

1.4. Impact of war on children health and nutrition

Beyond the immediate effects of the ongoing war of violence on children, this conflict has triggered other humanitarian crisis, as disease outbreaks and hunger. It has been estimated that 4 million children under the age of five years were expected to experience acute malnutrition in 2024, including 730,000 projected to suffer from life-threatening severe acute malnutrition (UNICEF). The combination of hunger, poor sanitation and the collapse of healthcare systems has left children increasingly vulnerable to diseases and death. At the same time, vaccination coverage has declined due to fighting and conflict, and many communities don't have access to safe drinking water, which has contributed to diseases outbreaks such as cholera, measles, malaria, and dengue fever.

According to Mohamed & Homeida (2024), food accessibility during fights, interaction between conflict and climate change, and the breakdown of local food markets and supply chains had made the food insecurity among children and women even worse, leading to disrupting the food system in Sudan.

Addressing the resulting decline in child health requires a multifaceted response, as sustained and equitable access to food aid and nutritional support is essential to prevent further health crises. (Mohamed & Homeida, 2024).

1.5. Maternal mortality rising rate



Figure 11, Talk about Sudan series. Artwork by Sudanese artist Galal Yousif Goly, 2023

According to Hassan et al., (2025), the conflict has resulted in a severe maternal health crisis, leaving the vulnerable pregnant women facing not only physical risks but also psychological trauma and exposure to violence.

Some personal narratives have been documented to reflect the real suffering. Aisha, a displaced mother from North Darfur, was forced to flee her home while heavily pregnant as violence engulfed her community. With roads unsafe and health facilities destroyed, she walked for days with her children, lacking access to food, clean water, or medical care. When labour began, she delivered her baby inside a makeshift shelter, assisted only by a neighbour with limited midwifery experience. There was no access to skilled health personnel, sterile equipment, or postnatal care. (Hassan et al., 2025)

Although both mother and child survived, Aisha's experience reflects the extreme vulnerability faced by thousands of Sudanese women during the ongoing conflict. Such stories are not isolated incidents but symptoms of a broader collapse of maternal health systems across Sudan, where more than 70% of health facilities in conflict-affected areas are no longer operational and over 1.1 million pregnant women require urgent medical care. The absence of safe maternal services exposes women to life-threatening complications and places newborn children at heightened risk of trauma, malnutrition, and long-term developmental challenges. These lived experiences reveal how the war's impact on maternal health directly contributes to child vulnerability and the growing need for protective, therapeutic environments for children affected by displacement and loss. (Hassan et al., 2025)

CHAPTER 2.

REINTERPRETING THE MEDINA LAYOUT FOR A
HUMANITARIAN DESIGN



2.1. The Medina Layout: Origins and Spatial Characteristics.

The term “Medina” is used to describe the historic cores of many cities in north Africa and other Islamic-Arabic countries, which represents an urban form that developed through centuries of cultural, environmental and socio-economic adaptation.

According to Fezzai (2024), “A medina refers to the old part of an Arab-Muslim city, as opposed to modern European-style neighbourhoods”. Also, other scholars have framed the medina as a historically rooted urban typology shaped by socio-cultural, environmental, and planning traditions distinct from modernist planning paradigms (Amirahmadi, 1993).

The medina is often discussed through the lens of Islamic civilization and governance, even though its physical structure is equally significant as a model of compact urban morphology shaped by climate responsiveness, social organization, and pedestrian-based movement.



Figure 12, Urban fabric in the stereotypical Islamic city (Isfahan). Source: From Islamic urbanism (p. 605), <https://doi.org/10.1016/B978-008044910-4.01058-0>

In North Africa, medinas remain a defining example of pre-modern urban planning, reflecting a logic behind its settlement which is the opposite of the grid-based planning and contemporary zoning approaches.



Figure 13, Urban morphology of the Medina of Tunis. Source: ASM of Tunis, 2015).



Figure 14, Médina de Tunis, rue Halfaouine, 1900. (Postcard). Source: https://commons.wikimedia.org/wiki/File:Tunis_Rus_Halfaouine.jpg.

UNESCO identifies the Medina of Tunis as a representative example of North African Islamic city typology, describing it as a walled urban core with gates, dense courtyard housing of two to three stories, which are closely placed together, and minarets that rise above a network of narrow lanes and twisting streets that homogeneously form shaded paths and courtyards that remains cool during hot weather (UNESCO World Heritage Centre, 2023).

Urban morphology studies emphasize that historic urban centres can demonstrate strong spatial logic and hierarchy even when their patterns appear non-linear. In this context, analytical approaches such as space syntax have been used to examine the degree of connectivity and integration in historic city cores, showing that traditional urban fabrics contain structured movement networks linking public, semi-public, and private zones (Benkari et al., 2024).

The hierarchical spatial organization of the medina is further supported by case-study research on the Medina of Tangier, which demonstrates how medina form is shaped through layered historical development and defensive urban planning. The medina of Tangier is described as a dense and compact historic settlement influenced by multiple historical periods, including Islamic and Portuguese interventions, while still maintaining a recognizable traditional morphology defined by enclosed boundaries and a tightly packed street network (Khoukhi & Bouchra, 2024).

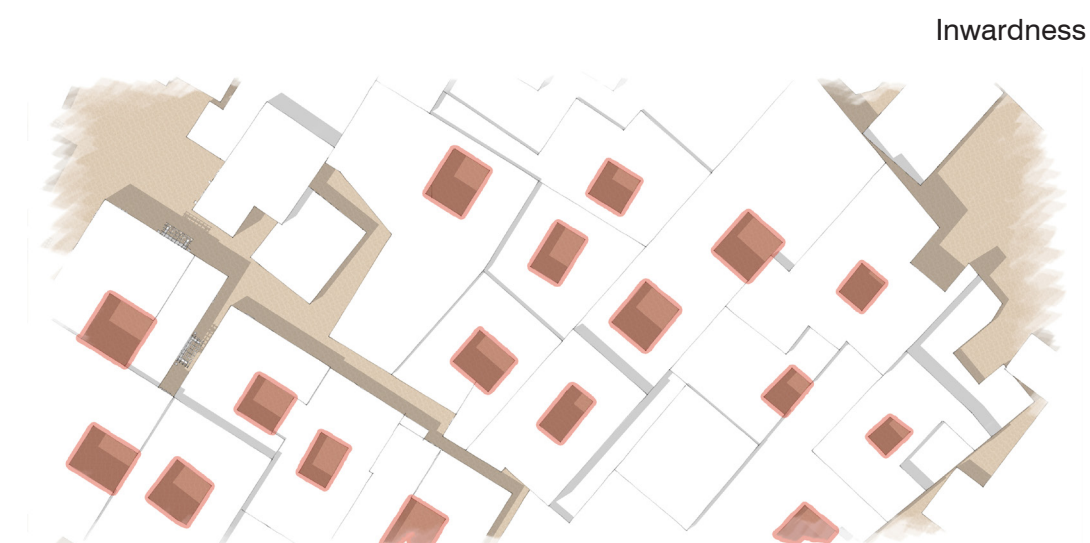
While medinas emerged historically within Islamic and North African socio-cultural contexts, their architectural form can also be understood as a practical response to environmental conditions and communal living needs. Contemporary urban morphology studies demonstrate that medina layouts exhibit measurable spatial organization and connectivity, reinforcing their value as an intentional urban system rather than an unplanned settlement pattern (Benkari et al., 2024).

2.2. Understanding the Medina Morphology

The medina represents one of the most distinctive urban forms developed within Islamic cities, shaped by a combination of environmental, social, cultural, and religious factors. Rather than following rigid geometric planning principles, medina settlements evolved organically over time, producing compact urban fabrics characterized by inward-oriented dwellings, shaded circulation networks, and a clear hierarchy of public and private spaces. Beyond their physical configuration, medinas embody a sophisticated response to climatic conditions and social values, particularly those related to privacy, community interaction, and environmental comfort. Understanding the morphology of the medina is therefore essential for identifying the spatial principles that have enabled these settlements to remain both culturally relevant and environmentally responsive.

2.2.1. The Inward- Oriented Dwelling (Hosh)

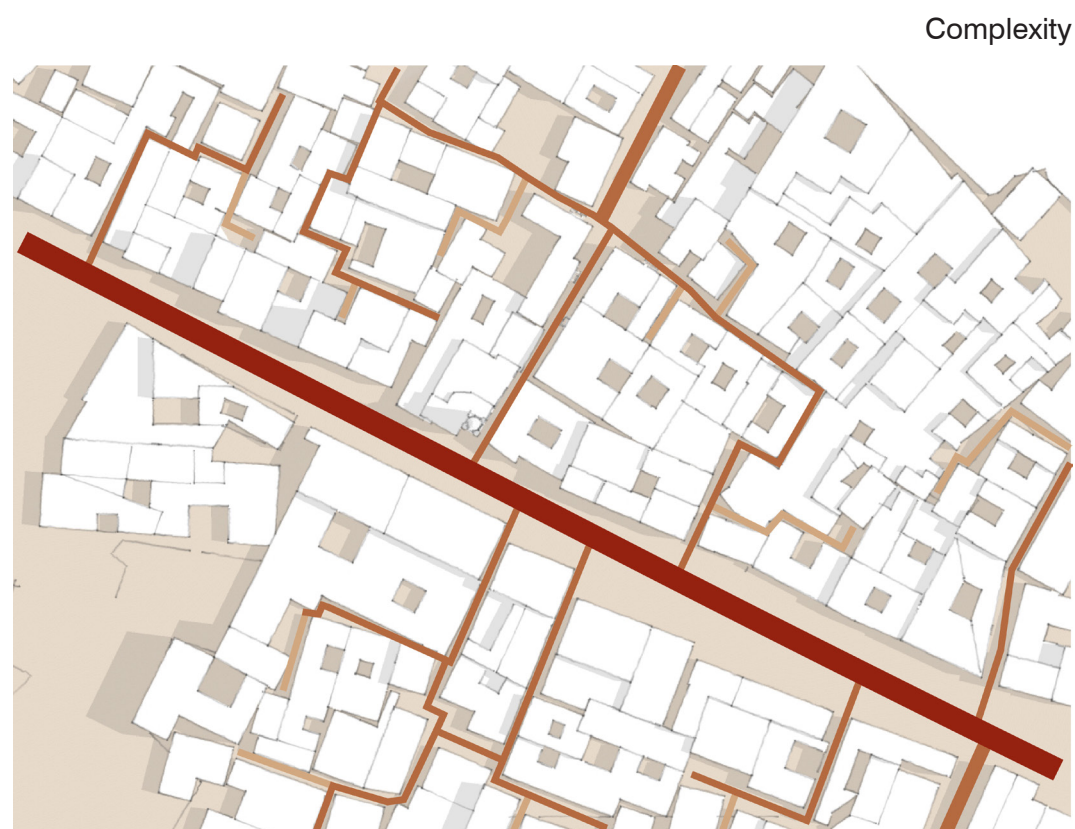
Architecturally, medina layouts are typically characterized by high-density residential clustering organized around courtyard-based dwellings. Courtyard housing represents one of the most constant typologies in traditional medina environments, allowing the houses to unfold in semi-private internal courtyards rather than outward-facing streets.



2.2.2. Organic Street Network

One of the defining spatial characteristics of the medina is the organic and irregular street network. Unlike modern planned cities based on rigid grid systems, medina streets evolved gradually through incremental growth of individual dwellings and social needs. As a result, streets tend to be narrow, winding, and irregular, creating a highly compact urban grain.

This irregularity serves several environmental and social functions. The winding configuration reduces direct solar exposure and wind penetration while also slowing movement through the city, reinforcing the intimate scale of neighbourhood life. The resulting spatial complexity enhances pedestrian experience and contributes to the sense of enclosure and human scale characteristic of traditional medina environments.



2.2.3. Spatial Hierarchy and Social Privacy

From a spatial design perspective, one of the most significant characteristics of the medina is the transition between public and private space. Streets often narrow as they approach residential areas, and movement becomes progressively more intimate and controlled. Semi-private alleys can serve as transitional buffers, limiting through-movement and enhancing the privacy and security of households. This arrangement is especially relevant in the context of humanitarian design, where displaced populations often experience high level of vulnerability, insecurity, and disruption of social norms. The medina model demonstrates how spatial form can be used to regulate visibility, access, and social interaction through architectural hierarchy rather than formal monitoring or rigid barriers.



2.2.4. Thermal Density and Shaded Circulation

This inward orientation is reinforced by the close placement of buildings, which creates a continuous built fabric with limited open exposure to the hot climatic conditions. In hot environments, such spatial density is not only an aesthetic feature but a functional design strategy, reducing solar gain on building facades while increasing shaded pedestrian circulation routes.



2.2.5. Urban Anchors: Landmarks and Communal Nodes

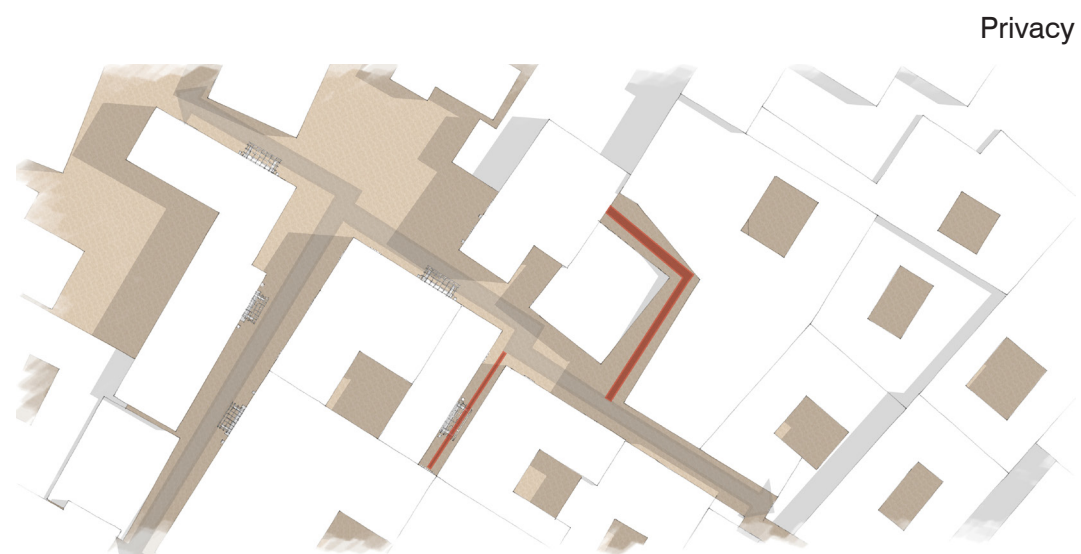
This inward orientation is reinforced by the close placement of buildings, which creates a continuous built fabric with limited open exposure to the hot climatic conditions. In hot environments, such spatial density is not only an aesthetic feature but a functional design strategy, reducing solar gain on building facades while increasing shaded pedestrian circulation routes.



2.2.6. Cul-de-Sacs (Dead-End Alleys)

Another common element within medina morphology is the presence of cul-de-sacs or dead-end alleys, which provide access to clusters of houses. These small alleyways typically serve only a limited number of households and therefore function as semi-private extensions of domestic space.

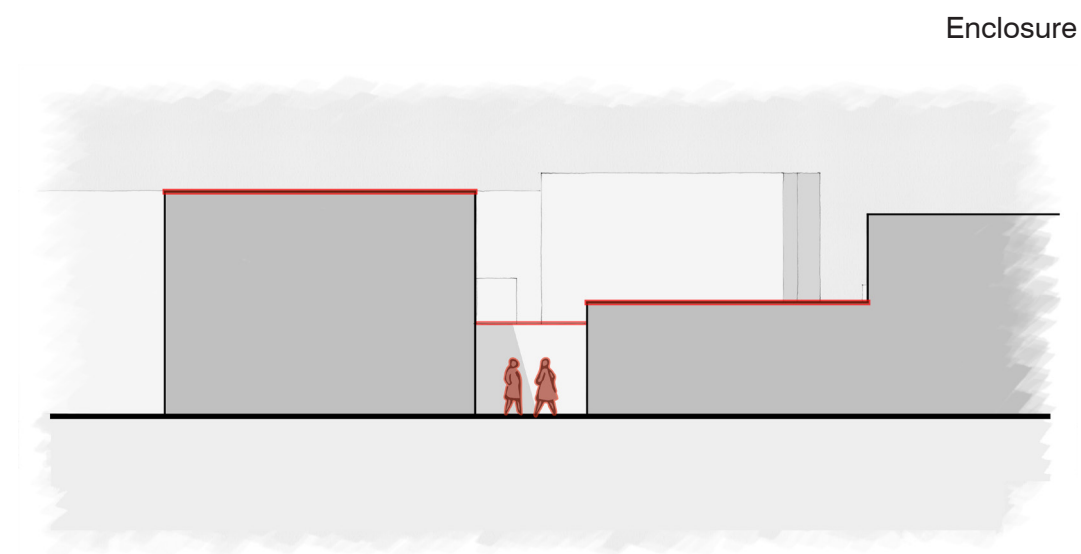
The cul-de-sac system contributes to the social organization of neighbourhoods by limiting through traffic and creating spaces where children can play and neighbours can interact safely. In many traditional settlements, residents of the same cul-de-sac often shared strong social ties, reinforcing collective responsibility and community cohesion.



2.2.7. Human-Scale Urban Proportions

The medina environment is characterized by human-scale spatial proportions, where building heights and street widths maintain a balanced ratio that enhances environmental comfort and spatial enclosure. Narrow streets bordered by two- to three-storey buildings generate shaded pedestrian corridors and reduce the exposure of surfaces to intense solar radiation.

This proportional relationship between built form and circulation space creates an urban environment that is both climatically responsive and socially engaging. Such spatial configurations encourage walking and informal interaction, reinforcing the medina as a pedestrian-oriented urban system.



2.3. Social and Cultural Relevance of the Medina in Sudanese Context.



Figure 15, The Sudanese village Nouri/ North Sudan.
Source: photo by Hisham Karouri, 2021.

The medina spatial logic is often associated with the historic urban cores of the Islamic cities, which corresponds with the principles embedded in the traditional Sudanese architecture. Rather than being a purely North African phenomenon, the medina represents a broader socio-spatial system shaped by Islamic values, social organization, environmental adaptation, and daily life cultural practices. The same aspects have the role of shaping the domestic Sudanese architecture, particularly within courtyard-based housing typologies, which is found in many areas Sudan.

In *Courtyard Housing: Past, Present and Future*, courtyard housing is identified as a sustainable and adaptable



Figure 16, Courtyard (Hosh) of traditional Sudanese house. Source: Photo by Fatima Alam

typology capable of supporting low-rise, high-density development while maintaining climatic efficiency and social functionality. The courtyard operates as a passive environmental regulator, enhancing ventilation, shading, and thermal comfort.

Traditional Sudanese courtyard houses employ similar strategies, using thick walls, internal open spaces, and limited external openings to mitigate heat and dust. These design responses are not isolated technical solutions, but culturally refined adaptations developed over generations.

Awadelkarim's research emphasizes that house form is the consequence of an integrated range of socio-cultural factors, meaning that architectural change inevitably influences lifestyle and identity. When modern housing models ignore these embedded spatial logics, they risk disrupting not only functional comfort but also cultural continuity. The decline of courtyard-based layouts in favour of standardized apartment typologies in Khartoum illustrates how imported spatial models may insufficiently reflect Sudanese norms of hospitality, privacy, and extended family life.

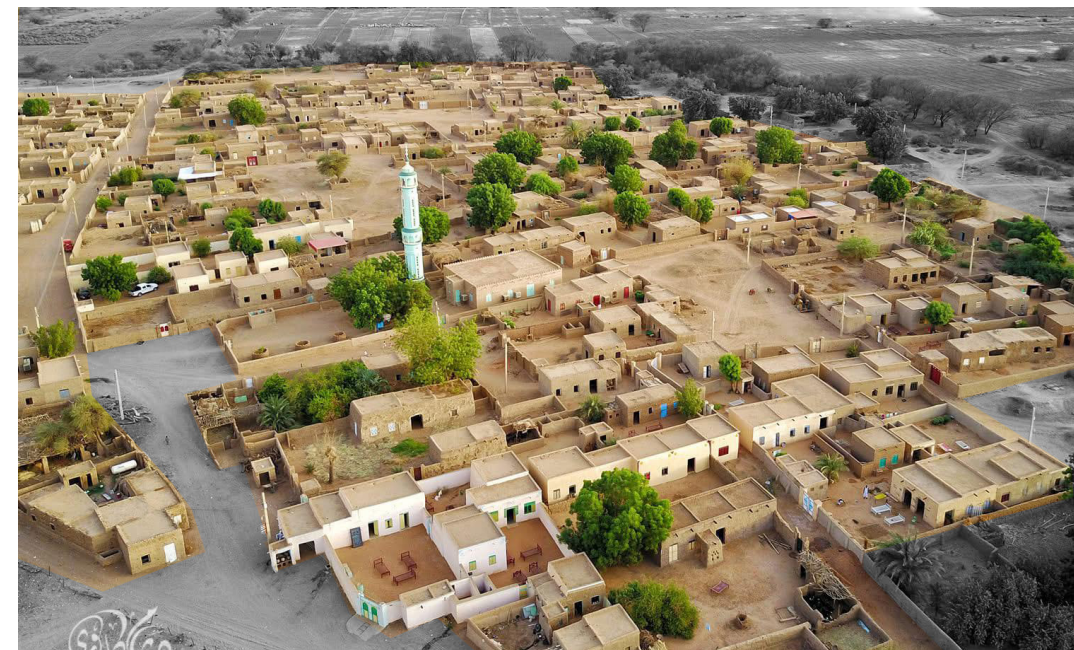


Figure 17, The Sudanese vernacular courtyard houses in Al-Bajrawiya village/ Khartoum. Source: photo by Hisham Karouri, 2018)

The layered spatial organization of the medina reflects Islamic principles of modesty, controlled visibility, and gender-sensitive organization. A similar logic is evident in traditional Sudanese courtyard houses.

In *Towards Contemporary Traditional Housing Architecture*, Awadelkarim demonstrates through field investigations that Sudanese house forms are not accidental physical outcomes but are shaped directly by socio-cultural

forces, including hospitality practices, extended family structures, daily routines, and religious norms. The inward-facing courtyard becomes the organizing nucleus of domestic life, regulating privacy while enabling social interaction within a protected environment. This reflects the medina's broad urban framework, in which internal unity is maintained while access to the public domain is constantly regulated.



Figure 18, Sudanese women gathering in (hosh) courtyard. Source: <https://theepicerie.com>

In the context of war and displacement, this relationship between space

and identity becomes especially critical. Orphaned and displaced children have lost not only caregivers but also the spatial environments that once structured their sense of security and belonging. Architecture, therefore, assumes a therapeutic dimension. Reinterpreting medina-based principles through Sudanese courtyard traditions- such as protected internal gathering spaces, hierarchical access systems, shaded pedestrian circulation, and clustered neighbourhood units- can help recreate culturally familiar environments.



