Envisioning CEB for Fiambala

Alex Nathanel Cohen

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Elizabeth Golden

Alex Anderson

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ABSTRACT

Envisioning CEB for Fiambala

Alex Nathanel Cohen

Chair of the Supervisory Committee:
Associate Professor Elizabeth Golden
Architecture

This thesis investigates the process to encourage compressed earth block (CEB) adoption in Fiambala, Argentina addressing the local government, architects, and community members. The need for introducing CEB stems from shifting the demand for easily accessible masonry units away from import-dependent concrete blocks and fired bricks. Analyzing the town's cultural and housing conditions provides the considerations to demonstrate a context-responsive CEB incorporation through mixed-use and adaptive single-family housing. Also, the target population is renters and co-habiting married couples requiring a residence in the local community. The thesis asks how to implement CEB through a study that enables Fiambala's architects to suggest the material to the community and municipal government. The results include a consideration framework and a hypothetical urban, architectural and detail level proposal.

ACKNOWLEDGMENTS

I have enjoyed my time at the University of Washington, especially at the Department of Architecture, as their doors opened to a transformative academic experience that I was fortunate to share with 2 cohorts.

Having Professors Elizabeth Golden and Alex Anderson's support as my thesis committee was invaluable to accomplish this thesis, especially through their guidance and patience in the process.

I am also grateful for Professors Kathryn Rogers Merlino and Sergio Palleroni's advice, which instilled in me a passion for vernacular architecture and revealed its role in collaborating with communities.

Thanks should go to Pablo Dorado and Santiago Cabrera, regional compressed earth block experts whose assistance was instrumental in understanding the existing construction practices while connecting me with Fiambalá's community and a network of architects familiar with the material.

I would also like to acknowledge the community of Fiambalá, Tinogasta, and regional architects for their contribution to building the context that binds this thesis together.

I want to dedicate this thesis to my parents, Alejandra and Roberto, and my sister Luziana. Their constant presence and support are sources of inspiration that have encouraged me to keep pursuing this thesis, especially facing the challenges that came through the work.
Thank you all...

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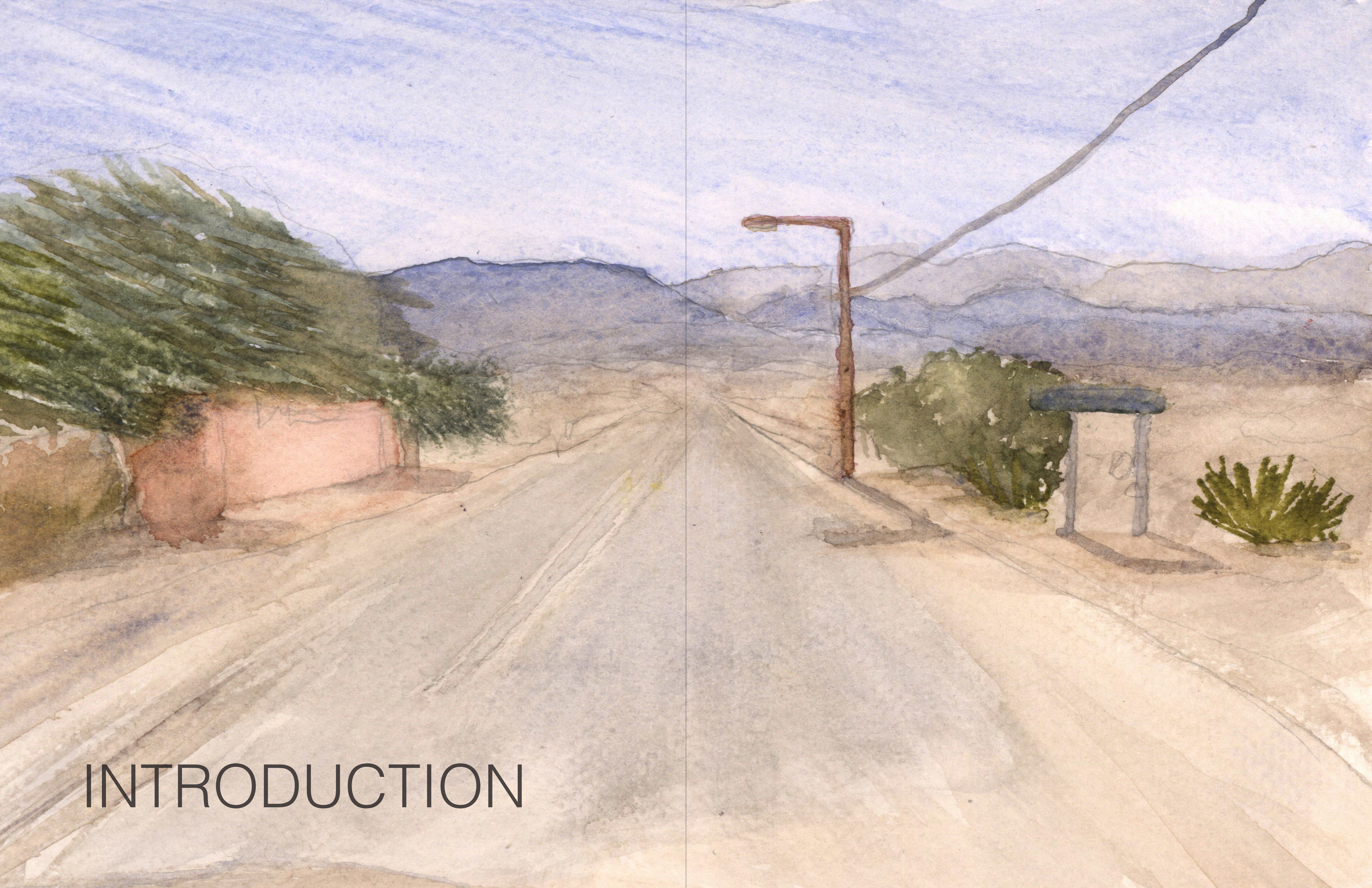