Figure 19, Children coming back from school, walking through village's alleys. Source: Photo by Fatima Alam

Courtyard-centred spaces offer secure zones for play and social bonding, layered thresholds preserve privacy, and clustered housing encourages community rebuilding. For orphaned children affected by conflict, such environments can support the gradual reconstruction of identity by reconnecting them to recognizable cultural spatial patterns. In this way, the medina- understood not as a historical artifact but as a living socio-spatial framework- becomes a foundation for healing, resilience, and sense of belonging.

2.4. Case Studies: Design analysis and evaluation

2.4.1. Falatow Jigiyaso Orphanage



Figure 20, Falatow Jigiyaso Orphanage. Source: photo by Vanja Bjelobaba, 2013.

Location: Dialakoroba, Mali

Year: 2012

Area of project: 891 m²

Capacity: 30 children

Program:

Ground Floor:

- Housing (Children and Staff).
- Small medical centre.
- Administration offices.
- Toilet and shower blocks
- Kitchen and dining hall.

First Floor:

- Classrooms



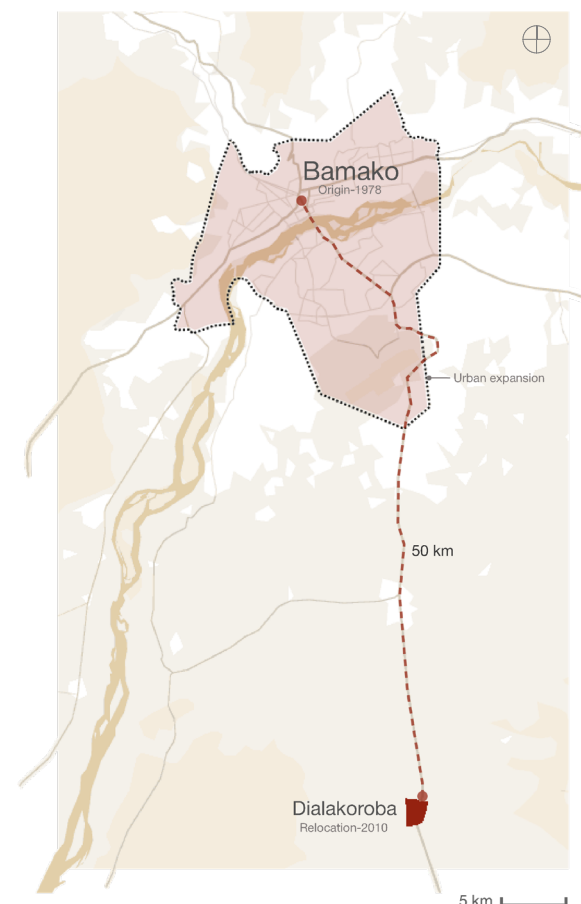
Figures 21, 22, Falatow Jigiyaso Orphanage. Source: photo by Vanja Bjelobaba, 2013.

About the project

The Falatow Jigiyaso Orphanage began in Bamako in 1978, when Fatoumata Goundourou (originator of the orphanage) found an abandoned baby in the street and decided to take him home. Over time, her house became a shelter for around 30 children of different ages.

In 2010, Jean-Jacques Bridey, the mayor of Fresnes in southern Paris, learned about her work through members of his community. He later visited Mali, met Fatoumata, and decided to support the construction of a proper orphanage in Dialakoroba, about 50 km south of Bamako.

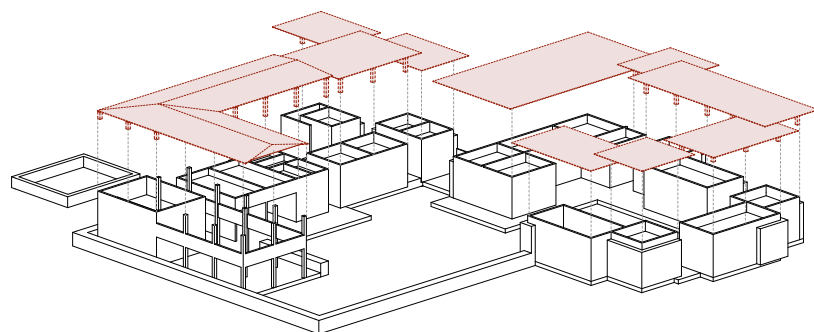
The orphanage includes housing for children and staff, as well as basic facilities such as a small medical centre, administrative offices, toilets and showers, a kitchen, and a dining area.



Design Principles and Spatial Strategies

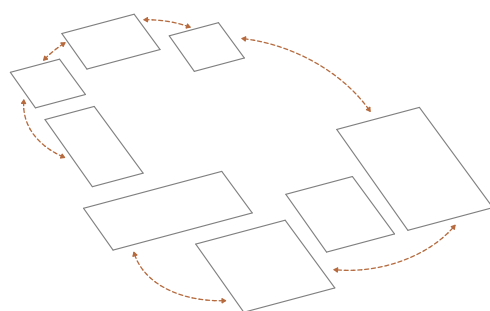
Double Roof

A secondary roof layer reduces solar heat gain and creates shaded spaces around the buildings.



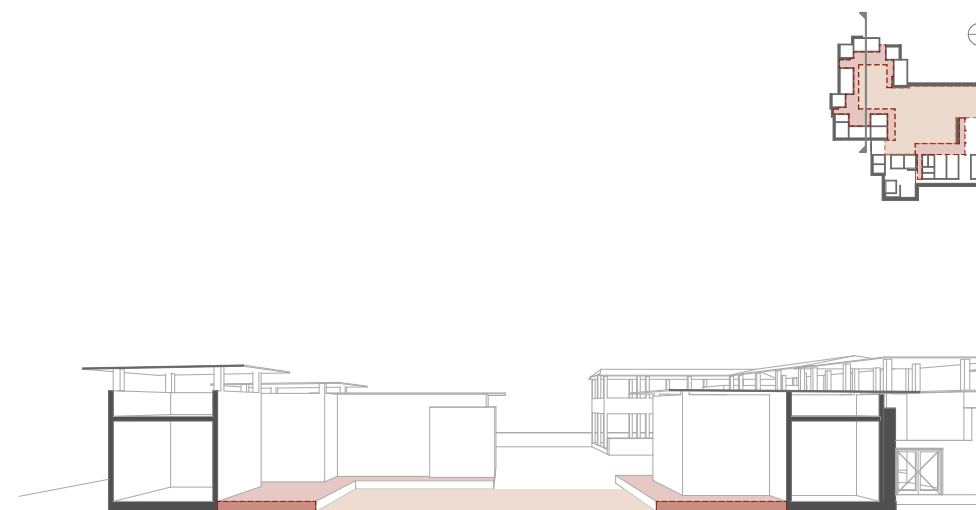
Clustered Layout

A secondary roof layer reduces solar heat gain and creates shaded spaces around the buildings.



Shaded Circulation

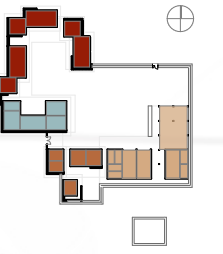
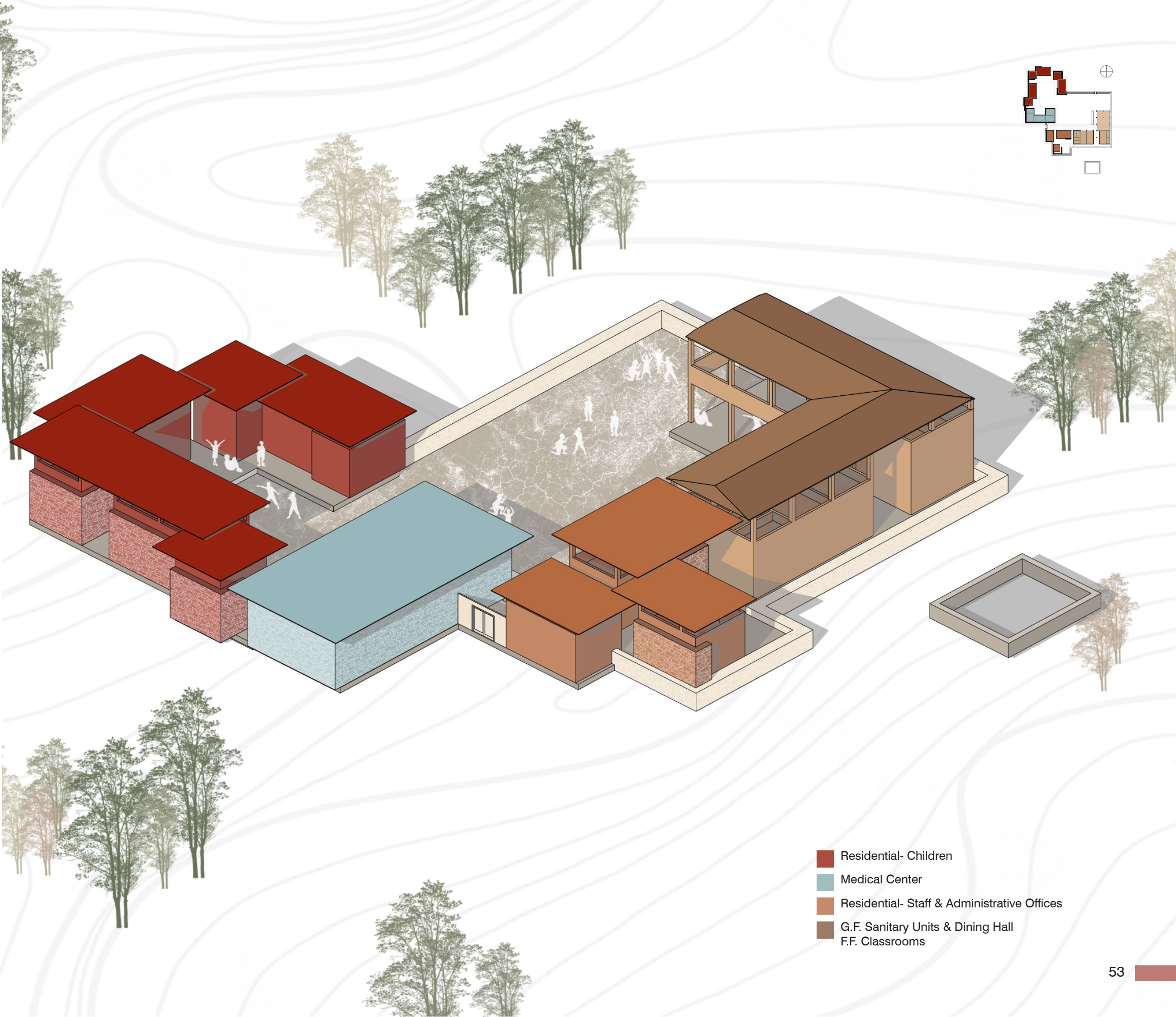
Covered walkways and narrow passages connect the different functions while providing protection from the harsh climate.



Spatial Organization

The project is organized through a clear division of functions that supports both daily living and communal activities. Residential spaces for children and staff form the core of the layout, ensuring a sense of stability and continuous supervision. Supporting facilities, including the medical centre, administration offices, and sanitary blocks, are strategically positioned to remain accessible while maintaining separation from private living areas.

Communal functions such as the kitchen and dining hall act as shared spaces that encourage interaction and collective routines. On the upper level, classrooms and terraces are dedicated to children's activities, providing areas for learning, play, and social engagement in a more open and flexible environment. This vertical and horizontal distribution of functions creates a balanced relationship between private, semi-private, and communal spaces within the project.



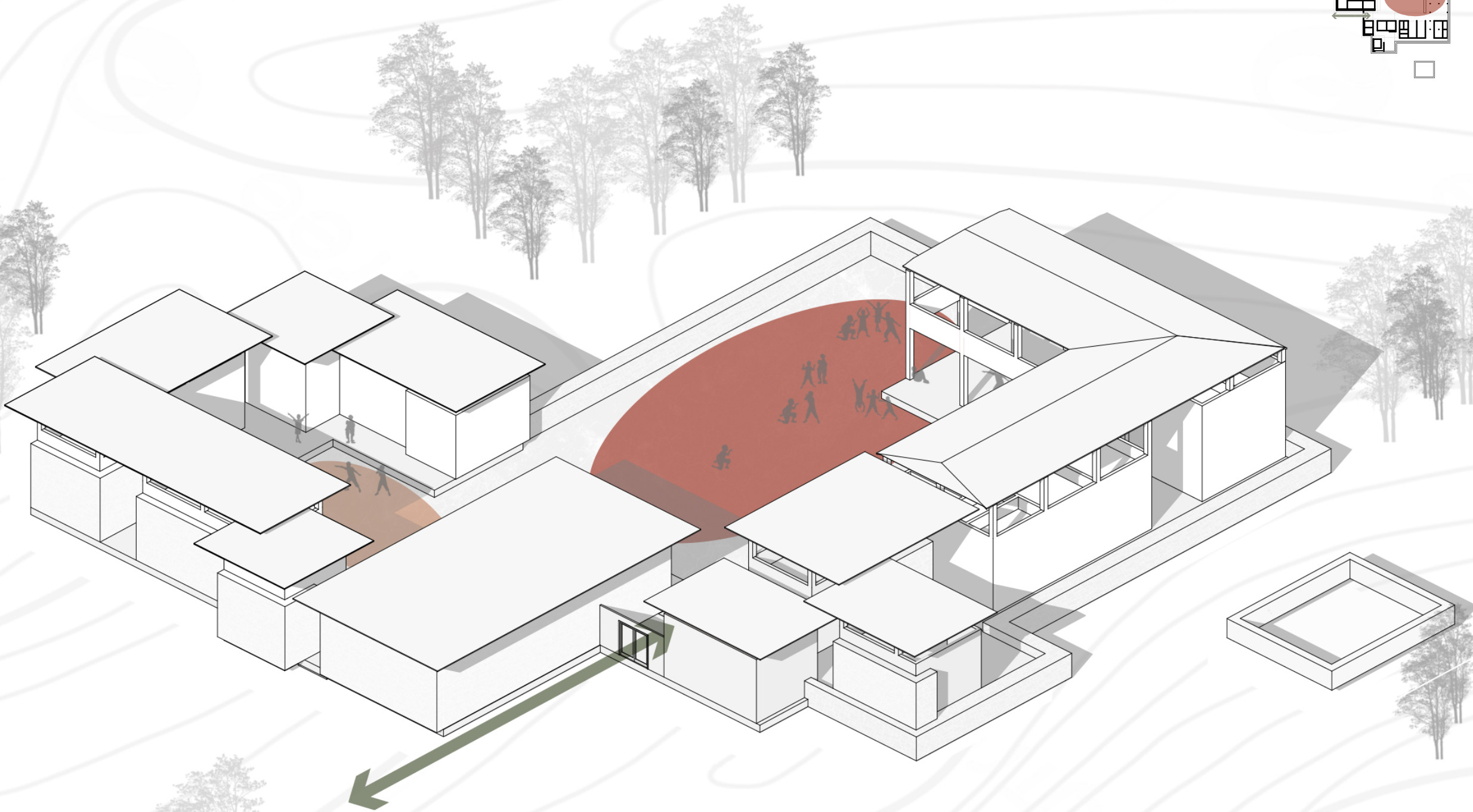
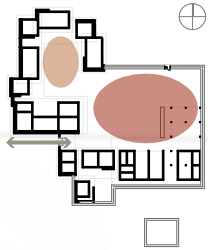
- Residential- Children
- Medical Center
- Residential- Staff & Administrative Offices
- G.F. Sanitary Units & Dining Hall
F.F. Classrooms

Courtyards and Accessibility

The orphanage features two main outdoor courtyards that structure daily life and social interaction. The larger courtyard functions as a public gathering space, connecting the residential clusters with the communal facilities such as the dining hall, kitchen, and medical centre. It serves as a central hub for play, collective activities, and social interaction, accommodating larger groups of children and staff.

In contrast, a smaller, semi-private courtyard is located directly in front of the children's dormitories, providing a quieter environment for informal play, smaller gatherings, and personal reflection. Both courtyards are accessible through a single entry point, which helps regulate movement and enhances safety.

Circulation throughout the orphanage follows an organic and hierarchical system, moving from public communal areas to the semi-private courtyards and finally to the private sleeping zones. This arrangement, with enclosed courtyards, gradual spatial transitions, and human-scale clustering, reinforces a sense of security, orientation, and social cohesion for the children.



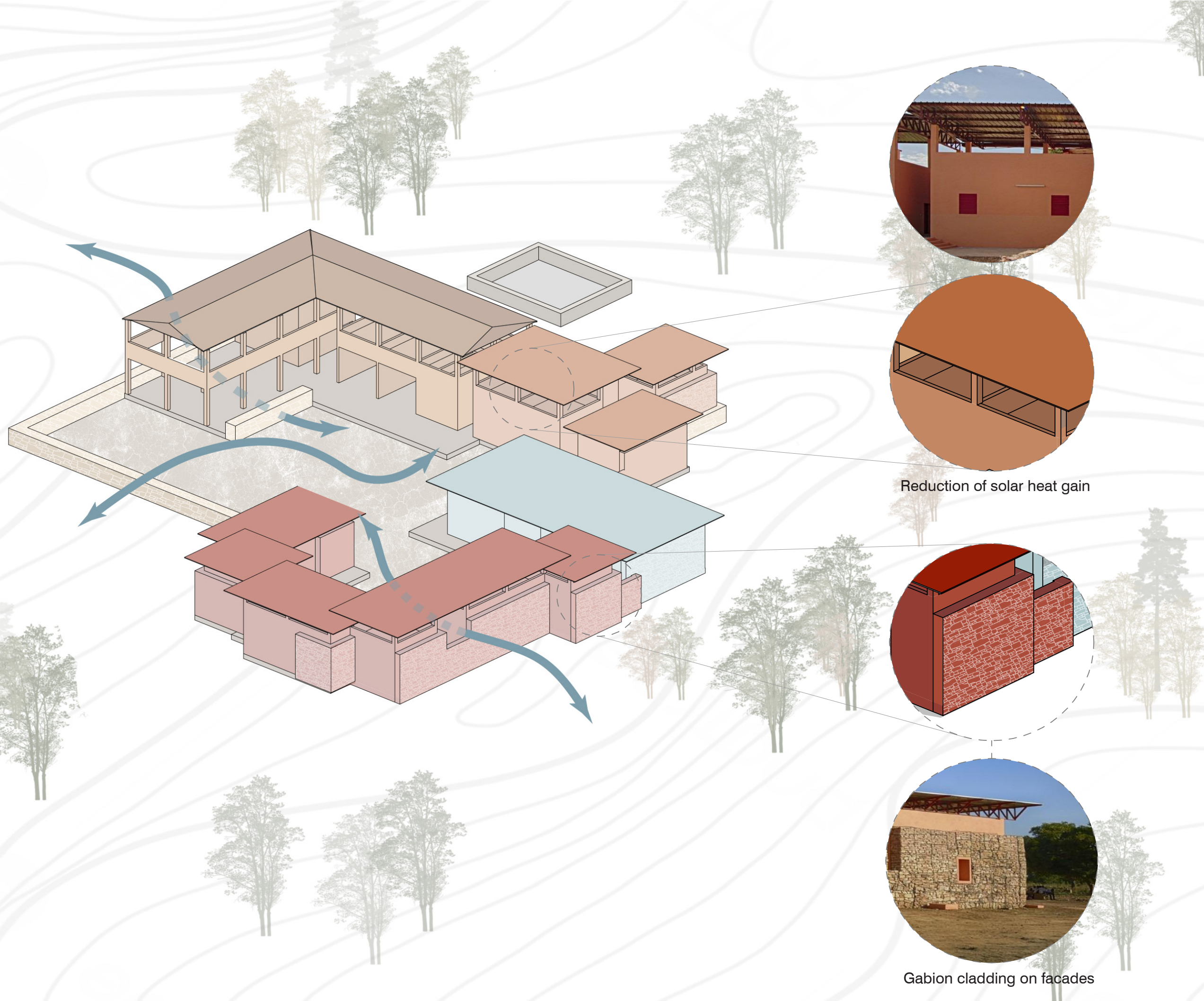
- Public courtyard
- Semi-private courtyard
- Main Access

Climate Responsive Strategies

The design of the orphanage is guided by a set of passive environmental strategies aimed at improving thermal comfort in a hot climate. The first principle focuses on reducing solar heat gain through the use of an additional roof layer placed above the buildings. This secondary roof extends beyond the edges of the walls, providing continuous shading that protects interior spaces from direct sunlight. It also creates shaded outdoor areas, particularly over the first-floor terraces used for children's activities, allowing these spaces to remain usable throughout the day.

The second strategy enhances the thermal performance of the building envelope by increasing the thermal mass of the walls. The walls are constructed using locally available materials. This composition improves the walls' ability to absorb heat during the day and release it slowly over time, helping to regulate indoor temperatures. In addition, the most exposed façades are protected with a layer of gabion cladding, which further reduces heat gain and shields the structure from harsh environmental conditions.

The final principle addresses natural ventilation. At the scale of the overall layout, the arrangement of the buildings is designed to encourage air movement across the site, promoting ventilation between blocks. At the building level, openings and ventilation grilles are carefully integrated to allow continuous airflow, supporting passive cooling and maintaining a comfortable indoor environment without reliance on mechanical systems.



2.4.2. SOS Children Village



Figure 23, SOS Children Village in Djibouti. Source: photo by Javier Callejas.

Location: Tadjoura, Djibouti

Year: 2014

Area of project: 2,600 m²

program:

Ground Floor:

- 10 Children houses + common spaces:

- Kitchens
- Dining areas
- Living areas
- Courtyards

First Floor:

- Director's house
- Aunts' house
- Guests' house



Figure 24, 25, SOS Children Village in Djibouti. Source: photo by Javier Callejas.

About the project

The SOS Children Village is located in the city of Tadjoura, 180 kilometres north of the capital city of Djibouti. It's a residential compound consisting of 13 housing units, intended to support family- strengthening programs.

The project adopts a spatial logic inspired by the medina, derived from traditional architectural references in similar cultural and environmental contexts, which has been reinterpreted to meet the children's needs.



The resulting environment is conceived as a safe, car-free setting where narrow streets and small squares function as spaces for play and social interaction.

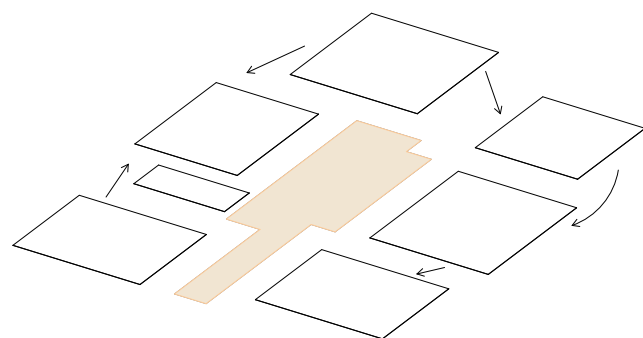
Vegetation has been integrated in the projects to encourage children and residents to take care of the plants, enhancing environmental quality and daily life.



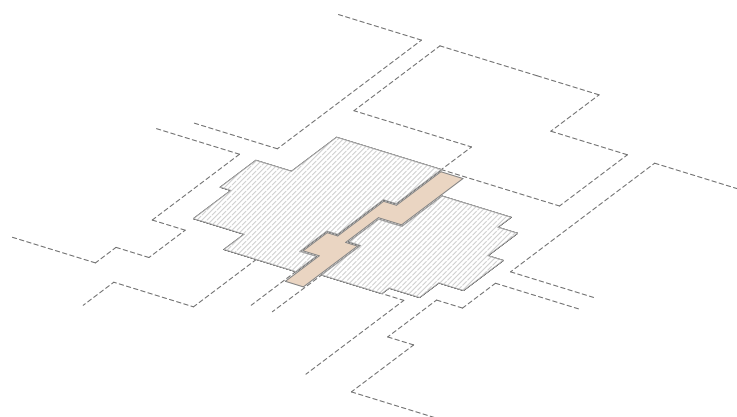
Figure 26, 27, SOS Children Village in Djibouti. Source: photo by Javier Callejas.

Spaces Configuration

The houses are designed with an inward orientation, limiting exposure to the exterior environment while creating protected internal spaces. This configuration enhances privacy, improves thermal comfort, and allows controlled airflow throughout the dwellings.



The close placement of the houses allows them to provide mutual shading while creating a network of narrow alleys and transitional spaces. This seemingly irregular arrangement contributes to both climatic comfort and the intimate spatial character of the settlement.



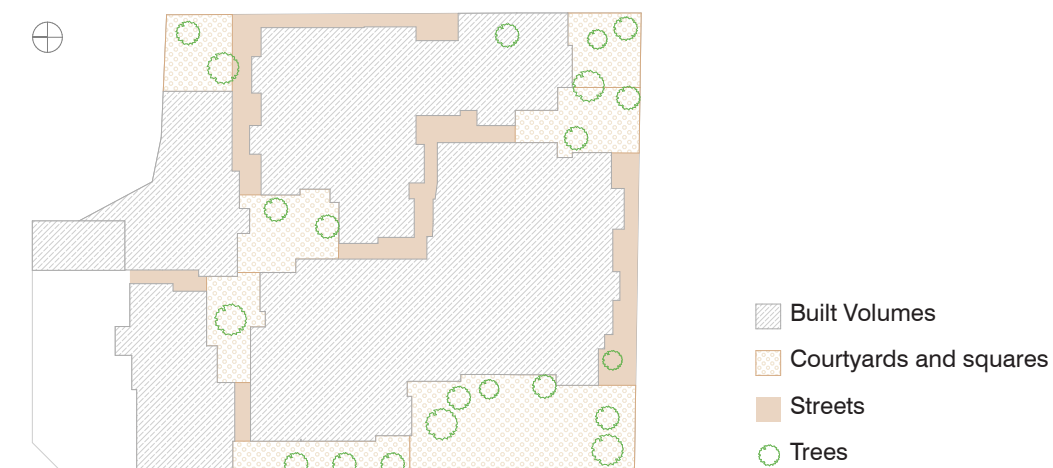
Common spaces and Courtyards

There is a common – semi open- shared space within each unit, attached to strengthens the relationship between indoor and outdoor living while encouraging social interaction and natural ventilation.

The village is designed with an inclusion of inward oriented courtyards, limiting exposure to the exterior environment while creating protected internal spaces, in addition to the shared playing areas and yards.



The close placement of the houses allows them to provide mutual shading while creating a network of narrow alleys and transitional spaces. This seemingly irregular arrangement contributes to both climatic comfort and the intimate spatial character of the settlement.



Climate Responsive Strategies

The project incorporates several passive climate-responsive strategies adapted to the harsh environmental conditions of the region. The compact arrangement of the housing units creates shaded alleys and reduces direct solar exposure, while inward-oriented courtyards support natural ventilation and cooler microclimates.

In addition, the integration of ventilation towers and carefully positioned openings enhances airflow throughout the village, improving thermal comfort without relying on mechanical cooling systems.



Spatial Organization

The spatial organization of the SOS Children’s Village is based on a clustered arrangement of residential units connected through a network of narrow pedestrian streets and communal squares. The project is structured around a hierarchy of public, semi-private, and private spaces, creating gradual transitions between collective and domestic environments.

Residential units form the main fabric of the village and are complemented by shared functions including kitchen-dining halls, seating areas, restrooms, and utility buildings distributed throughout the site. Transitional spaces and pedestrian pathways connect the different clusters while reinforcing the walkable and child-friendly character of the settlement. The irregular placement of the buildings generates shaded alleys and communal open spaces that encourage social interaction, recreation, and a strong sense of community among residents.



CHAPTER 3.

SUDAN CLIMATIC CONTEXT



3.1. Climate Classification of Sudan

Sudan's climate can be broadly understood through the Köppen–Geiger climate classification system, which categorizes global climates based on temperature and precipitation patterns. According to this system, the majority of Sudan falls within the hot desert climate (BWh- hot desert (arid) climates), while the southeastern regions transition into a hot semi-arid climate (BSh- semi-desert (arid) climate). These climatic conditions are characterized by high temperatures, intense solar radiation, and limited precipitation.

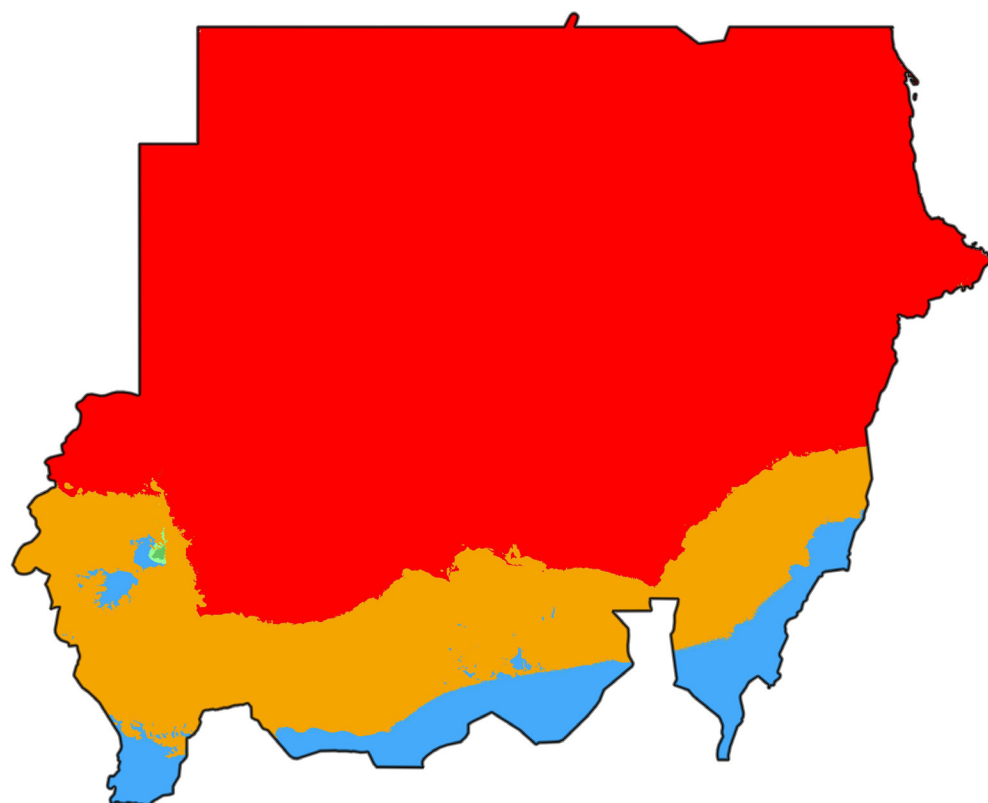


Figure 28, Climate zones of Sudan based on Köppen–Geiger classification, 1991-2020. Source: Beck et al. (2018).



3.2. Selection of Representative Cities

To understand the variation of climatic conditions across Sudan, three representative cities were selected for analysis: Khartoum, Port Sudan, and Ad-Damazin. Khartoum represents inland desert conditions typical of central Sudan. Port Sudan represents coastal desert conditions influenced by the Red Sea. Ad-Damazin represents a semi-arid climate with comparatively higher precipitation levels. This selection allows the examination of climatic differences across hot arid and semi-arid environments and their implications for architectural design.

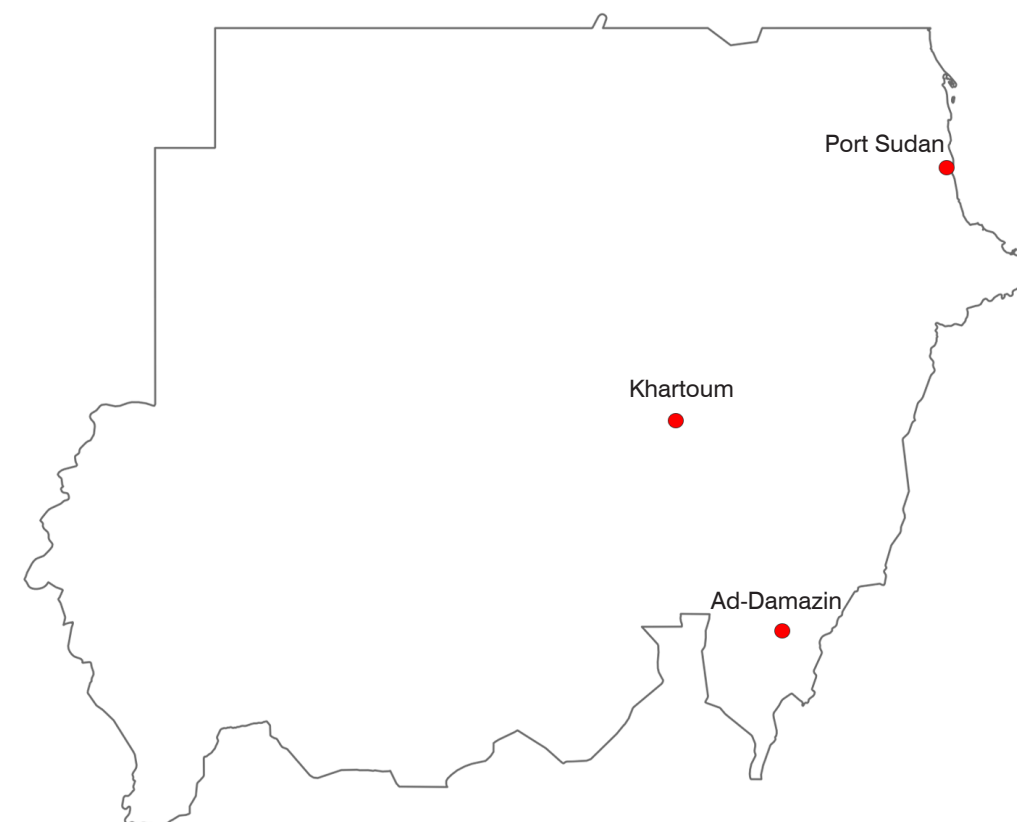


Figure 29, Representative cities in Sudan.

Although Port Sudan is located along the Red Sea coast, it remains classified as BWh due to extremely low annual precipitation. However, coastal conditions introduce higher humidity and maritime influences that differentiate it from inland desert environments such as Khartoum.

3.3. Comparative Climate Analysis

Climate data visualizations, including temperature profiles, psychrometric charts, humidity levels, and wind patterns, were generated using the CBE Climate Tool developed by the Centre for the Built Environment at University of California, Berkeley.

3.3.1. Temperature Graph

The dry bulb temperature data indicates distinct climatic variations across the representative Sudanese cities.

Port Sudan experiences relatively moderate temperatures throughout the year due to the maritime influence of the Red Sea, with temperatures generally ranging between 22°C and 36°C and peaking during summer months. Khartoum shows a more continental hot-arid climate, characterized by significant seasonal fluctuations. Temperatures increase steadily from January, reaching peak values of approximately 34–35°C during late spring and summer before decreasing toward the end of the year. Ad-Damazin maintains comparatively high temperatures throughout the year, with values generally ranging between 25°C and 35°C. Unlike Khartoum, temperature variation is less extreme, reflecting the city's warmer semi-humid climatic conditions.

Overall, the graph demonstrates continued periods of elevated dry bulb temperatures across all three cities, emphasizing the importance of passive cooling strategies such as natural ventilation, shaded courtyards, and wind catchers in improving thermal comfort within buildings in Sudanese climates.

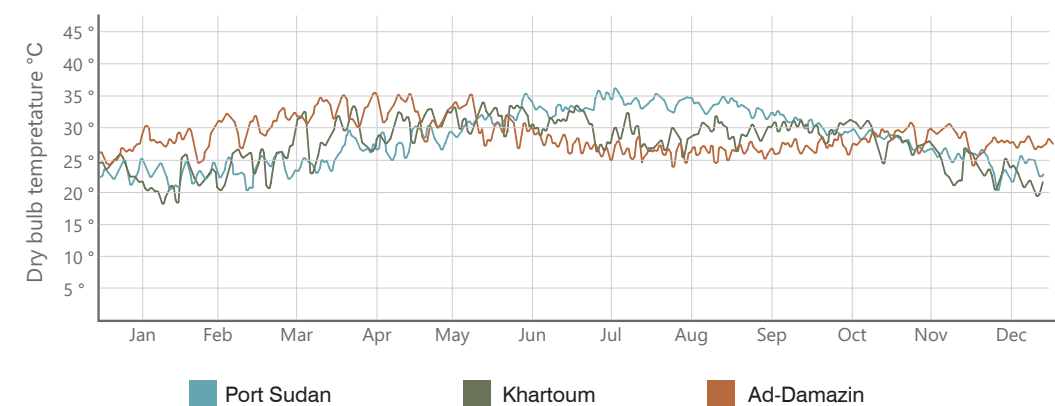


Figure 30, temperature graph.

The temperature range graphs also reveal differences in the daily temperature variation among the three cities. Khartoum exhibits the largest day–night temperature fluctuations, particularly during the hot and dry months, indicating strong potential for passive cooling strategies based on thermal mass and night ventilation.

Ad-Damazin shows moderate daily temperature variations, allowing thermal mass to remain beneficial, although to a lesser extent than in Khartoum. In contrast, Port Sudan experiences the smallest day–night temperature differences due to the moderating influence of the Red Sea and higher humidity levels, reducing the effectiveness of thermal storage strategies and increasing the importance of ventilation-based cooling approaches.

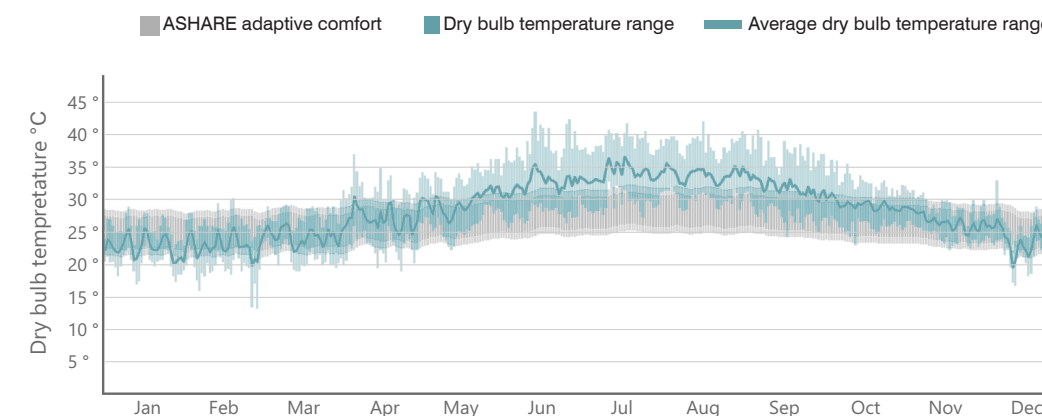


Figure 31, Port Sudan temperature graph.

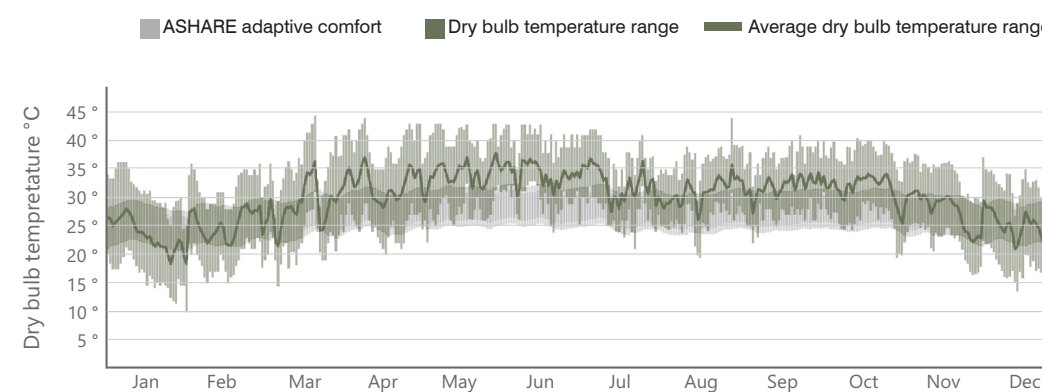


Figure 32, Khartoum temperature graph.

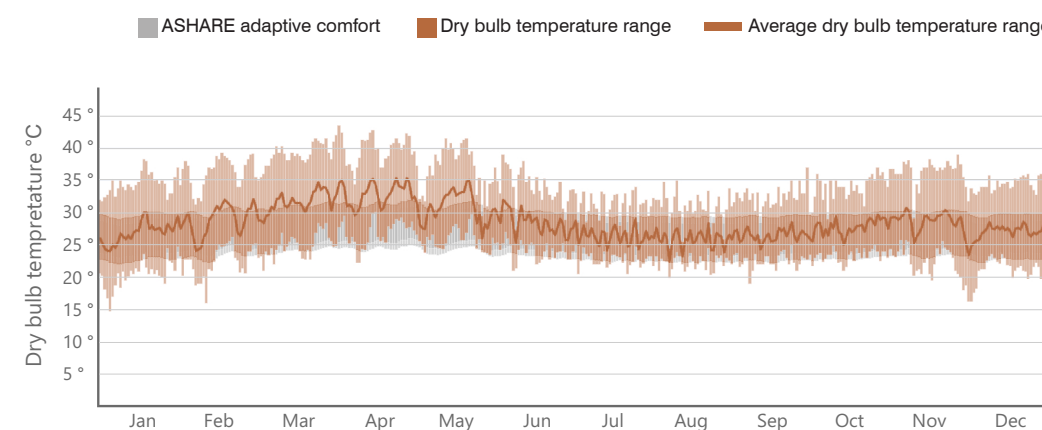


Figure 33, Ad-Damazin temperature graph.

3.3.2. Psychrometric Chart

The psychrometric chart provides a comprehensive representation of the relationship between temperature, humidity, and human thermal comfort. The analysis of the selected cities indicates that a large proportion of the yearly hours lie outside the thermal comfort range, primarily due to high temperatures and varying humidity levels. In Khartoum and Port Sudan, most data points are in the high-temperature region of the chart, indicating a strong need for cooling strategies, while Damazin shows slightly improved conditions due to its semi-arid climate. The psychrometric analysis therefore highlights the importance of passive environmental design strategies such as shading, natural ventilation, thermal mass, and courtyard-based spatial organization to mitigate heat stress and improve indoor comfort.

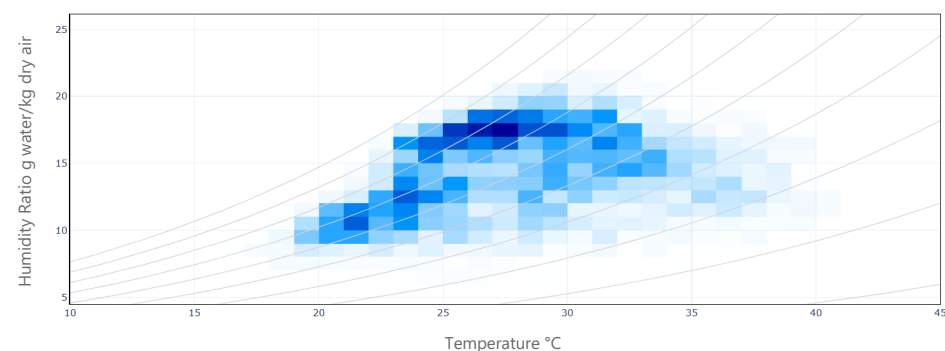


Figure 34, Psychrometric Chart, Port Sudan.

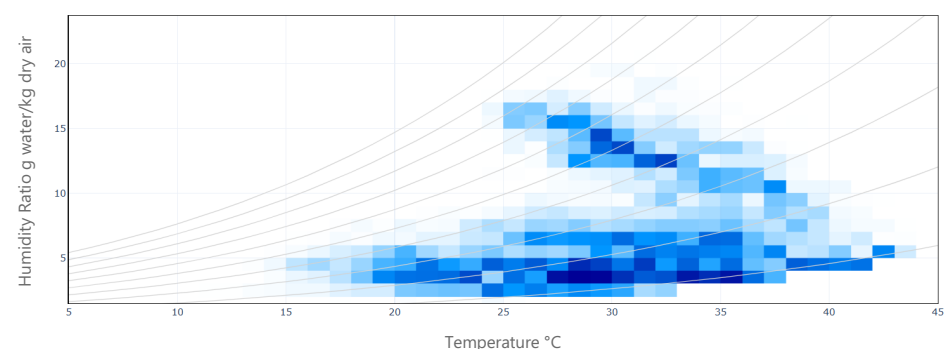


Figure 35, Psychrometric Chart, Khartoum.

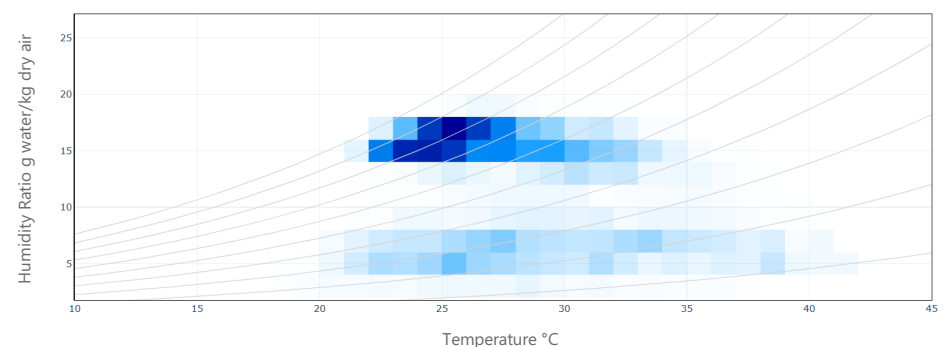


Figure 36, Psychrometric Chart, Ad-Damazin.

3.3.3. Relative Humidity graph

Relative humidity levels vary significantly among the selected cities. Port Sudan experiences higher humidity due to its coastal location along the Red Sea, whereas Khartoum remains comparatively dry. Ad-Damazin shows moderate humidity levels associated with semi-arid climates. These variations influence the effectiveness of passive cooling strategies such as evaporative cooling and natural ventilation.