INTRODUCTION

Thesis Statement, Goals & Question

The thesis examines the potential introduction of CEB to contemporary building practices in the Northwestern Argentinian town of Fiambalá (fig. 1). With an expanding population of over 4000 inhabitants, the town is rapidly changing. As a result, traditional building methods dependent on local resources, such as adobe construction, are increasingly being abandoned in favor of practices relying on imported masonry and other industrial products.

Compressed earth block (CEB) is a masonry material made of mixed fine aggregate (such as sand), subsoil, and a stabilizer such as cement (as low as 2.5%). Adobe is a brick made of subsoil, rich in clay, often mixed with straw for reinforcement and sun-dried as rectangular prisms. This thesis establishes the foundation for adopting CEB as the return to traditional materials through a newer system fitting contemporary social, cultural, and economic needs.

This investigation proposes strategies for encouraging the adoption of CEB by different audiences, including the local government, architects, and community members. The thesis also strives to facilitate material incorporation by producing affordable and context-responsive single-family housing and mixed-use buildings that address the town's social, cultural, and environmental needs. By providing a middle-ground alternative based on CEB, this thesis challenges negative local perceptions of adobe construction and offers a low-carbon, locally sourced contemporary option with environmental benefits.

The thesis proposes the design of two housing typologies that could set an example for architects and facilitate wider adoption of CEB by the community and government. The site analysis scope of the thesis includes Fiambalá's demographics, housing typology, building code, climate, and hydrology, which respond to suitability, configuration, and user questions. Then, the topics stemming from envisioning CEB are two low-cost housing prototypes and future collaborative work with the town's government. Design is a supporting element since this is a material transfer-centered thesis, focusing on building the base to implement CEB as a masonry material in Fiambalá.