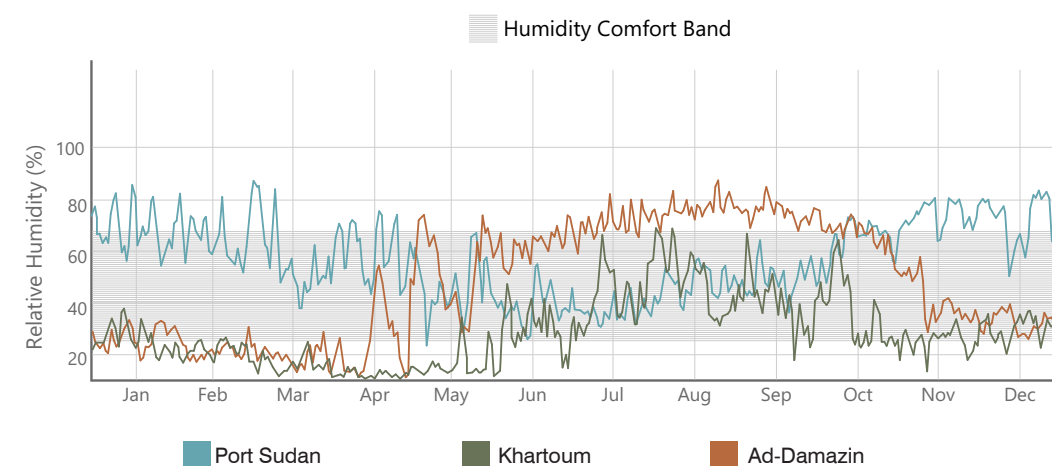


Figure 37, Relative Humidity Graph .

3.3.4. Wind Rose diagram

Wind analysis indicates that natural ventilation can play an important role in improving thermal comfort in Sudanese climates. Coastal winds in Port Sudan and seasonal winds in Khartoum provide opportunities for passive ventilation strategies through building orientation, courtyard layouts, and controlled openings.

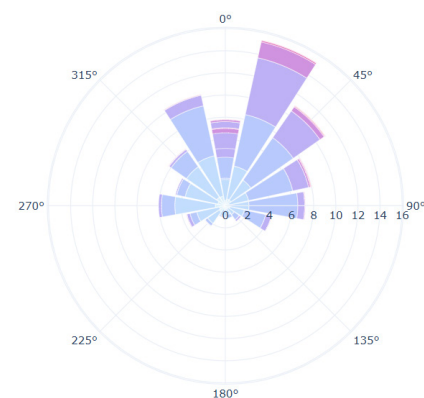


Figure 38, Wind rose diagram, Port Sudan.

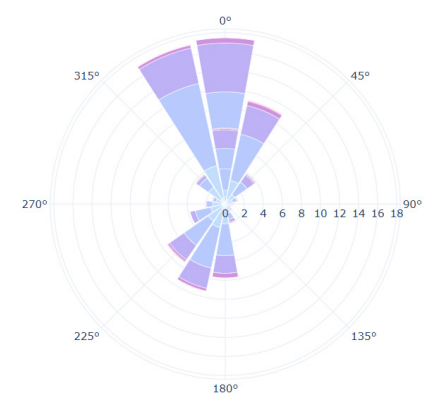


Figure 39, Wind rose diagram, Khartoum.

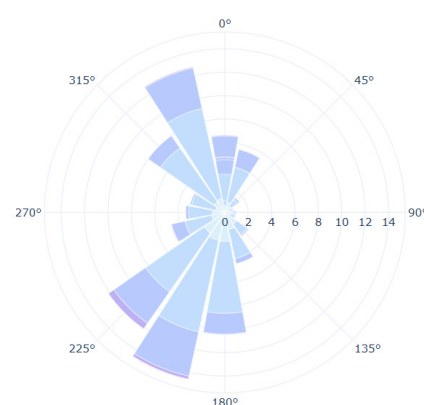


Figure 40, Wind rose diagram, Ad- Damazin.

Wind Speed (m/s)
 calm
 0.5 - 1.5 m/s
 1.5 - 3.3 m/s
 3.3 - 5.5 m/s
 5.5 - 7.9 m/s
 7.9 - 10.7 m/s
 10.7 - 13.8 m/s
 13.8 - 17.1 m/s
 17.1 - 20.7 m/s
 >20.7 m/s

3.3.5. Sun Path charts

High levels of solar radiation are characteristic of Sudan's climate throughout most of the year. As a result, minimizing solar exposure becomes a key architectural strategy. Traditional settlements often respond to this condition through compact urban form, narrow streets, shaded walkways, and internal courtyards.

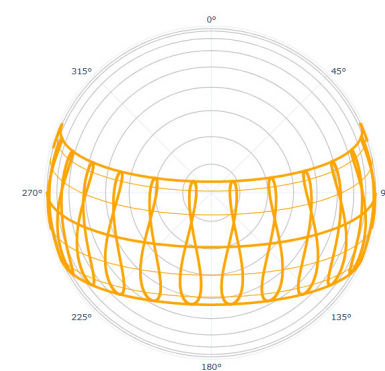


Figure 41, Sun path chart, Port Sudan.

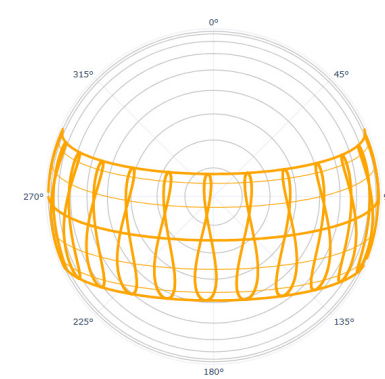


Figure 42, Sun path chart, Khartoum.

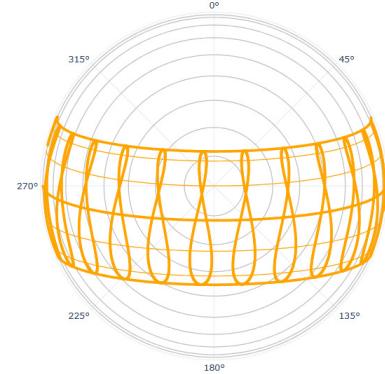


Figure 43, Sun path chart, Ad- Damazin.

3.3.6. Precipitation chart

Monthly precipitation data indicate that rainfall in the selected Sudanese cities is highly seasonal. Most of the precipitation occurs between June and September, with peak rainfall typically recorded in July and August. While annual rainfall totals remain relatively low compared to humid climates, these short but intense rainfall events can result in localized flooding, particularly in urban areas and low-lying sites. Therefore, architectural design must incorporate adequate drainage systems, slightly elevated building platforms, and appropriate roof slopes to manage seasonal rainfall effectively.

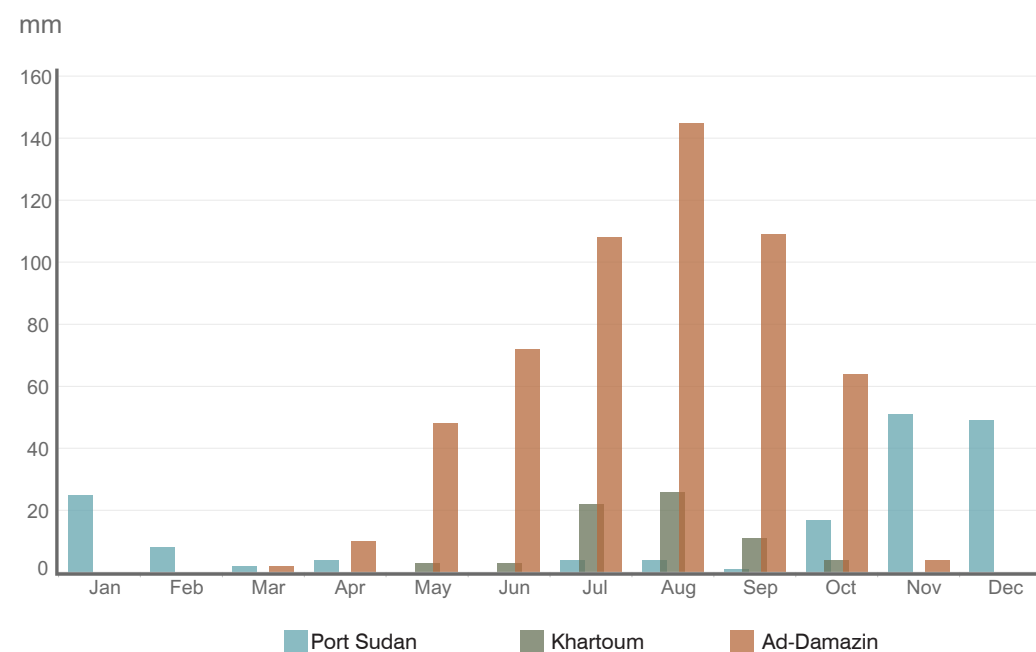


Figure 44, Precipitation chart.

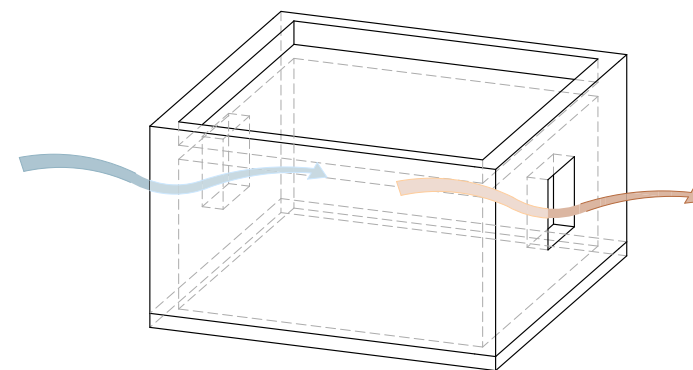
3.4. Vernacular Environmental Design Strategies in Sudan

The climatic analysis highlights several environmental challenges including extreme temperatures, strong solar radiation, and varying humidity levels. These conditions emphasize the importance of passive cooling strategies in Sudanese architecture. Traditional urban forms such as courtyard housing, shaded circulation routes, and compact settlement patterns demonstrate effective climatic adaptation. These principles align with spatial characteristics found in medina urban morphology, where courtyards and narrow streets create microclimatic comfort through shading and ventilation.

3.4.1. Natural ventilation

Natural ventilation represents one of the most significant climate-responsive strategies in Sudanese vernacular architecture, contributing to thermal comfort through passive cooling and heat-loss promotion. Its effectiveness varies according to climatic conditions; while daytime ventilation may be less suitable in hot-arid regions because of excessive outdoor heat, night ventilation becomes highly effective in cooling building masses and improving indoor comfort. Traditional courtyard systems demonstrate an efficient response to these contrasting environmental conditions by facilitating controlled airflow, shaded microclimates, and thermal regulation (Osman & Sevinc, 2019). In more humid regions, natural ventilation plays a greater role throughout the day by enhancing air movement and reducing heat accumulation.

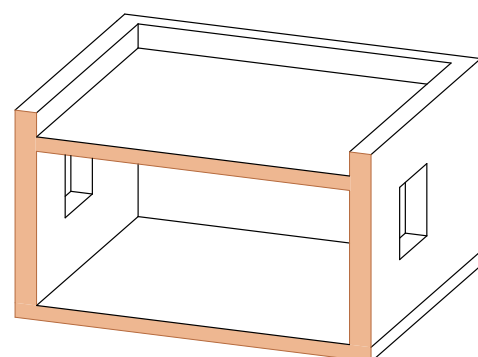
Sudan's abundant renewable resources, particularly wind and solar energy, further support passive ventilation strategies through architectural elements such as courtyards, verandas, wind towers, and solar chimneys that stimulate continuous air circulation and improve environmental performance (Osman & Sevinc, 2019).



3.4.2. High thermal mass

Thermal mass represents one of the most effective passive cooling strategies in hot-arid climates, where it helps moderate the large temperature differences between day and night. Materials with high thermal mass, such as earth, brick, and stone, absorb heat during the daytime and gradually release it when outdoor temperatures decrease, contributing to improved indoor thermal comfort (Osman & Sevinc, 2019).

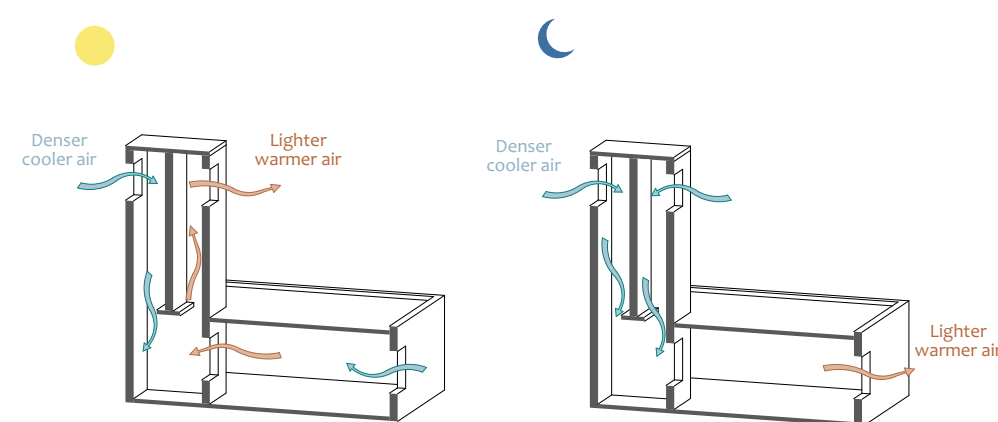
In traditional Sudanese architecture, thick earthen walls demonstrate this principle by reducing indoor heat gain and stabilizing interior temperatures. However, for thermal mass to function effectively, it should be combined with adequate ventilation strategies, particularly night ventilation, to dissipate stored heat and enhance cooling performance (Osman & Sevinc, 2019).



3.4.3. Wind catcher

Wind catchers represent a sustainable passive cooling strategy traditionally used in hot climatic regions to improve indoor thermal comfort and natural ventilation. As environmentally responsive architectural elements, they rely entirely on natural forces to provide airflow and fresh air without dependence on mechanical cooling systems (Ali, 2021). Wind catcher function by capturing prevailing winds and directing cooler air into interior spaces while simultaneously extracting warm air through pressure differences and the stack effect (Ali, 2021).

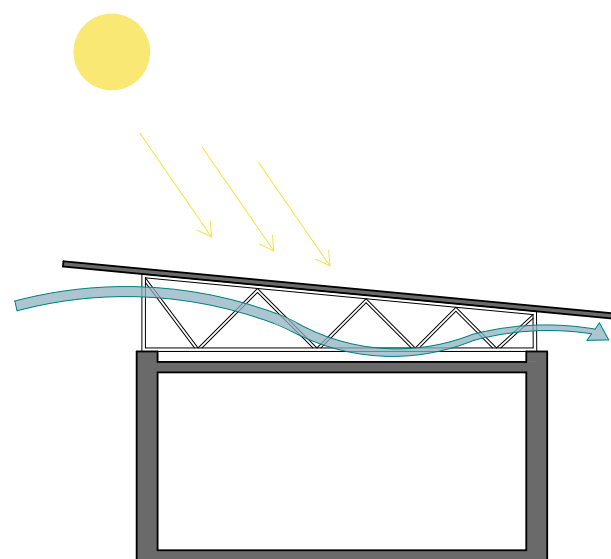
In hot and dry climates, they contribute to evaporative cooling, convective ventilation, and night-time ventilation, helping reduce indoor temperatures and enhance occupant comfort (Ali, 2021). Integrated with courtyard architecture and thick earthen construction, wind catchers demonstrate how vernacular building technologies respond effectively to climatic conditions through sustainable and energy-efficient environmental design.



Function of windcatcher due to stack effect during daytime and night.

3.4.4. Double roofing system

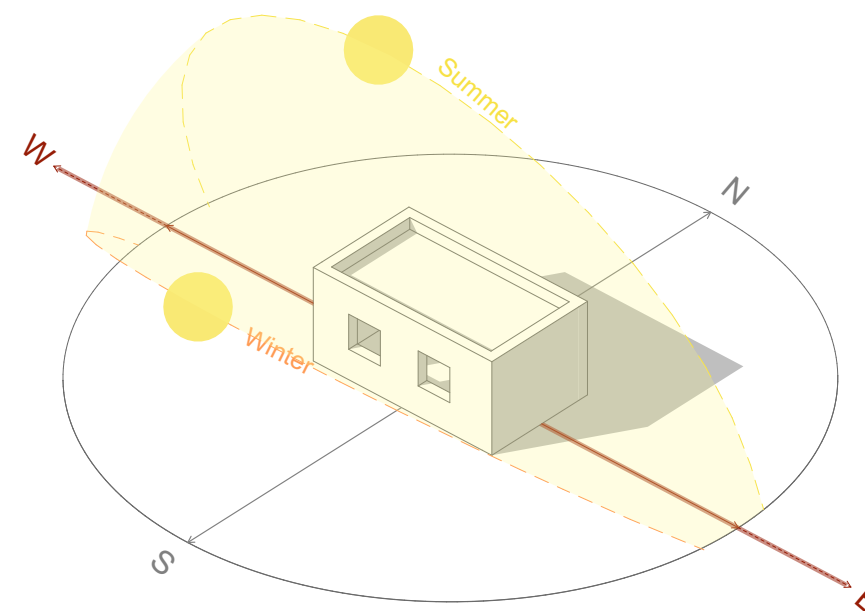
Double roofing, also known as a ventilated or dual-layer roof system, represents a climate-responsive building technology that can be effectively adapted to the harsh environmental conditions of Sudan. The system consists of two separate roof layers with an air cavity between them, creating a thermal buffer that reduces direct heat transfer into interior spaces (Ali, 2021). The upper roof layer acts as a protective shading element that absorbs and reflects a significant portion of solar radiation, while the ventilated gap allows accumulated hot air to escape through natural convection, improving indoor thermal comfort (Ali, 2021).



3.4.5. Building orientation

Building orientation represents a fundamental climate-responsive strategy in vernacular architecture, influencing both solar exposure and natural ventilation within buildings. The orientation of a building determines the amount of solar radiation received and therefore plays a significant role in passive heating and cooling performance (Osman & Sevinc, 2019). Appropriate orientation varies according to climatic conditions and is particularly critical in hot-arid regions, where reducing heat gain is essential for thermal comfort.

Traditional design approaches often orient the longer façades toward the north and south to minimize direct solar exposure, especially from the intense eastern and western sun. Openings are strategically positioned toward prevailing wind directions to maximize cross-ventilation and enhance indoor airflow (Osman & Sevinc, 2019).

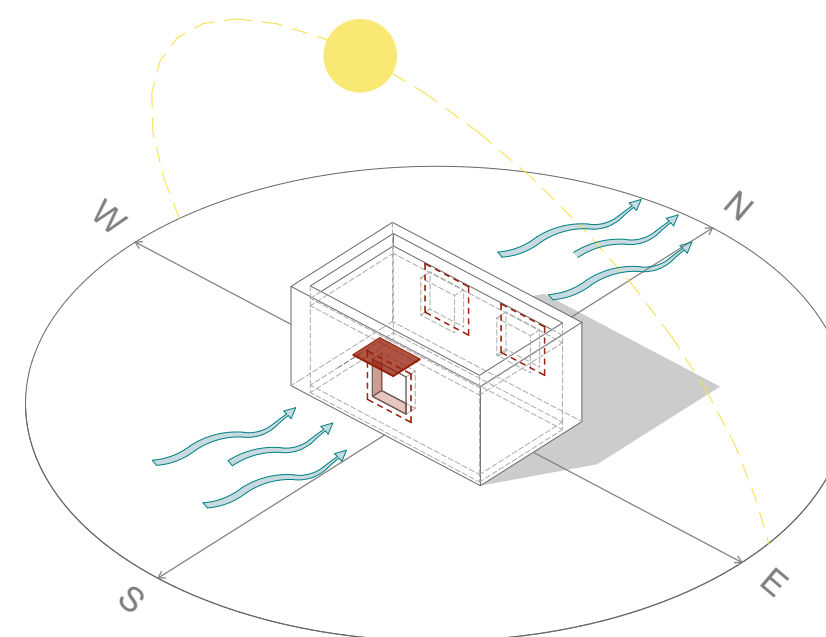


3.4.6.1. Solar Control

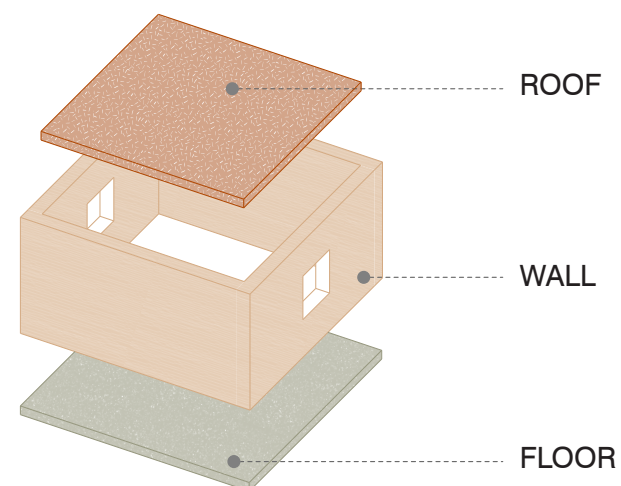
Shading devices represent an essential climate-responsive strategy in hot-arid regions, where controlling solar radiation is critical for improving indoor thermal comfort and reducing heat gain. The effectiveness of shading systems depends on factors such as building orientation, geographical location, and window type, requiring shading elements to be carefully designed and proportioned according to the movement of the sun throughout the day. Properly designed shading devices can significantly reduce direct solar exposure on façades and openings while still allowing natural daylight and ventilation into interior spaces. In vernacular architecture, roof overhangs, recessed openings, verandas, and external screens are commonly used to provide solar protection and enhance environmental comfort. Osman & Sevinc (2019) mentioned that horizontal overhangs can provide effective solar control for south-oriented façades in hot-arid climates by limiting excessive summer solar gain while maintaining shaded openings and cooler indoor conditions. As a passive environmental strategy, shading devices contribute to energy-efficient and climate-responsive architecture through simple yet effective solar control principles.

3.4.6.2. positioning of windows

Window placement represent important climate-responsive strategies in vernacular architecture, contributing significantly to thermal comfort and passive cooling performance. In traditional buildings, windows were carefully positioned and sized according to solar orientation, prevailing winds, and the thermal properties of construction materials. Strategically placed operable windows enabled cross ventilation by capturing cooling summer breezes and enhancing indoor airflow. Building orientation and roof design also played a critical role in controlling solar exposure, allowing winter sunlight penetration while reducing excessive heat gain during hot seasons through shading devices and roof overhangs (Elhassan, 2023).



3.5. Vernacular Building Materials and Construction Applications in Sudan



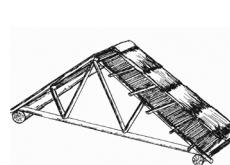
ROOF SYSTEMS

Domes



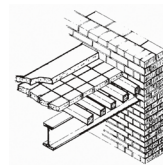
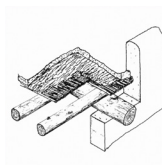
Thatched Domes

Sloped Roof



Thatched Roofs

Flat Roofs

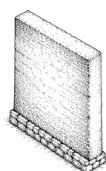
Shagig (Palm purlins)
RoofTraditional earth
roof

Figures 45, 46, 47, 48. Source: Adam, E.A. & Agib, A.R.A., 2001.

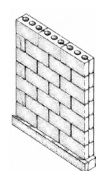
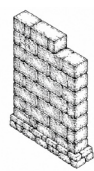


WALL SYSTEMS

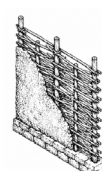
Monolithic Walls



Block-Based Walls

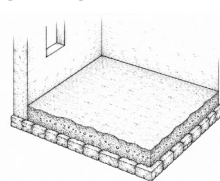


Lightweight Framed Walls



FLOOR SYSTEM

Lightweight Framed Walls



Sudan's construction sector has traditionally relied on locally available materials that respond to the country's climatic conditions, environmental resources, and economic context. Across different regions of Sudan, building materials have evolved from traditional earth-based techniques to the increasing use of industrial materials such as fired bricks, cement blocks, and reinforced concrete, particularly in rapidly growing urban areas like Khartoum. While these modern materials offer structural advantages and construction efficiency, they often require high energy consumption during production and may not always provide optimal thermal performance in hot climates.

According to Akram Ahmed Elkhailifa, the growing reliance on imported or energy-intensive building materials in Sudan has raised concerns regarding sustainability, affordability, and environmental impact, highlighting the importance of promoting appropriate local building technologies.

Traditional materials such as mud bricks and other earth-based construction techniques have long been adapted to the harsh climatic conditions of the region, providing good thermal mass and indoor comfort. However, these materials also present challenges related to durability and resistance to moisture. Therefore, the stabilized earth technologies, such as compressed stabilized earth blocks (CSEB), can significantly improve the strength and durability of traditional mud construction while maintaining the thermal advantages and environmental benefits of earthen materials. These technologies are particularly suitable in hot climates because of their high thermal mass and the widespread availability of suitable soil resources across many regions of Sudan. (Adam, E.A. & Agib, A.R.A., 2001)

Adam & Agib (2001), Also stated that buildings in Sudan can be made entirely or partially of soil, as soil construction techniques are used in a wide range in Sudan. 80% of urban buildings are made of soil, and this percentage exceeds 90% in rural areas.

3.5.1. Earth Based Materials

The diversity of soil types across Sudan has significantly influenced vernacular construction practices and the development of earthen building technologies. Due to the widespread availability of local soils, earth-based materials remain among the most used construction resources in different regions of the country. The main soil types identified in Sudan include black cotton soils (badobe), red sand-ironstone soils (Goz), and lateritic soils, each characterized by distinct physical properties and varying suitability for construction applications. These variations have contributed to the adaptation of different earthen building techniques according to local climatic and environmental conditions. (Adam, E.A. & Agib, A.R.A., 2001)

3.5.1.1. Soil Diversity

- **Black Cotton Soil (Badobe)**

Black cotton soil, locally known as badobe, is one of the most used earthen materials in central Sudan due to its wide availability. It is characterized by its high clay content and is traditionally used in adobe and mud wall construction. However, its expansion and shrinkage during wet and dry cycles often reduce building durability and increase maintenance requirements (Adam & Agib, 2001).

- **Goz Soils (Red Sand-Ironstone Soils)**

Goz soils are widely distributed across western Sudan and consist of sand, silt, and clay mixtures with lower clay content than black cotton soils. Due to their greater stability and reduced shrinkage, buildings constructed from Goz soils often demonstrate improved durability, making them suitable for earthen construction applications in Sudan (Adam & Agib, 2001).

- **Lateritic Soils**

Lateritic soils are iron-rich soils commonly found in higher rainfall regions of Sudan. Their relative stability and resistance to erosion make them suitable for stabilized earthen construction technologies, particularly in areas exposed to seasonal rainfall and humid climatic conditions (Adam & Agib, 2001).

3.5.1.2. Traditional Earthen Construction Methods

Traditional earthen construction in Sudan commonly relies on three principal techniques: jalous (cob), wattle and daub, and adobe construction. These construction methods demonstrate the adaptability of vernacular architecture to locally available materials and climatic conditions, particularly using thick earthen envelopes that contribute to thermal mass and indoor thermal regulation.

- **wattle and daub**

wattle and daub systems combine woven timber or twig frameworks plastered with earth.

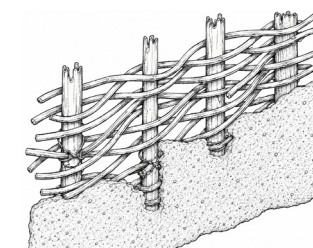


Figure 49, Wattle and daub construction. Source: Warpaths2PeacePipes.com

- **Jalous (cob)**

Jalous consists of mixtures of clay, gravel, and straw applied as monolithic earthen walls.

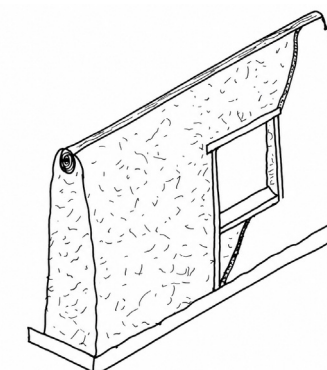


Figure 50, Cob construction. Source: endeavourcentre.org

- **Adobe**

Adobe construction utilizes sun-dried moulded clay bricks of varying sizes assembled into thick wall systems.

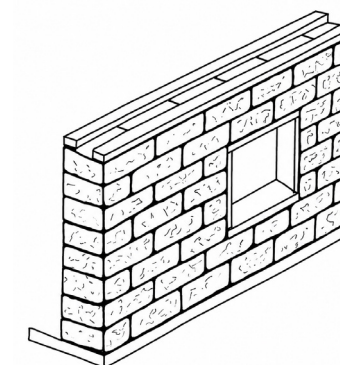


Figure 51, Adobe construction. Source: endeavourcentre.org

3.5.1.3. Limitations of Traditional Earth Construction

While these traditional techniques demonstrate adaptation to local climatic conditions and material availability, The limited durability of unstabilized earth materials, particularly under climatic fluctuations and seasonal rainfall, has encouraged further research into improving earth-based construction technologies in Sudan. Research institutions in the Khartoum area have contributed to the development of more durable techniques, including rammed earth and stabilized compressed earth blocks (CSEB), which enhance the structural performance and longevity of earthen construction systems. (Adam & Agib, 2001)

3.5.1.4. Stabilized Earth Technologies and CSEB

The previous sections have demonstrated the limitations of traditional earthen construction systems and the need for more durable and standardized building technologies. In this context, compressed stabilized earth blocks (CSEB) present significant potential for the Sudanese construction industry due to their improved durability, structural stability, and suitability for climate-responsive architecture. The development and promotion of high-quality stabilized earth blocks can contribute to more sustainable and affordable construction solutions, particularly for low-income communities and developing regions where locally available materials remain essential building resources.

The basic materials required to produce compressed stabilized earth blocks include soil, water, and a stabilizing agent such as cement or lime. Due to the widespread availability of suitable soils across different regions of Sudan, CSEB technology presents a practical and accessible construction solution that builds upon traditional earthen practices while improving durability and structural performance. The use of locally available materials also supports environmentally responsive and economically sustainable construction approaches within the Sudanese context.

3.5.2. Wood

Timber represents an important vernacular construction material in the architecture of Sudan, particularly in roof systems, shading structures, and lightweight building components. Despite the diversity of indigenous tree species available in Sudan, the use of local timber within the construction sector remains limited, while dependence on imported structural wood products continues (Abdelatif et al., 2022).

Traditionally, timber has been utilized in the roofs of local houses as well

as larger public buildings, demonstrating its adaptability within Sudanese construction practices. Common Sudanese timber species investigated for construction purposes include Sahab (*Anogeissus leiocarpus*), Heglieg (*Balanites aegyptiaca*), and Humeid (*Sclerocarya birrea*), highlighting the potential of locally available wood resources within climate-responsive and sustainable building systems (Abdelatif et al., 2022).

Availability

Sudan possesses a diverse range of indigenous timber resources distributed across different ecological regions, particularly within woodland and savannah zones. Among the commonly identified timber species are:

- **Sahab (*Anogeissus leiocarpus*)**, which is widespread in Kassala, Kordofan, Darfur, Blue Nile, Sennar, and Gedaref states, where it grows within dry forests and savannah environments (Abdelatif et al., 2022).
- **Heglieg (*Balanites aegyptiaca*)**, is primarily found within the arid and semi-arid regions of central Sudan, particularly in Kordofan and Darfur, where it adapts to both clayey and sandy soils (Abdelatif et al., 2022).
- **Humeid (*Sclerocarya birrea*)**, which occurs mainly within the high-rainfall woodland savannah regions of Darfur, Kordofan, and Blue Nile states and can grow in a variety of soil conditions excluding flood-prone areas (Abdelatif et al., 2022).

The geographical distribution of these timber species demonstrates the potential availability of local wood resources across multiple climatic regions in Sudan, supporting their use within climate-responsive and vernacular construction practices.

Suitability

Several indigenous timber species in Sudan demonstrate potential for architectural and construction applications due to their durability, adaptability, and availability across different ecological regions.

Studies indicate that Sahab (*Anogeissus leiocarpus*) possesses high density and structural strength, making it suitable for structural and roofing applications, while Humeid (*Sclerocarya birrea*) offers greater workability and adaptability for construction elements requiring easier processing. Other species such as Heglieg (*Balanites aegyptiaca*), *Khaya senegalensis*, and *Eucalyptus camaldulensis* contribute to a diverse local timber resource base suitable for shading structures, roof systems, and lightweight construction. The varying characteristics of these species demonstrate the potential of locally available wood resources to support climate-responsive and sustainable building practices in Sudan. (Younis & Yasin, 2025)

Application and uses

In Sudanese vernacular construction, timber is utilized in both raw and processed forms depending on the architectural application and availability of resources. Round timber poles are commonly employed as structural supports and lightweight framing elements, while sawn timber sections are adapted into beams, rafters, roof supports, and shading structures. Timber components are frequently integrated with earthen construction systems and lightweight roofing materials such as reeds, thatch, or corrugated metal sheets to create climatically responsive roof assemblies suitable for hot environments. The simplicity of timber processing and its local availability in several regions of Sudan contribute to its continued relevance within vernacular and contemporary construction practices. (Adam & Agib, 2002).

Timber Species	Availability	Application and use	Suitability
Sahab (<i>Anogeissus leiocarpus</i>)	Dry forests, savannah regions	Roof beams, structure	Durable
Humeid (<i>Sclerocarya birrea</i>)	Arid and semi-arid regions	Screens, light framing	Adaptable
Heglieg (<i>Balanites aegyptiaca</i>)	Savannah regions	Outdoor elements	Weather resistant

Table 1, Common Timber Species and Construction Uses in Sudan

3.5.3. plant-based materials

Layered roof systems represent an important climate-responsive strategy in vernacular architecture across Sudan and other hot climatic regions. These roof assemblies commonly combine timber structural elements with lightweight plant-based materials such as reeds, thatch, straw, or hay to improve thermal performance and indoor comfort. Plant-based layers are typically placed between roof components or beneath outer roof coverings to reduce heat transfer, enhance ventilation, and provide additional insulation against intense solar radiation.

In some traditional systems, these materials are also integrated with earthen layers to improve cohesion and reduce cracking. Although earth is primarily used for wall construction, it can also be incorporated within roof assemblies, where its thermal insulation properties become particularly advantageous in hot-dry climates (Adam & Agib, 2001). Through the combination of timber, earth, and plant-based materials, layered vernacular roof systems demonstrate how locally available resources can be utilized to enhance passive cooling and environmental performance within traditional Sudanese architecture.

3.6. Preliminary Environmental Assessment

The proposed residential unit has been subjected to a preliminary environmental assessment to evaluate the effectiveness of its passive design strategies within the climatic conditions of the three representative Sudanese cities: Khartoum, Port Sudan, and Ad-Damazin. The assessment aims to examine the climatic suitability of the design and identify the relative importance of the implemented passive strategies in each context.

Courtyard Shading Analysis

The courtyard represents one of the principal passive environmental strategies incorporated within the residential unit. To evaluate its contribution to thermal comfort, a comparative shadow analysis was conducted for the hottest month of each representative city: June for Khartoum, July for Port Sudan, and April for Ad-Damazin. These periods correspond to the most thermally demanding conditions identified through the climatic analysis.

For each city, the courtyard was assessed at three representative times of the day (10:00, 13:00, and 16:00) in order to examine the evolution of shading patterns and solar exposure. The analysis investigates the ability of the courtyard geometry to generate self-shading, protect building façades from direct solar radiation, and create more comfortable outdoor spaces throughout the day. By comparing the shadow distribution under the critical climatic conditions of each city, the assessment provides insight into the effectiveness of the courtyard as a passive cooling strategy across different Sudanese climatic regions.

Comparative Evaluation of Passive Design Strategies

While the courtyard shadow analysis evaluates a specific passive strategy, the overall environmental performance of the residential unit depends on the interaction of multiple climate-responsive design measures. Therefore, a comparative evaluation matrix was developed to assess the relative importance of the passive strategies incorporated within the design for each representative city.

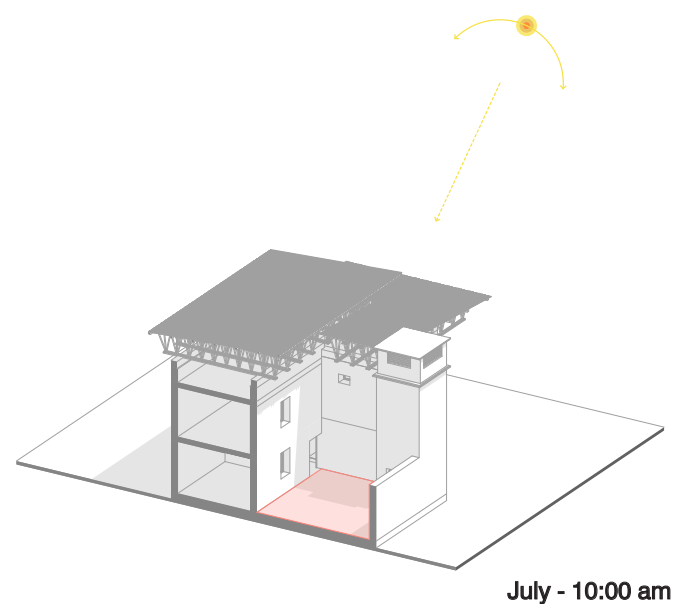
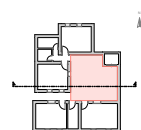
The matrix considers the climatic characteristics identified in the previous chapter, including temperature profiles, relative humidity levels, diurnal temperature variation, prevailing wind patterns, and rainfall distribution. Based on these parameters, each strategy is evaluated according to its expected contribution to environmental comfort within the respective climatic context.

Rather than determining whether a strategy is suitable or unsuitable, the matrix highlights the degree of influence of each strategy in supporting thermal comfort and environmental performance. This approach enables a comparative understanding of how the same architectural design responds to different climatic conditions and assists in identifying the context in which the proposed design is most climatically compatible. The results also demonstrate how the priority of passive strategies shifts between the hot-arid conditions of Khartoum, the hot-humid coastal environment of Port Sudan, and the seasonally humid climate of Ad-Damazin, while maintaining a consistent architectural concept.

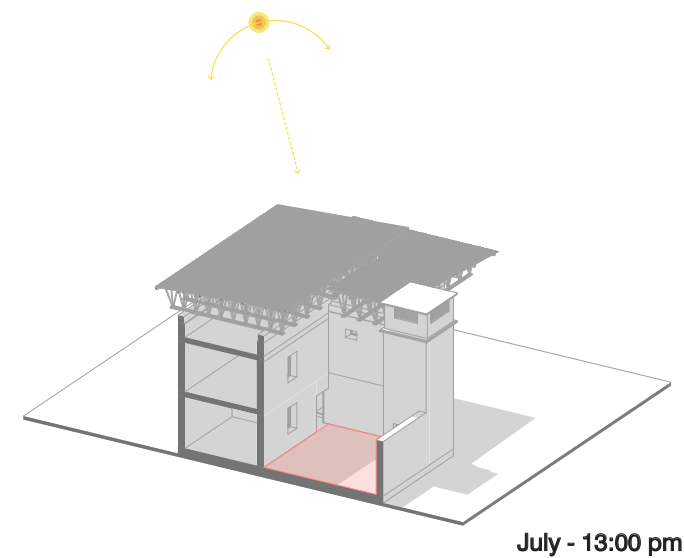
3.6.1. Courtyard Shading Analysis

3.6.1.1. Port Sudan

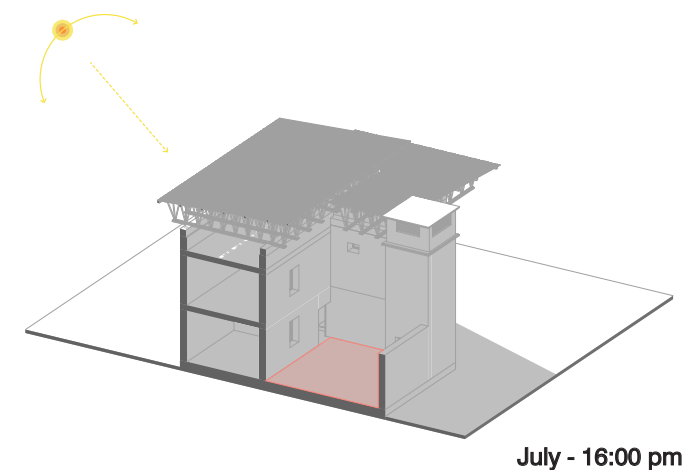
- At mid-morning, shadows are concentrated along the western side of the courtyard and adjacent façades.
- Significant portions of the courtyard remain shaded, limiting direct solar exposure during the morning hours.
- The courtyard provides a balance between shading and daylight access to the surrounding spaces.



- Solar exposure reaches its maximum extent as the sun approaches its highest position.
- Despite the sun reaching its highest position, the courtyard retains substantial shaded areas generated by the surrounding building volumes and roof overhangs.
- The persistence of shaded zones during peak solar exposure demonstrates the effectiveness of the courtyard geometry in limiting direct solar gains within the courtyard.

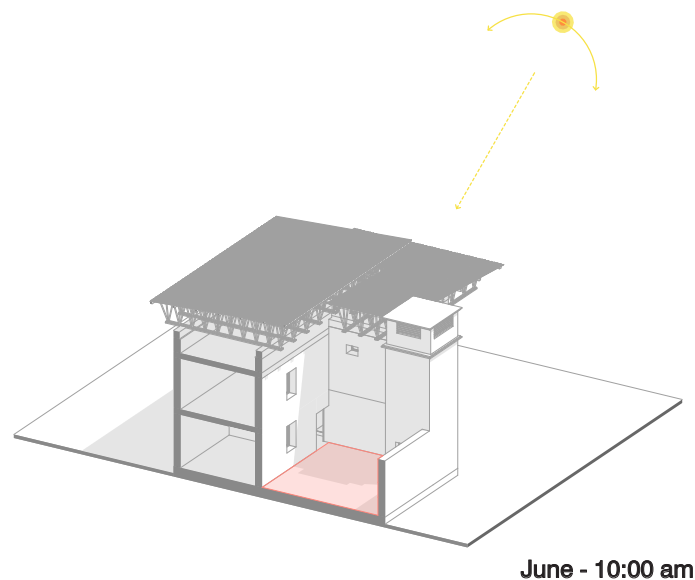
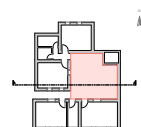


- Shadows progressively extend across the courtyard as the sun moves westward.
- The increase in shaded areas further reduces direct solar exposure within the courtyard.
- The late afternoon period exhibits the highest degree of courtyard shading, demonstrating the effectiveness of the courtyard configuration in protecting outdoor spaces from prolonged solar exposure.

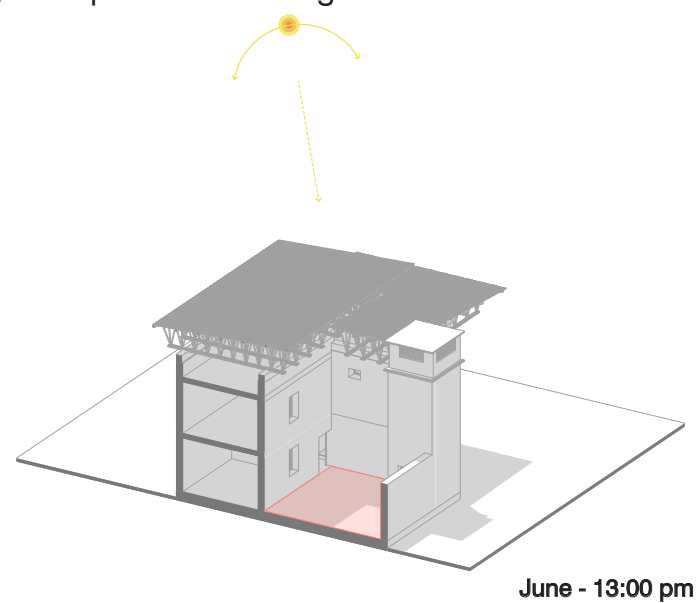


3.6.1.2. Khartoum

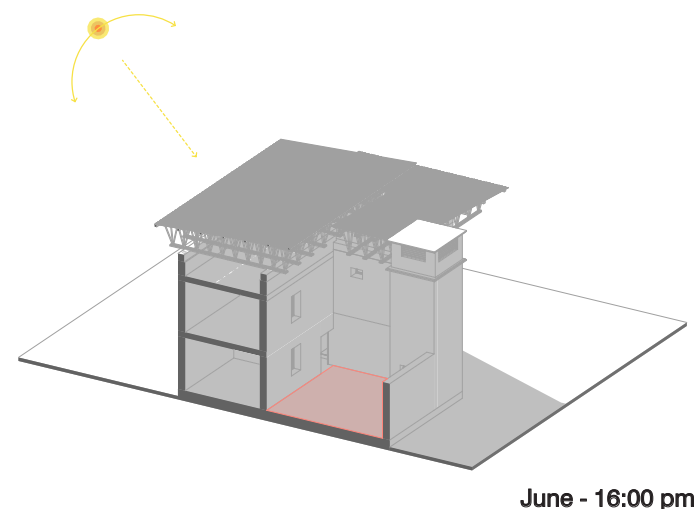
- Shading is concentrated along the western and southern edges of the courtyard.
- The courtyard geometry limits direct solar penetration into surrounding spaces during the morning period.
- Early shading contributes to reducing heat accumulation within the residential unit.



- Solar exposure reaches its peak during the midday period.
- The courtyard nevertheless remains largely shaded due to the combined effect of the surrounding building masses and roof overhangs.
- This demonstrates the effectiveness of the courtyard geometry in providing solar protection during the most critical hours of the day.