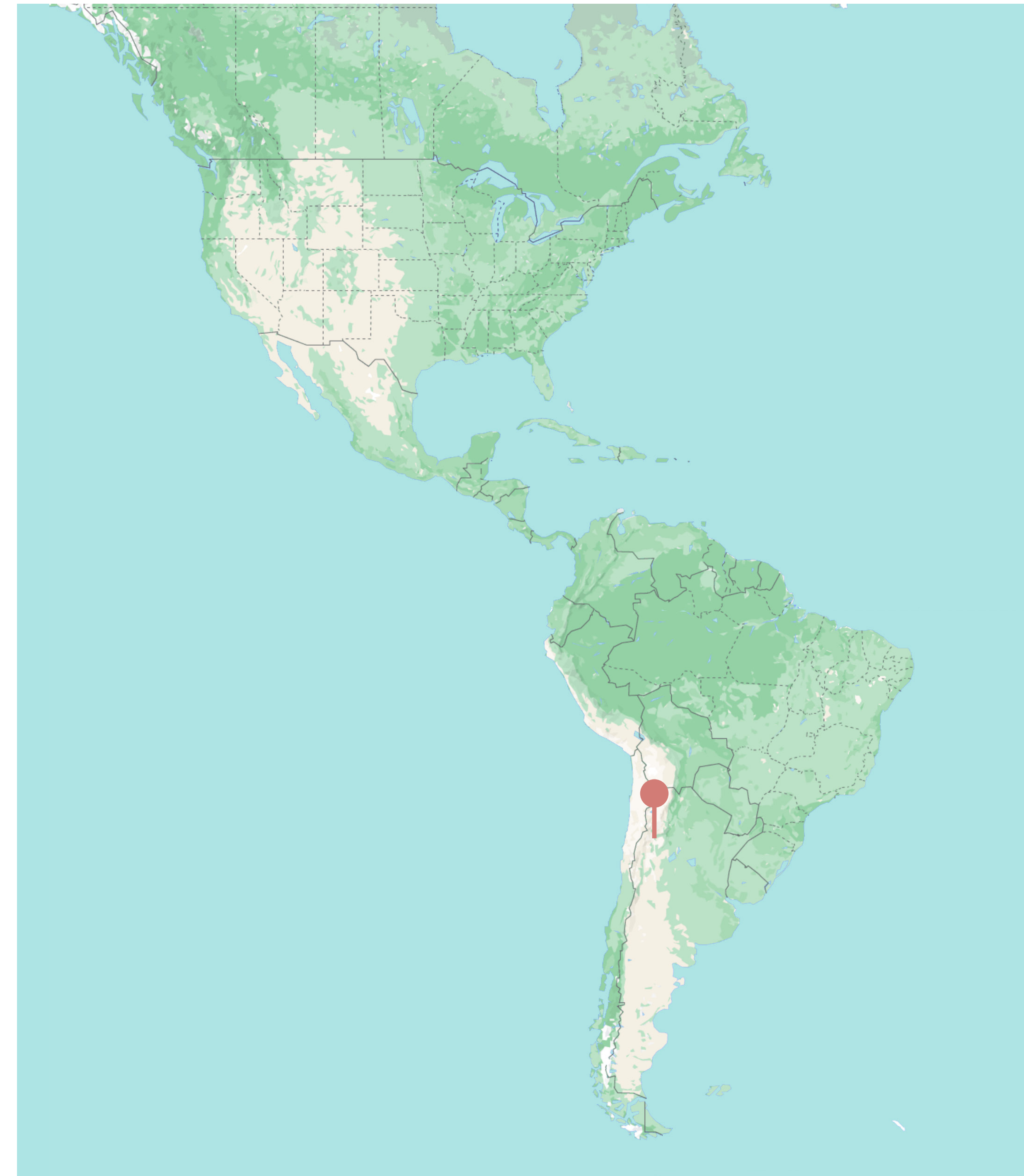


Fig. 1: Google Maps,Key map, March 2024. ■ *Fiambalá Location*

Process of Arrival to this Thesis & Site

Growing up in Argentina's northwestern province of Tucumán, I was surrounded by construction and architecture while growing up since my mother is an architect who designed and led the construction of the house where I grew up (fig. 2). In one of my elementary school trips around the province, I remember an adobe building that caught my attention, but I have forgotten the name since. Later in 2019, I traveled with my family to Fiambalá on what would initially be a tourist trip, which helped resurface childhood memories of my curiosity about the material. This childhood curiosity inspired my statements of purpose each time I applied and got into academic architecture programs. The re-emergence of my interest in adobe fueled my academic exploration during an independent research study I conducted under Professor Alex Anderson's guidance as an undergraduate architectural design student in 2022 at the University of Washington. As a graduate student, I investigated rammed earth automation technologies for a research methods class under Professors Tyler Sprague and Ann Huppert's guidance.
Also, I experimented with adobe and rammed earth in Prof. Elizabeth Golden's traditional materials and methods class which allowed testing the effort-intensive production process. Compressed earth blocks emerged from childhood, undergraduate, and graduate experiences with adobe and rammed earth.