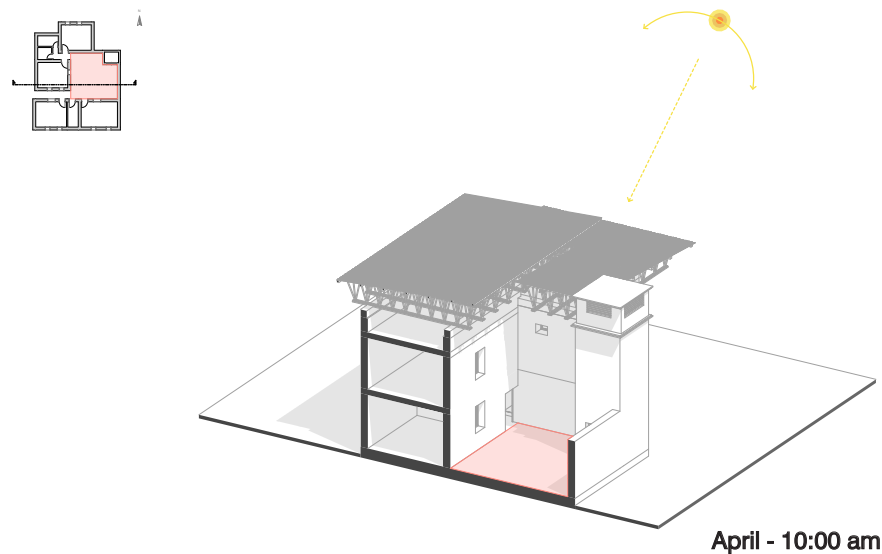


- The courtyard gradually becomes more shaded as shadows extend across the open space during the afternoon.
- While the western façades become increasingly exposed to low-angle solar radiation, the compact arrangement of the residential units may contribute additional mutual shading and reduce direct exposure.
- The larger day–night temperature variation in Khartoum enhances the effectiveness of thermal mass and night ventilation strategies, allowing accumulated heat to be dissipated during the cooler evening period.

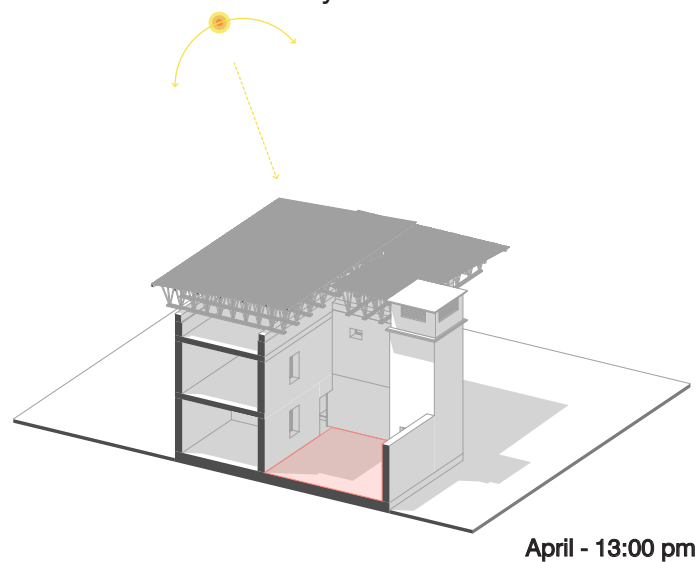


3.6.1.3. Ad- Damazin

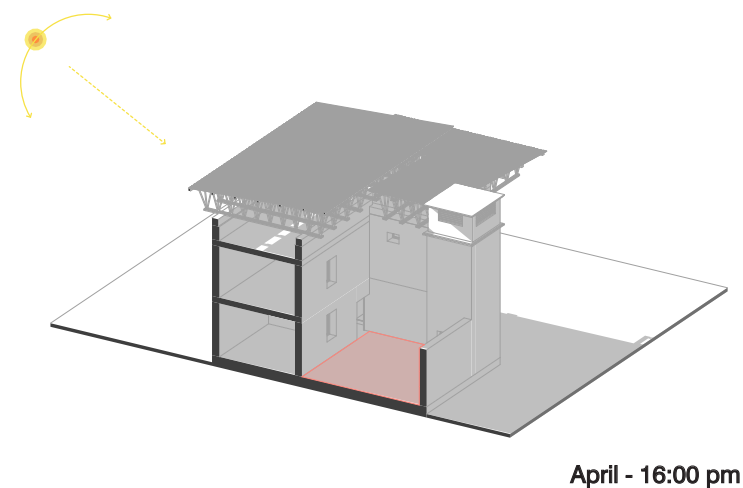
- Morning shadows cover portions of the courtyard and adjacent façades, providing protection from direct solar radiation.
- The courtyard maintains a balance between daylight access and shading, supporting comfortable outdoor use during the early hours.



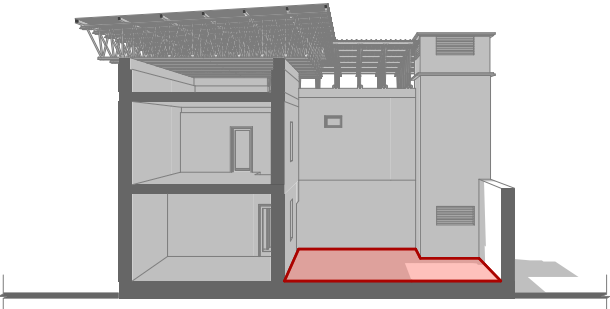
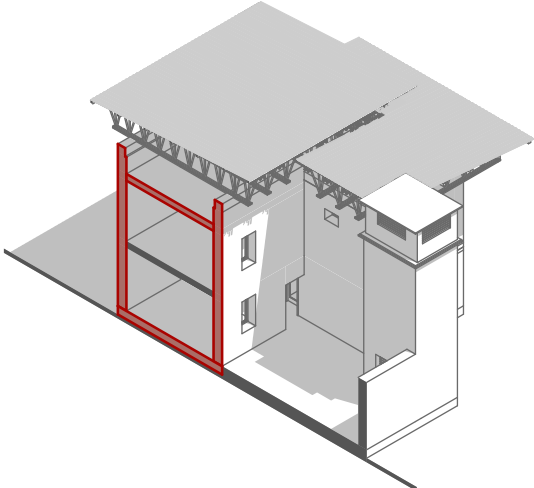
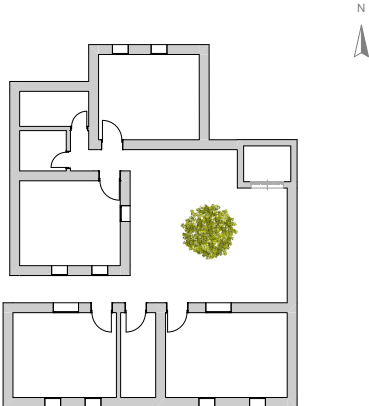
- Solar exposure reaches its highest intensity as the sun approaches its maximum altitude.
- Despite the midday conditions, a significant portion of the courtyard remains shaded by the surrounding building volumes and roof overhangs.
- The persistence of shaded areas across both the courtyard perimeter and a substantial part of the courtyard floor demonstrates the effectiveness of the courtyard configuration in limiting direct solar exposure during the most critical hours of the day.



- Shadow coverage increases considerably as the sun lowers in the sky.
- The courtyard returns to a predominantly shaded condition, improving outdoor comfort and reducing façade heat gain.
- The shaded environment supports passive cooling and provides protected outdoor space during the late afternoon.



3.6.2. Table 2: Comparative Evaluation of Passive Design Strategies

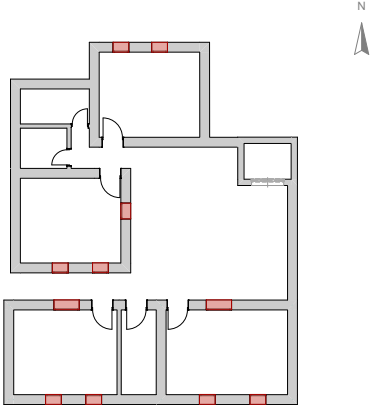
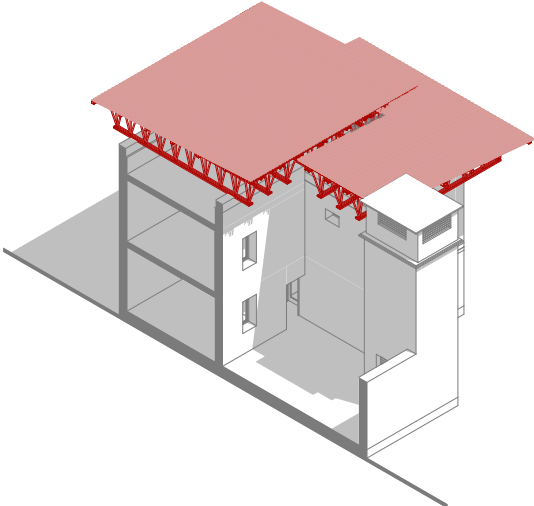
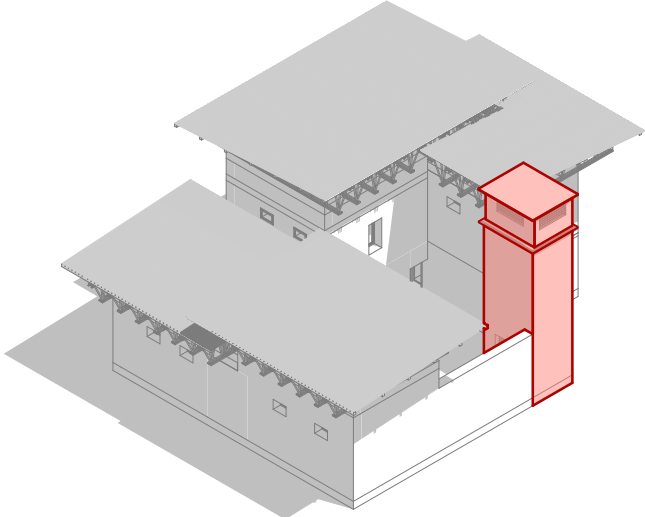
Strategy	Port Sudan	Khartoum	Ad-Damazin
 Courtyard Shading	Effectiveness of Strategy ○ ○ Key Observation - The courtyard generates shaded outdoor areas through the surrounding building volumes and roof overhangs, reducing direct solar exposure. - The open courtyard configuration allows air movement to complement shading under hot and humid conditions. Design Implication - Increasing roof overhangs or introducing lightweight shading elements could further improve comfort during periods of high humidity.	Effectiveness of Strategy ○ ○ ○ Key Observation - Reduces solar heat gain during prolonged hot and dry periods. - Creates a cooler shaded microclimate within the residential unit.	Effectiveness of Strategy ○ ○ ○ Key Observation - Limits solar gain during hot months and improves outdoor comfort. - Supports shaded activity areas during periods of high humidity.
 High Thermal Mass/ Night Ventilation	Effectiveness of Strategy ○ Key Observation The smaller day–night temperature variation in Port Sudan reduces the effectiveness of thermal mass, as outdoor temperatures remain relatively high during the evening period. - High humidity levels increase the importance of air movement and ventilation-based cooling strategies. Design Implication - Reducing reliance on wall mass and strengthening ventilation strategies, such as larger openings. Night ventilation is therefore important to support heat dissipation.	Effectiveness of Strategy ○ ○ ○ Key Observation - Large day–night temperature variations increase the effectiveness of thermal mass by allowing heat stored within the CSEB walls during the day to be released when outdoor temperatures decrease. - The effectiveness of this process is enhanced by night ventilation through the courtyard and controlled openings, which facilitate the removal of accumulated heat and promote cooling of the wall surfaces during the evening and nighttime periods.	Effectiveness of Strategy ○ ○ Key Observation - Moderate day–night temperature variations allow thermal mass to contribute to reducing indoor temperature fluctuations, although its effectiveness is lower than in Khartoum and higher than in Port Sudan. - The CSEB walls delay heat transfer through the building envelope, improving indoor thermal stability during hot periods. Design Implication - Combining thermal mass with adequate ventilation and protective measures such as roof overhangs, raised plinths, and effective drainage can improve performance during warmer and more humid periods.
 Vegetation	Effectiveness of Strategy ○ ○ Key Observation - Vegetation provides localized shading within the courtyard and can improve the quality of outdoor activity spaces. - The courtyard layout creates the opportunity for airflow to pass through planted areas before entering adjacent spaces, improving the quality of incoming air. Design Implication - Increasing vegetation density or incorporating larger canopy trees could enhance shading and improve outdoor comfort.	Effectiveness of Strategy ○ ○ Key Observation - Vegetation provides localized shading and can contribute to evaporative cooling when air passes through the courtyard before entering adjacent spaces. In Khartoum, the effectiveness of vegetation is constrained by water availability despite its potential contribution to outdoor comfort, as it contributes to localized evaporative cooling and increased humidity levels within the courtyard, improving thermal comfort. Design Implication - Concentrating vegetation around seating areas and airflow paths could maximize shading and evaporative cooling benefits while minimizing water demand.	Effectiveness of Strategy ○ ○ ○ Key Observation - Higher rainfall levels support denser vegetation within the courtyard environment. - Vegetation enhances shading and evaporative cooling, contributing to improved outdoor comfort and microclimatic regulation.

Low ○

Medium ○ ○

High ○ ○ ○

3.6.2. Table 3: Comparative Evaluation of Passive Design Strategies

Strategy	Port Sudan	Khartoum	Ad-Damazin
 Cross Ventilation	Effectiveness of Strategy ○ ○ ○ Key Observation - The arrangement of openings around the courtyard and on opposing façades promotes cross ventilation through the residential unit. - The courtyard and wind catcher help capture and distribute prevailing coastal breezes, enhancing indoor air movement under hot and humid conditions.	Effectiveness of Strategy ○ ○ ○ Key Observation - Cross ventilation is facilitated through the courtyard layout, opposite openings, and the wind catcher, allowing air movement across interior spaces. - Ventilation becomes most effective during the evening and nighttime periods, when outdoor temperatures decrease below indoor temperatures, allowing accumulated heat to be removed from the building envelope.	Effectiveness of Strategy ○ ○ ○ Key Observation - The courtyard-centered layout and opposing openings support airflow which is beneficial when outdoor temperatures are lower than indoor temperatures - Cross ventilation improves indoor comfort during humid periods by promoting air circulation and facilitating moisture removal from interior spaces.
 Double Roof System	Effectiveness of Strategy ○ ○ ○ Key Observation - The ventilated cavity between the metal roof and the ceiling reduces heat transfer to indoor spaces by allowing accumulated hot air to dissipate before reaching the occupied areas. - The strategy is particularly effective in limiting solar heat gains through the roof, which represents one of the most exposed building elements.	Effectiveness of Strategy ○ ○ ○ Key Observation - The double roof reduces daytime heat gains by limiting heat transfer through the roof assembly and preventing excessive heat accumulation within indoor spaces. - In Khartoum, the strategy works in conjunction with the thermal mass of the CSEB walls, reducing daytime heat storage and improving the effectiveness of nighttime cooling.	Effectiveness of Strategy ○ ○ ○ Key Observation - The double roof provides solar protection while reducing heat transfer into indoor spaces. - The proposed roof configuration, including its ventilated cavity, roof slope, and overhangs, is well suited to the seasonal rainfall conditions of Ad-Damazin, providing both thermal protection and effective rainwater management.
 Wind Catcher	Effectiveness of Strategy ○ ○ Key Observation - The wind catcher can contribute to indoor air movement by directing prevailing winds into the residential unit. - However, in Port Sudan, cross ventilation through openings and the courtyard is likely to remain the primary ventilation strategy due to the availability of coastal breezes and the humid climatic conditions. Design Implication - The effectiveness of the wind catcher depends on its orientation and number of faces. Multi-directional configurations can improve the ability to capture prevailing winds throughout the year, although this must be balanced against construction complexity and cost.	Effectiveness of Strategy ○ ○ ○ Key Observation - The wind catcher captures higher-level prevailing winds and directs airflow toward the courtyard and indoor spaces, improving natural ventilation during hot periods. - In Khartoum's hot-arid climate, the tower can also reduce the influence of dust-laden air near ground level and enhance the effectiveness of passive cooling strategies within the courtyard.	Effectiveness of Strategy ○ ○ Key Observation - The wind catcher contributes to natural ventilation by directing airflow into interior spaces during warmer periods. - While still beneficial, its relative importance is reduced because thermal comfort in Ad-Damazin is influenced not only by temperature but also by seasonal humidity and rainfall conditions. Design Implication - In Ad-Damazin, the wind catcher functions as a complementary ventilation strategy, while cross ventilation, vegetation, and rain-responsive design measures play a greater role in achieving thermal comfort.

3.7. Conclusion

The comparative evaluation demonstrates that the proposed passive design strategies can be successfully implemented across the three representative Sudanese climates, although their relative effectiveness varies according to local environmental conditions. The analysis indicates that courtyard shading, cross ventilation, and the double roof system perform consistently well across all cases, while strategies such as thermal mass, vegetation, and wind catchers show different levels of effectiveness depending on temperature fluctuations, humidity levels, prevailing winds, and rainfall patterns.

The results suggest that the proposed architectural concept is sufficiently adaptable to respond to multiple climatic contexts within Sudan. Rather than requiring a complete redesign for each location, the design can be refined through adjustments to specific passive design elements. In Khartoum, greater emphasis may be placed on thermal mass, night ventilation, and wind catchers to respond to large day–night temperature variations. In Port Sudan, larger openings, enhanced night ventilation, and increased air movement become more important in addressing hot-humid conditions. In Ad-Damazin, the design benefits from greater integration of vegetation, shaded outdoor areas, roof overhangs, and rain-responsive features that address seasonal humidity and rainfall. These adaptations allow the same architectural concept to respond to different climatic conditions while maintaining its spatial organization and design principles.

Although the matrix evaluates each passive strategy separately for clarity, the overall performance of the design depends on the interaction between these strategies. Courtyard shading, thermal mass, night ventilation, wind catchers, roof overhangs, and vegetation are intended to operate as an integrated passive system. Therefore, the matrix should be understood as an analytical tool that identifies the relative importance of each strategy within different climatic contexts rather than as an isolated assessment of independent elements.

Overall, the analysis confirms that the proposed design approach can be adapted to different regions of Sudan through targeted modifications to passive design elements, including the degree of thermal mass, ventilation strategies, shading devices, vegetation, and rain-responsive roof configurations, while maintaining the same architectural concept and spatial organization.

CHAPTER 4.

ARCHITECTURE OF HEALING: DESIGN PROPOSAL



4.1. Introduction

The design proposal presented in this chapter is the outcome of the climatic, cultural, and architectural investigations discussed in the previous chapters. The comparative climate analysis identified passive design strategies suitable for different climatic regions of Sudan, while the study of vernacular architecture highlighted the environmental and social significance of courtyard-based layouts, local construction techniques, and climate-responsive design principles. Based on these findings, Khartoum was selected as the reference context for the design development, while the adopted passive strategies remain adaptable to other regions through the adjustments identified in the comparative evaluation.

The project is conceived as an integrated children's community that combines residential units with educational facilities, a nursery, an infirmary, staff areas, security services, and sports and recreational spaces. Bringing these functions together creates a self-contained environment that supports children's daily life, learning, healthcare, recreation, and wellbeing while ensuring continuous supervision and safety.

The overall masterplan is inspired by the spatial organization of the traditional Medina, where individual buildings are connected through a compact urban fabric and protected internal spaces. This concept is closely related to the Sudanese Hosh, in which the courtyard forms the centre of domestic life and provides a secure, shaded, and socially active environment. Accordingly, the residential units are organized around central courtyards that promote environmental comfort, social interaction, and natural surveillance while creating protected outdoor spaces for children's daily activities.

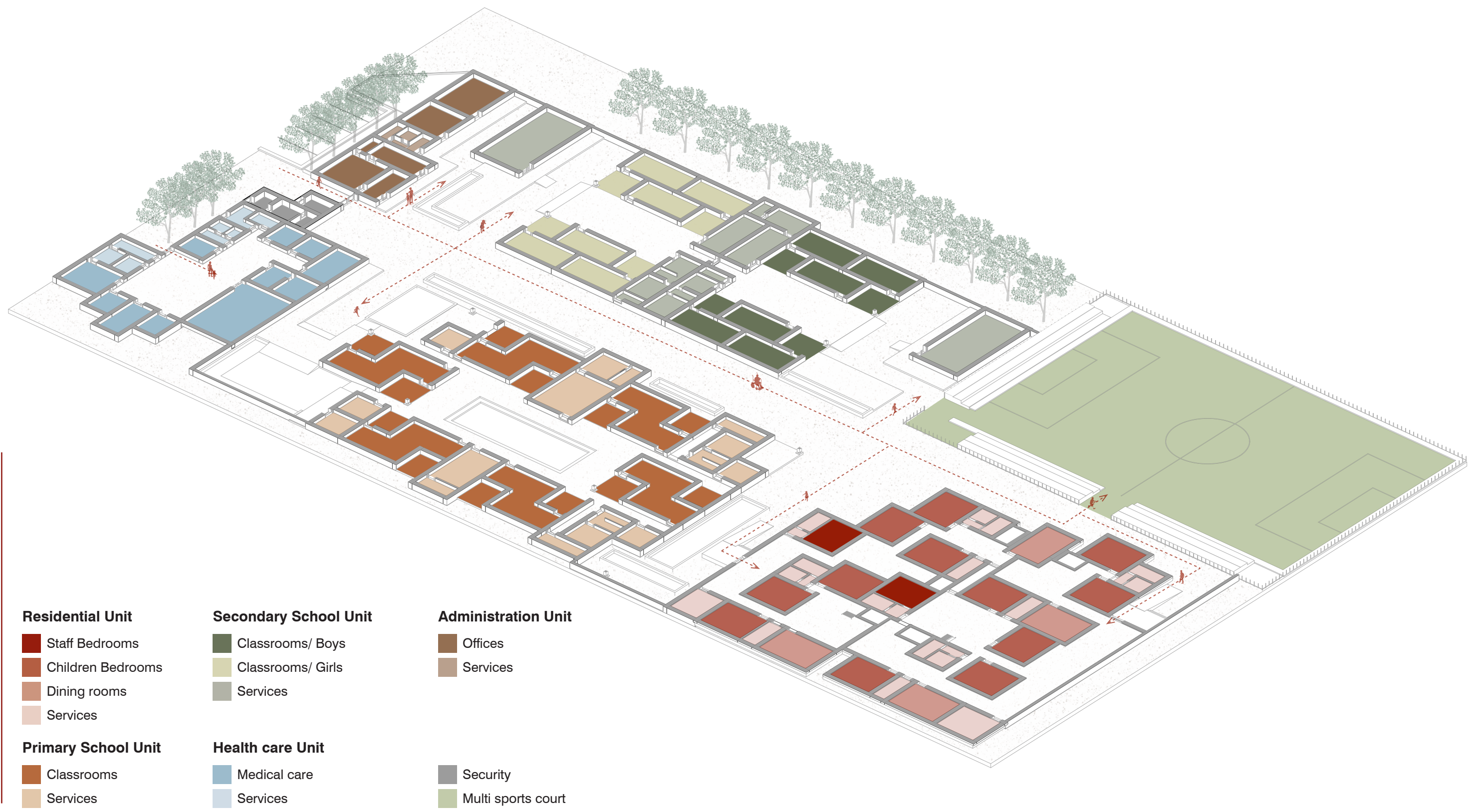
The courtyard-and-room arrangement is conceived as a modular unit that can be replicated according to different site conditions and accommodation capacities. Therefore, the proposed masterplan represents one possible configuration of these residential clusters together with the supporting community facilities. The same design principles can be adapted to create larger or smaller settlements while maintaining the environmental, cultural, and functional qualities established throughout the research.