Site Choice and Topic

The topic of this thesis is CEB introduction methods in an urban and sociocultural context that is unfamiliar with the material. As the setting for the introduction, choosing Fiambalá came from my visit and reemerging adobe interest experience. The town's small size and urban development also encouraged me to pick it based on the assumption it would facilitate its urban analysis. The thesis's socioeconomic focus to explore low-cost housing was inspired by my father's social justice work in Argentina before his forced departure in the 1970s. Therefore, Identity, memories, and family define my choice of Argentina, focusing on Fiambalá as the site for this thesis.

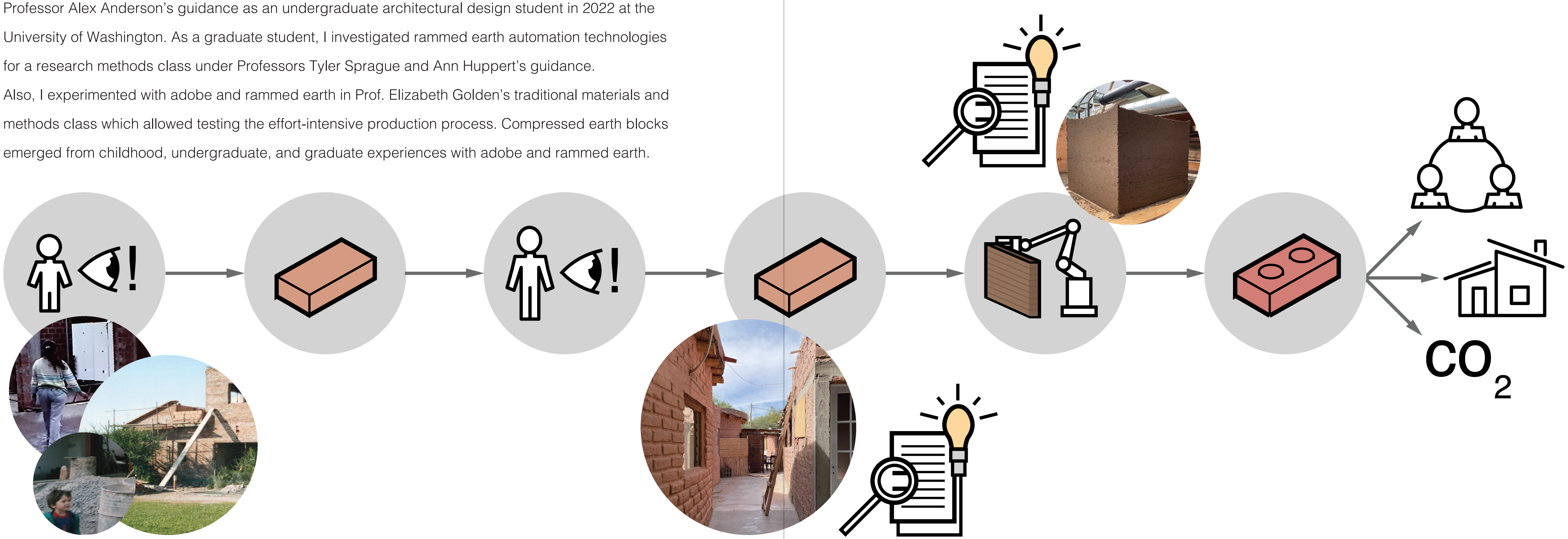


Fig. 2: Process arriving to Compressed Earth Block. Photographs on the left are courtesy of Roberto Cohen, 2003. On the right, Fiambalá Cabin Complex, 2019 and Rammed Earth block, 2023.