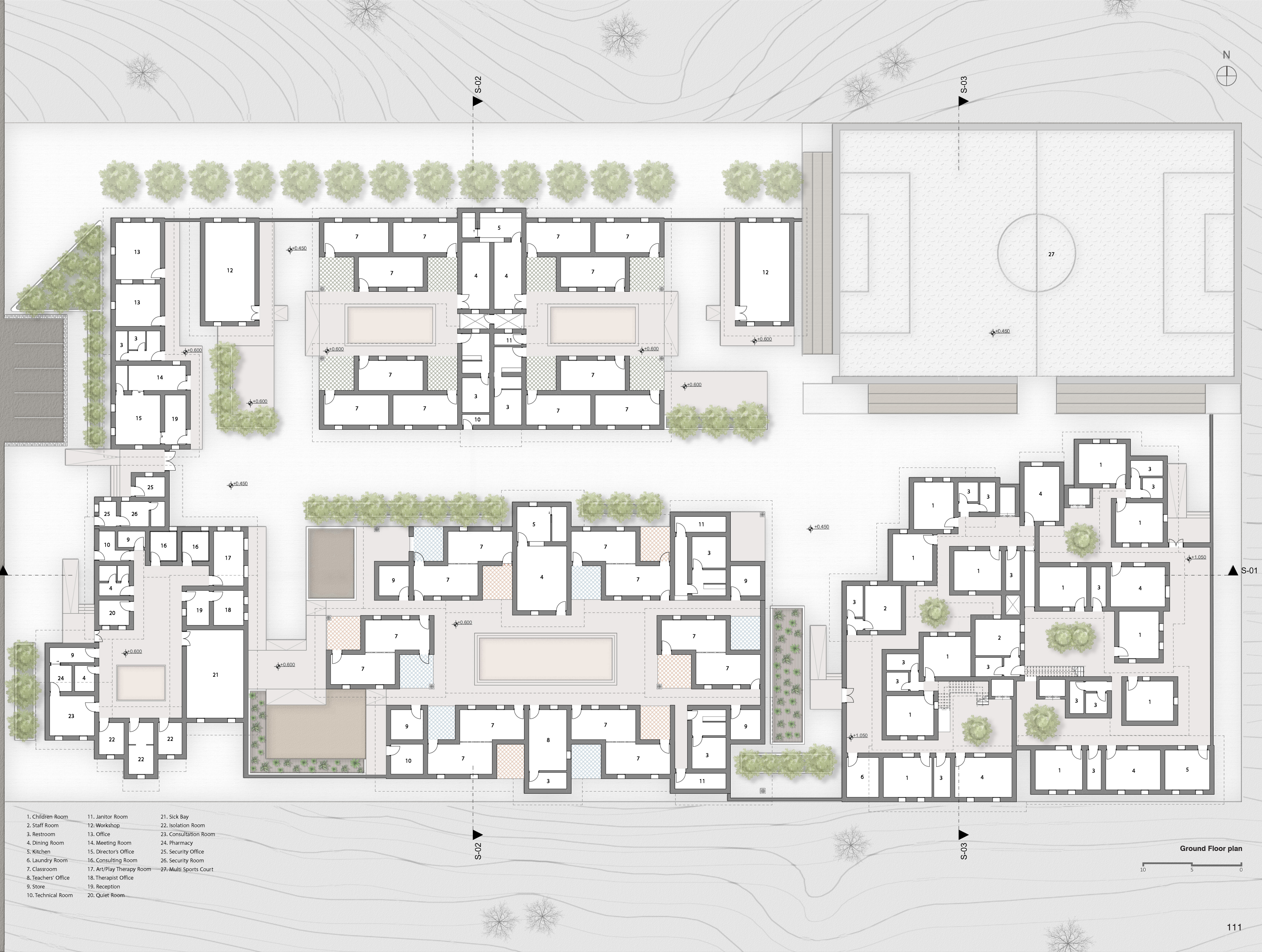
Functional Program and User Needs

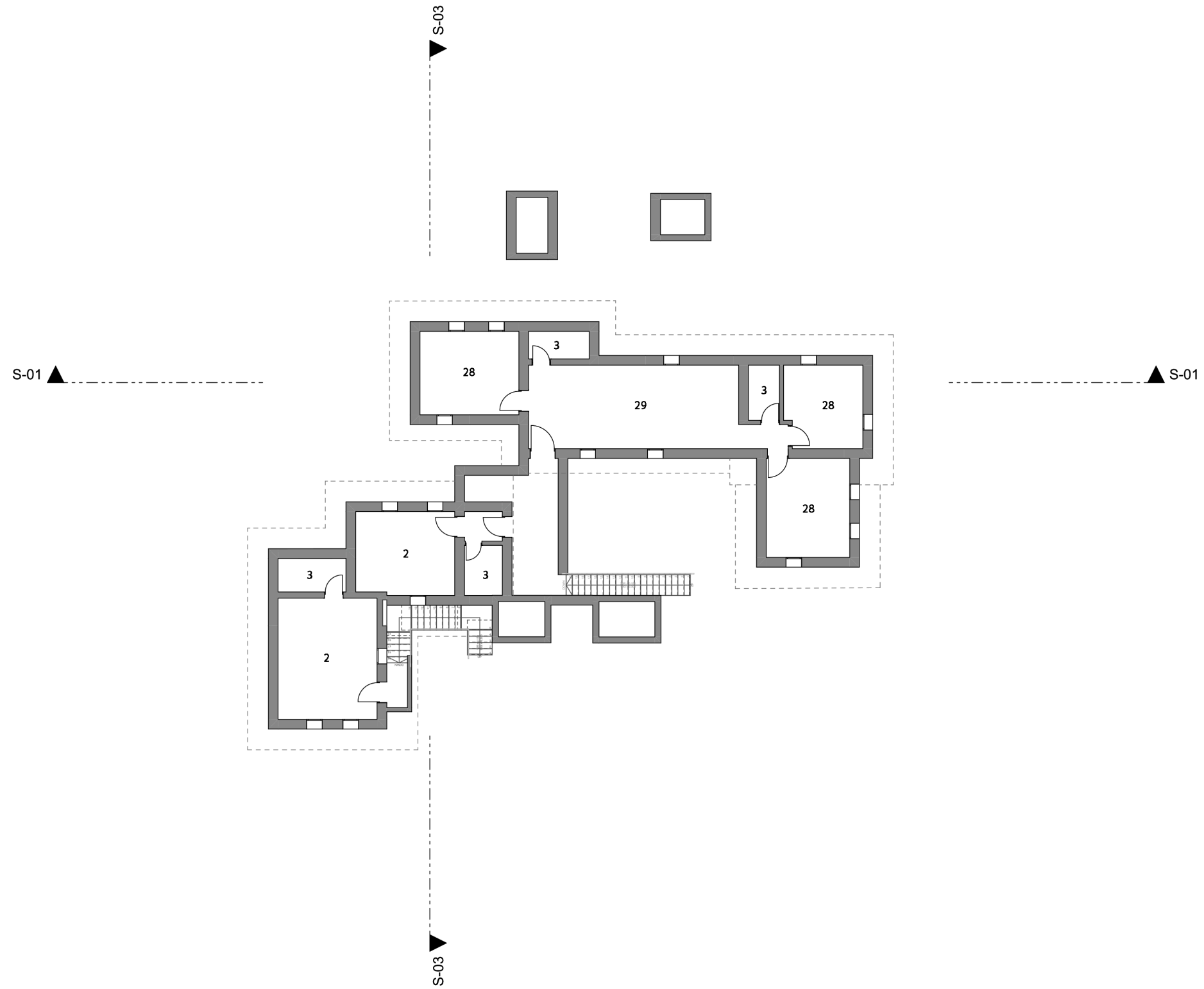
	Residential Capacity (Number of Children) 36 Child 4 Units 9 children/ unit	Key needs - Safety and security - Emotional comfort - Privacy and belonging	Design considerations - Family-like units with shared living spaces - Easy supervision - Connection to green and open courtyards
	Health care Capacity (Number of Children) 12 Child 2-4 inpatients	Key needs - Physical health - Mental well-being - Safety and care	Design considerations - Calm, welcoming environment - Privacy and confidentiality - Different care facilities
	Educational- Primary school Capacity (Number of Children) 36 Child (Grade 1- 6) 18 girls 18 boys (open for outside users)	Key needs - Learning and growth - Curiosity and creativity - Social interaction	Design considerations - Comfort environment - Flexible classrooms - Access to outdoor learning areas
	Educational- Secondary school Capacity (Number of Children) 36 Child (Grade 7- 9) 18 girls 18 boys (open for outside users)	Key needs - Personal development - Critical thinking - Social interaction	Design considerations - Spaces for collaboration - Flexible classrooms
	Recreational Capacity (Number of Children) Flexible use	Key needs - Physical activity - Play and well-being - Stress relief	Design considerations - Open and safe space - Variety of activities for all ages

4.2. Program

- The project combines six main zones: **the residential unit, primary school unit, secondary school unit, health care unit, administration and multi sports court.**
- The residential unit is divided into two separate zones for boys and girls, the same as in the secondary school. While the children in the primary school share the same courtyard but they have separate classrooms.
- The first floor of the residential unit contains staff bedrooms and the director's family house.







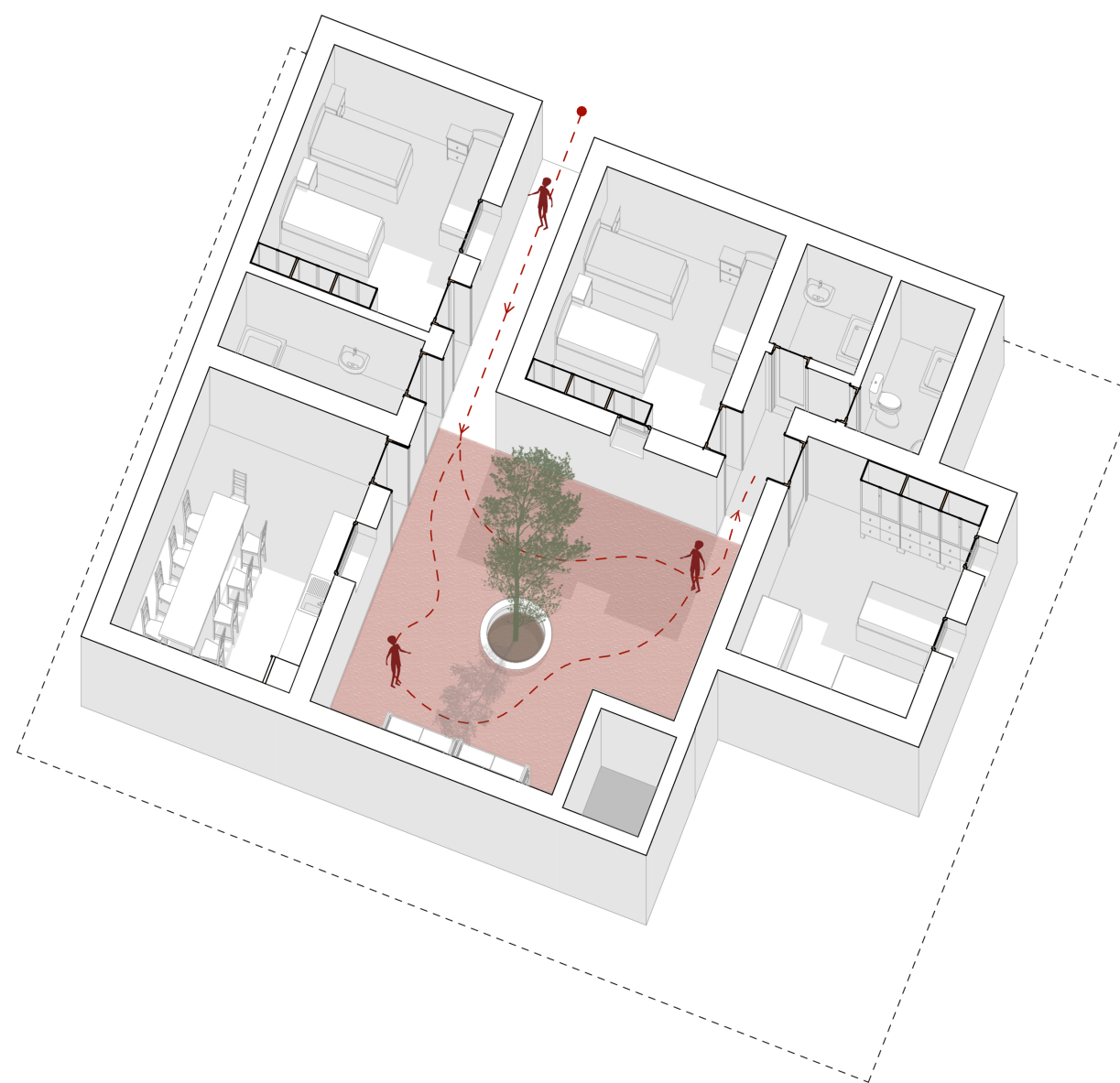
28. Bedroom
29. Living Area

First Floor Plan



Typical Residential Unit

The residential unit is organized around a central courtyard (hosh), a fundamental element of Sudanese domestic architecture that functions as the primary outdoor living space. The courtyard provides a safe environment where children can engage in daily activities such as playing, learning, socializing, and resting while benefiting from natural light, shading, and ventilation. By orienting all rooms toward the courtyard, the design strengthens visual connection and passive supervision, creating a sense of community and belonging. Furthermore, the residential unit is accessed through a single controlled entrance, which enhances security by regulating access and providing children with a protected and clearly defined living environment.



Typical residential unit

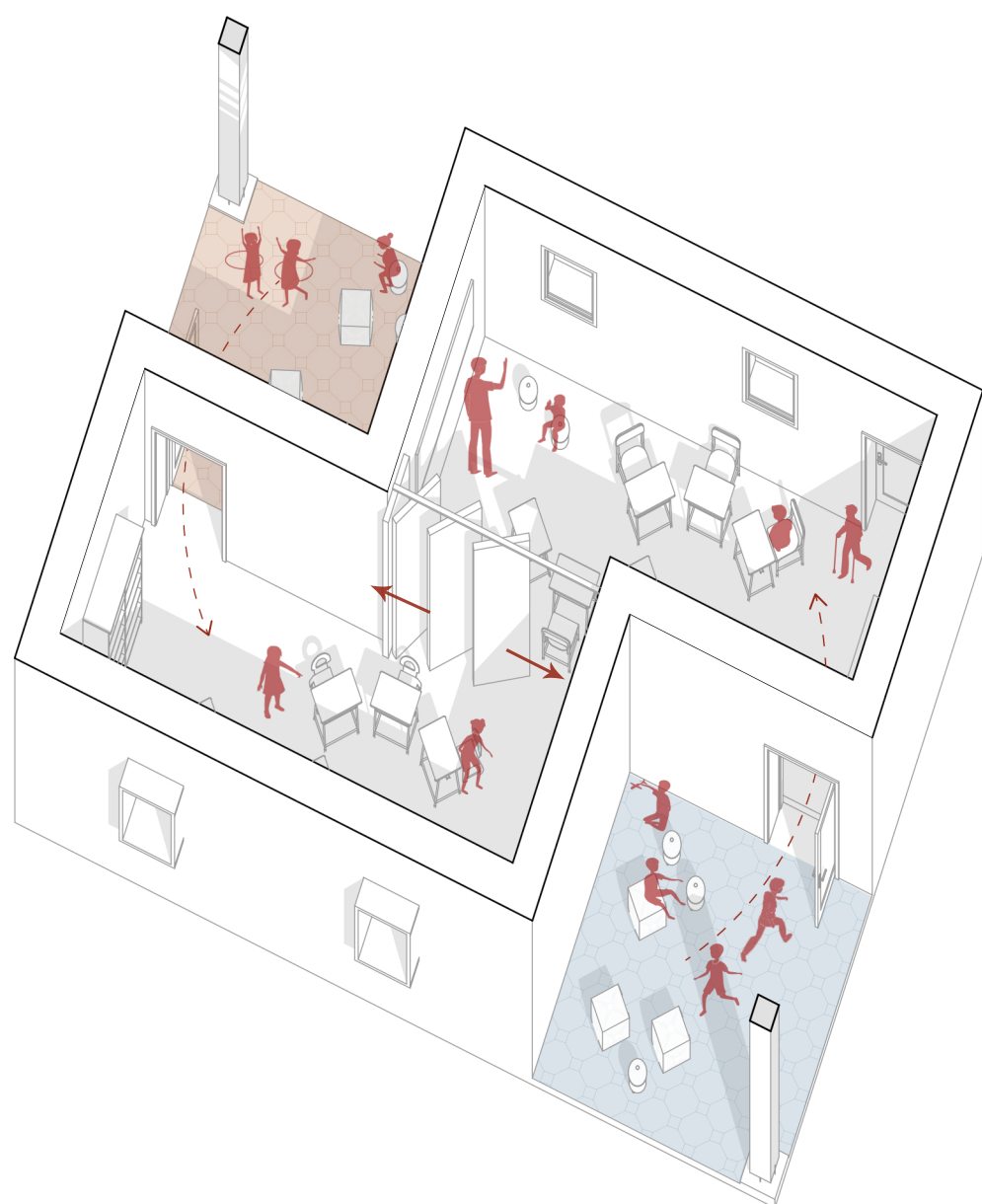
Residential Unit



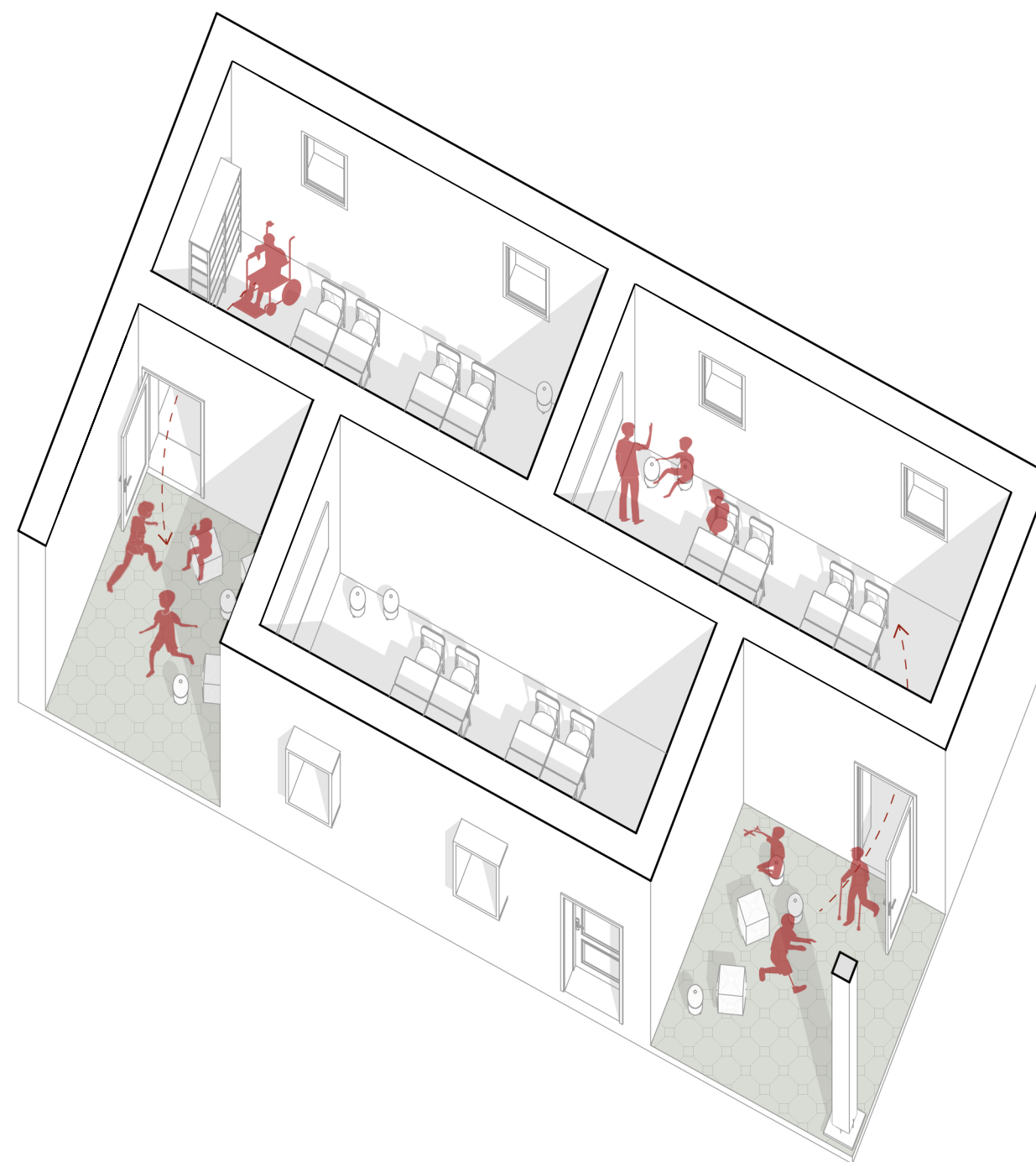
Typical Educational Units

The educational unit is designed to provide flexible and child-centered learning environments that extend beyond the classroom walls. Each classroom is connected to an extended outdoor learning space, allowing educational activities to take place in shaded open-air environments that encourage play-based learning, interaction with nature, and experiential education.

In addition, adjacent classrooms are separated by a movable partition, enabling them to function either as two independent teaching spaces or as a single larger room for group activities, workshops, or community events. This flexibility allows the educational unit to adapt to different class sizes and learning requirements while maximizing the efficient use of space.