CEB Implementation Justification

In Fiambalá, the stigma of adobe relates to its maintenance and time-consuming yet low-cost production. This negative perception led people looking for housing to shift their preference to readily available materials such as concrete blocks and fired bricks. However, these instantly accessible materials generate more carbon emissions due to production and transportation requirements (fig. 3). The conditions framing CEB encourage perceiving it as a solution to foster community around its production's potential lower cost and time due to its accessible on-site manufacturing option. The material would be introduced through mixed-use housing due to demographic needs. This thesis responds to the research gap in the integration of CEB in Fiambalá's community preferences. Its goal is setting a proposal that argues for CEB's acceptance in housing to address shifting material preferences.

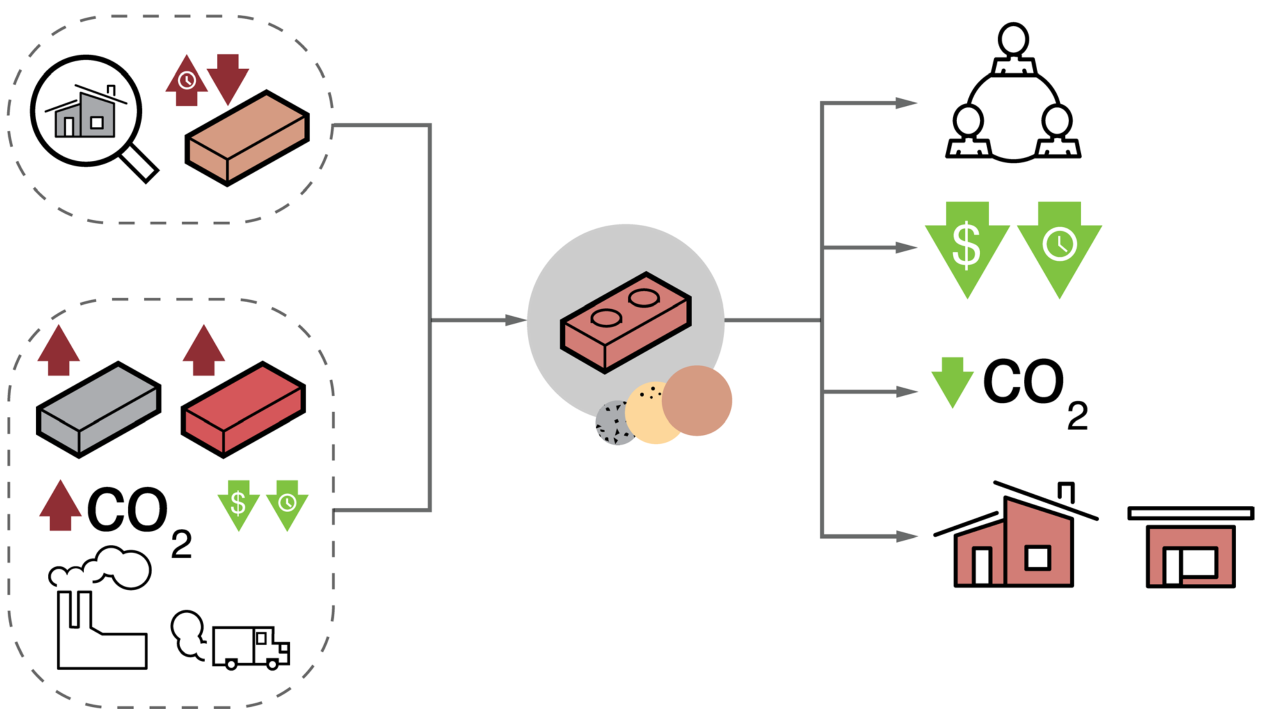
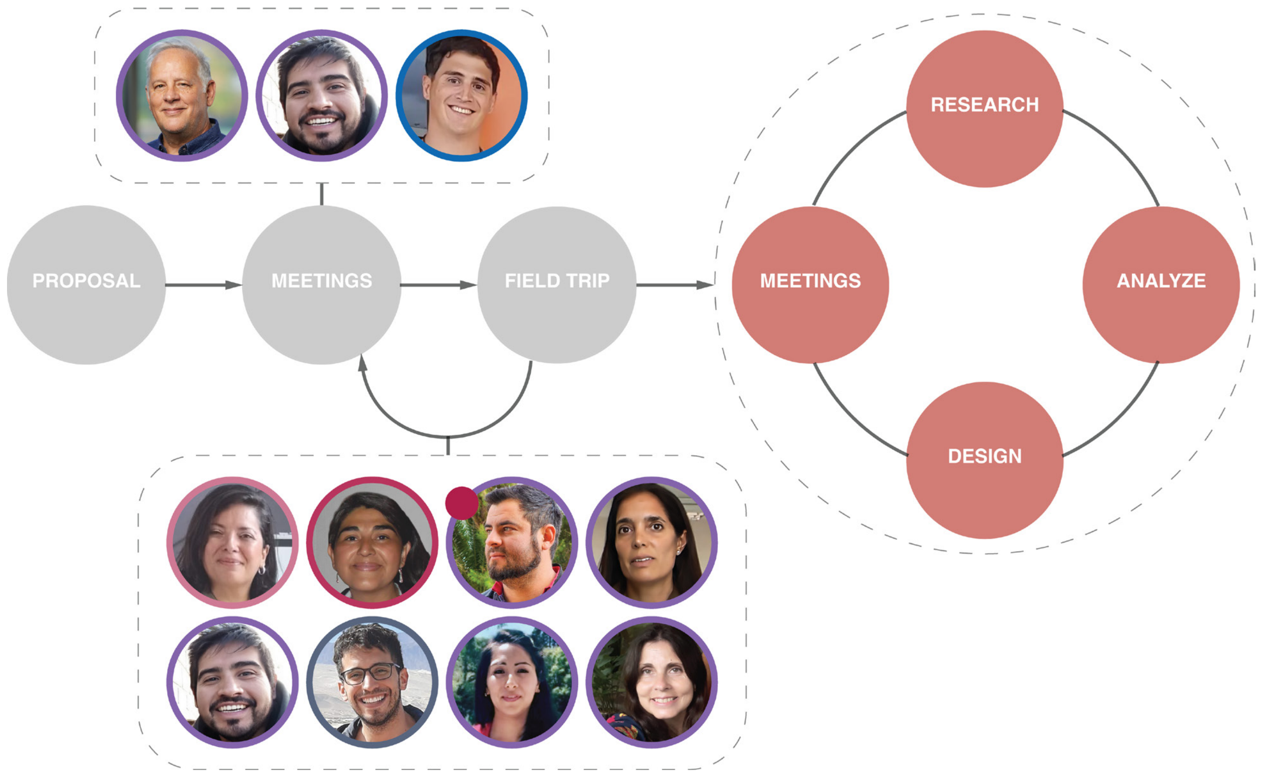