Typical Primary classroom unit

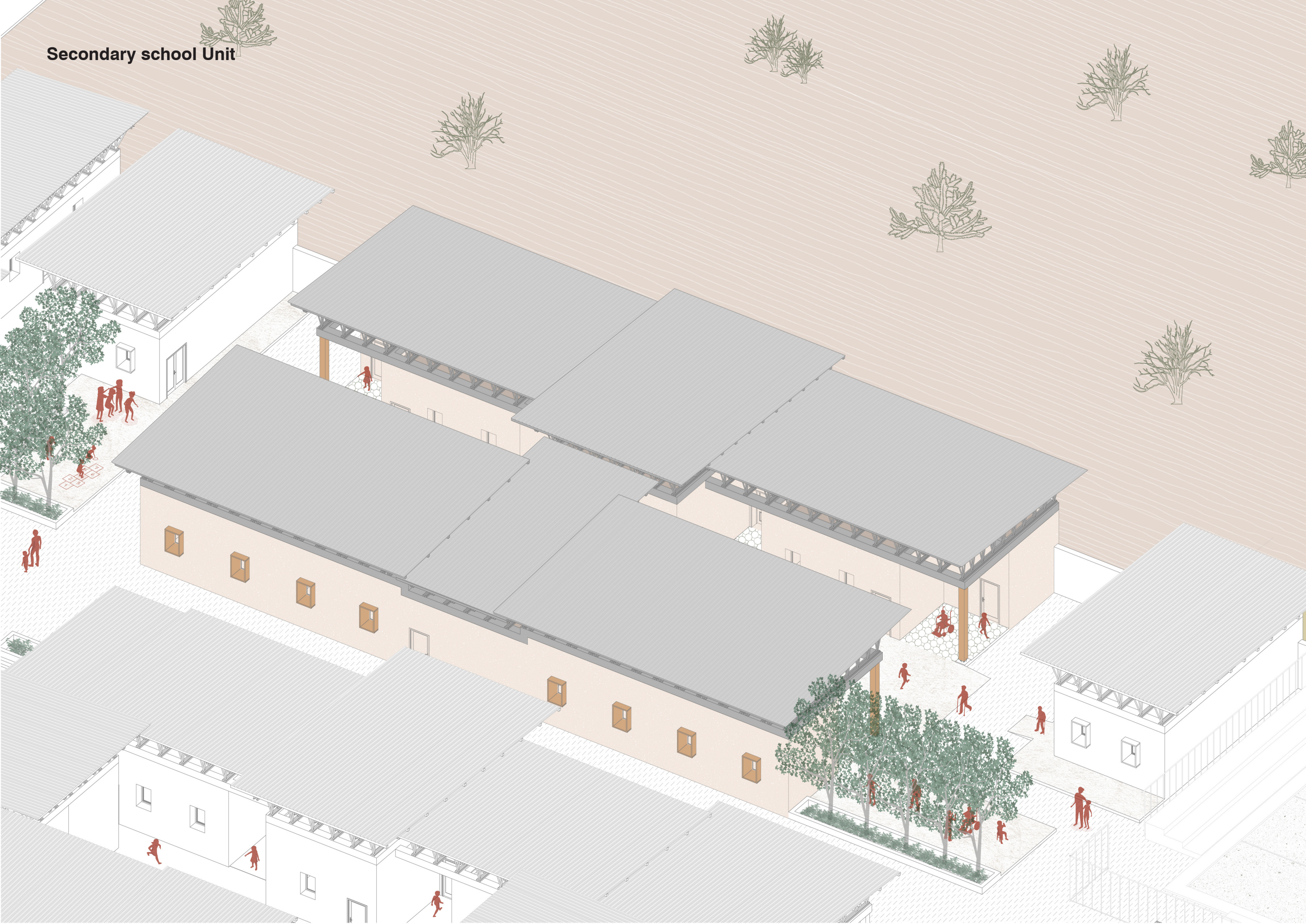


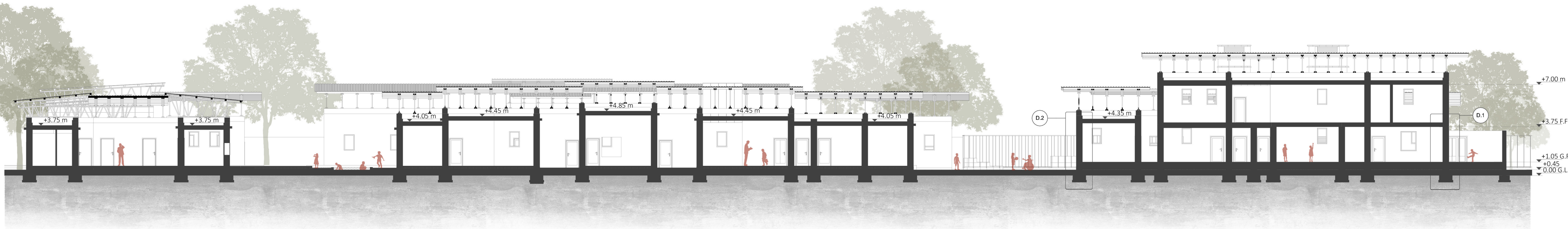
Typical secondary classroom unit

Primary school Unit

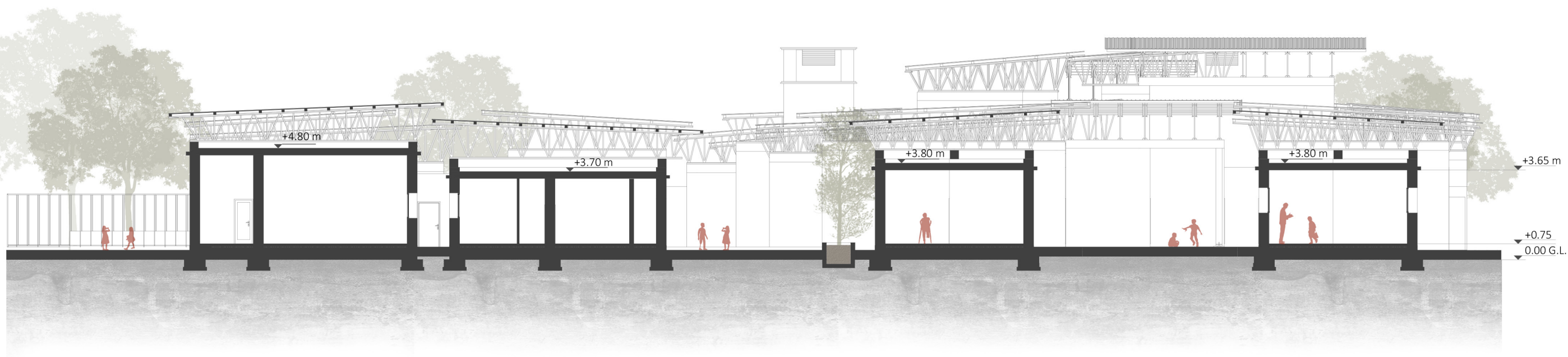


Secondary school Unit

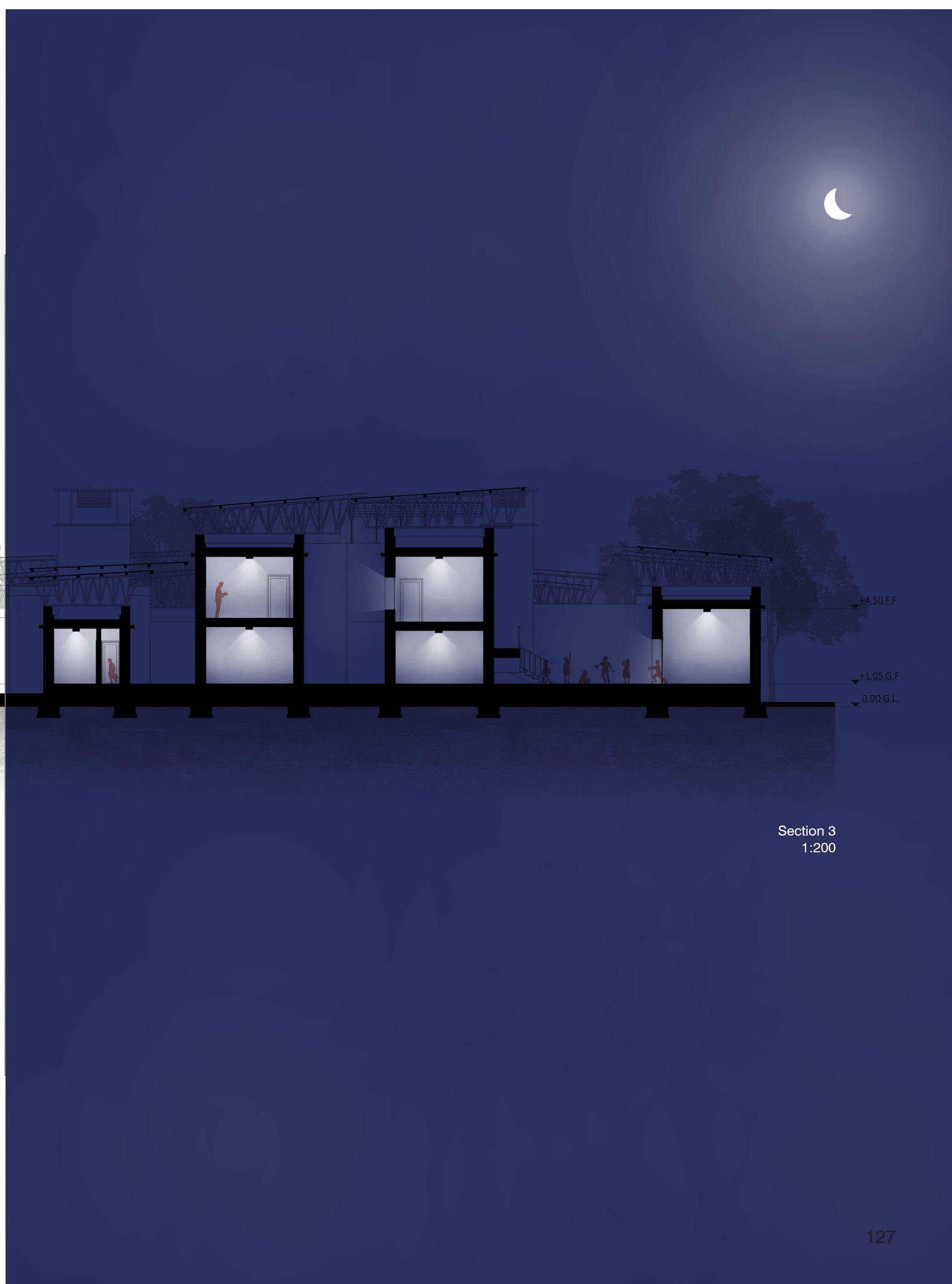
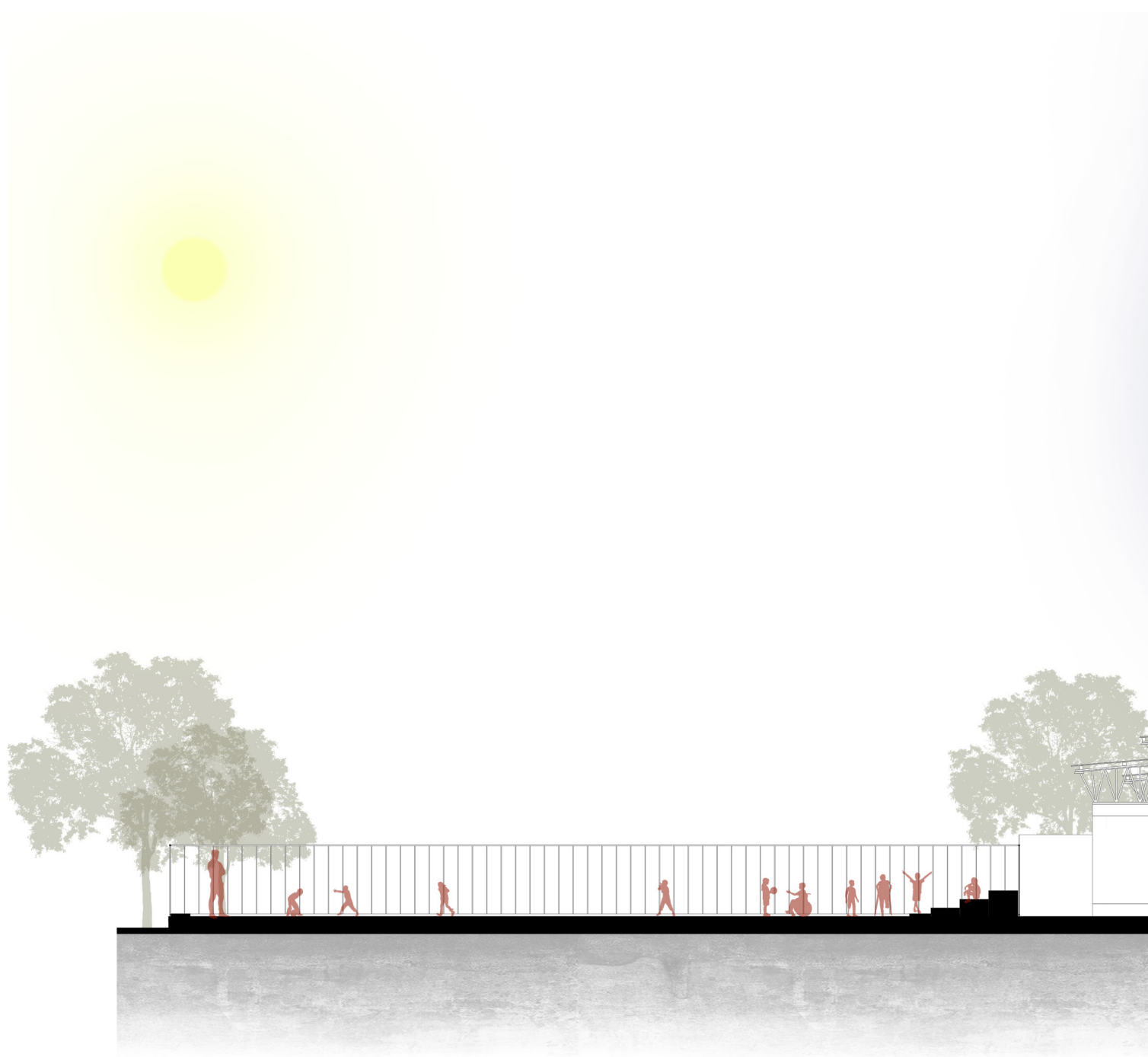




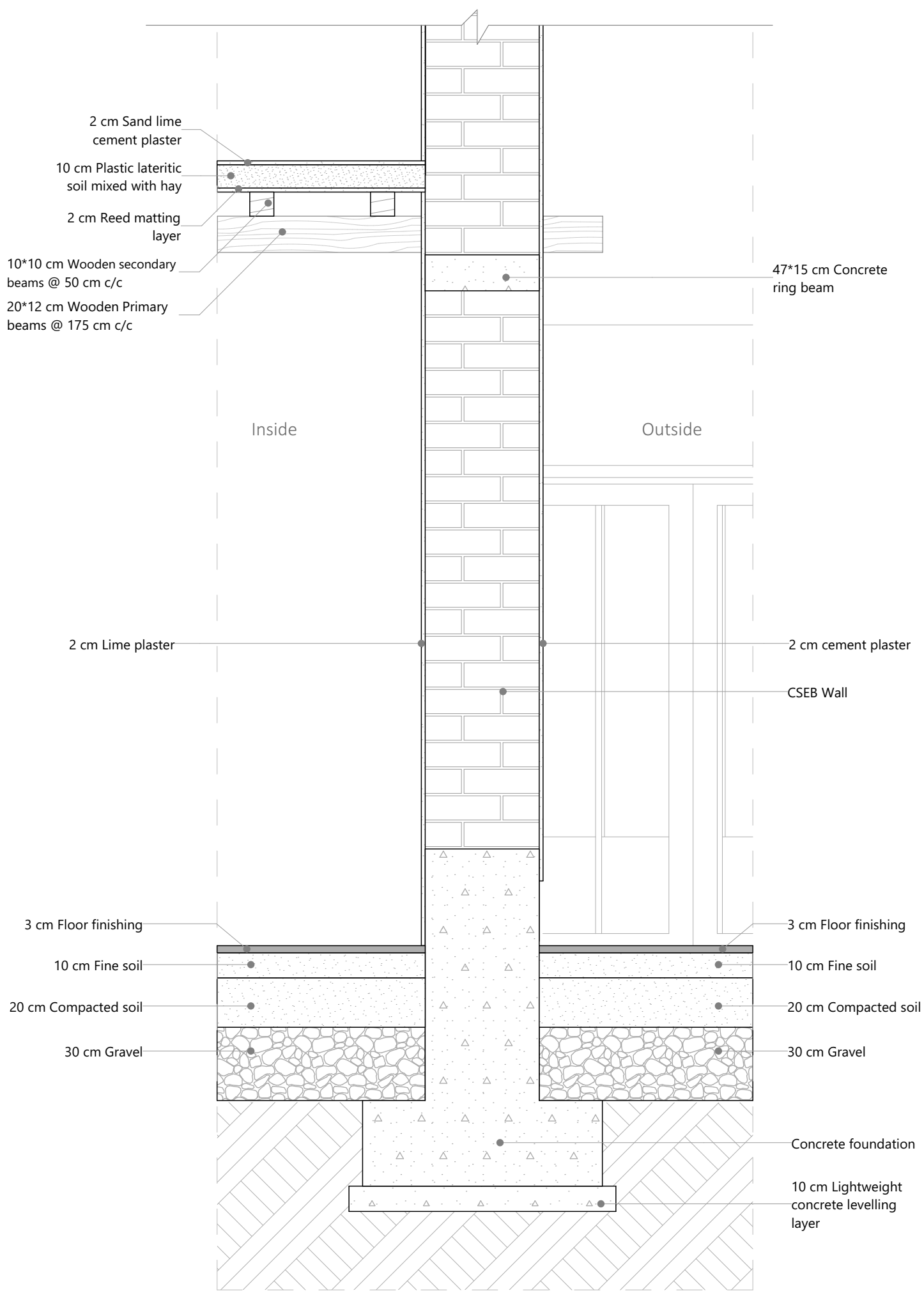
Section 1
1:200



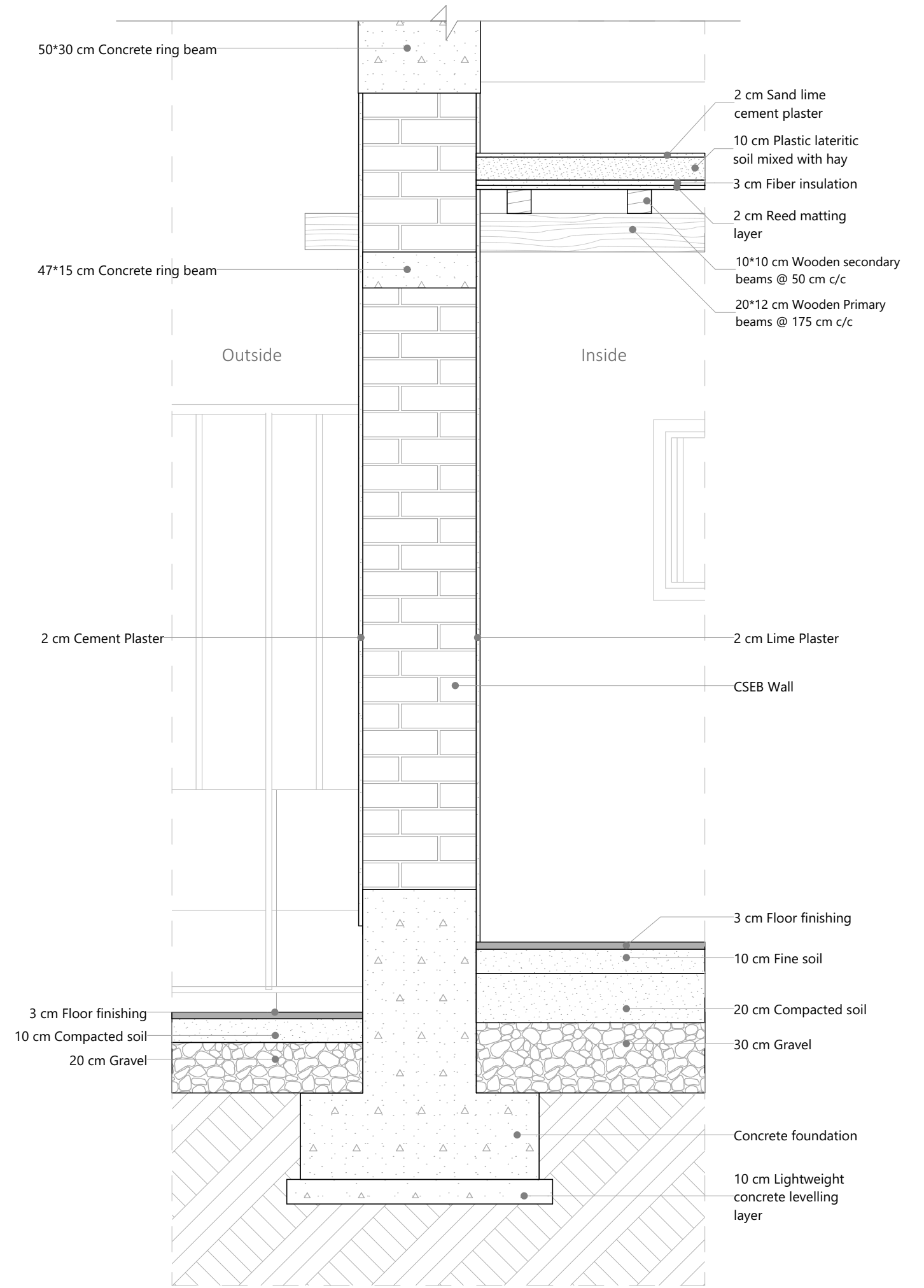
Section 2
1:200



Section 3
1:200



Detail 01
1:20



Detail 02
1:20









Conclusion

This thesis has explored the role of architecture in responding to the humanitarian challenges faced by children affected by the ongoing conflict in Sudan. Beginning with an examination of the social and psychological consequences of war, the research established the need for environments that provide not only shelter but also safety, stability, education, healthcare, and opportunities for social interaction as essential components of children's recovery and development.

Through the investigation of the spatial principles of the traditional medina and their relationship to the Sudanese cultural and social principles, the research demonstrated how vernacular urban and architectural knowledge can inform contemporary humanitarian design. The inward-oriented organization, hierarchical transitions between public and private spaces, and courtyard-centered layout provide a spatial framework capable of creating secure, familiar, and community-oriented environments while responding to the climatic and cultural context.

The comparative climatic analysis was undertaken not only to evaluate environmental performance, but also to demonstrate the adaptability of the proposed humanitarian model across Sudan. Given the widespread displacement caused by the conflict, future interventions may be required in different climatic regions throughout the country. Consequently, the research explored how the proposed design can respond to these varying environmental conditions through targeted modifications to passive design strategies rather than through a complete redesign. The findings indicate that while the architectural concept remains consistent, the relative emphasis placed on shading, natural ventilation, thermal mass, vegetation, and other passive measures can be adjusted or enhanced according to local climatic conditions, enabling the project to achieve climate-responsive performance in different regions of Sudan.

These findings informed the development of the final design proposal: a humanitarian residential and educational environment supported by healthcare, recreational, and community facilities. The proposal adopts a modular and replicable courtyard-based organization that can be expanded or adapted according to different capacities, site conditions, and regional climates. Rather than representing a fixed architectural solution, the project demonstrates a flexible design approach that integrates environmental performance, cultural identity, and children's physical, emotional, and educational needs within a coherent architectural system.

Finally, this research demonstrates that architecture can play a meaningful role in humanitarian recovery by creating environments that foster protection,

belonging, learning, and psychological well-being. By combining vernacular spatial principles with climate-responsive passive design strategies, the proposed approach offers a context-sensitive framework for humanitarian architecture in Sudan. It suggests that future interventions should move beyond providing shelter alone and instead create environments that support children's long-term recovery, resilience, and reintegration into society.

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