Fig. 3: Reasons behind CEB introduction.

Methodology

The thesis methodology is context based for engaging with Fiambalá and its residents. Also, the thesis considers the connection of population and place conditions as the source of a comprehensive design response that gradually incorporates project design from a hybrid abroad and regional perspective. Following the approval of the thesis proposal, there were interviews with local community members and regional Argentinian architects living in neighboring provinces and the US (fig. 4). Experts in construction using CEB included architect Pablo Dorado and civil engineer Santiago Cabrera, who work in the Tucuman and Santa Fe provinces, respectively. The meetings provided the groundwork for analyzing local needs, building programs, and material considerations shaping the project's outcome. The thesis process followed further meetings, research, analyzing conclusions, and designing in a loop.



Key:
School Principal (Regional) — *Architect* — *Tourism Industry (Regional)*
Local (Fiambalá) — *Civil Engineer*

Fig. 4: Thesis steps flow diagram.

Site Benefits

The dry climatic suitability and raw material deposits available were key in choosing Fiambalá as they will generate the proper environment for lower material transportation distance and climate-caused maintenance issues (fig. 5). However, Fiambalá experiences sandstorms and low precipitation with flash floods during the summer (fig. 6). All CEB sourcing materials are found in town, and there is a cement manufacturer in the province called "Loma Negra" which is 400 km (246 miles) east. The town is in a moderate seismic zone, surrounded by the Frontal Andean Cordillera and the Fiambalá Sierra (fig. 7) .

Fig. 5: Reasons behind CEB introduction diagram.

Fig. 6: Fiambalá Sandstorm, Dec. 2019.

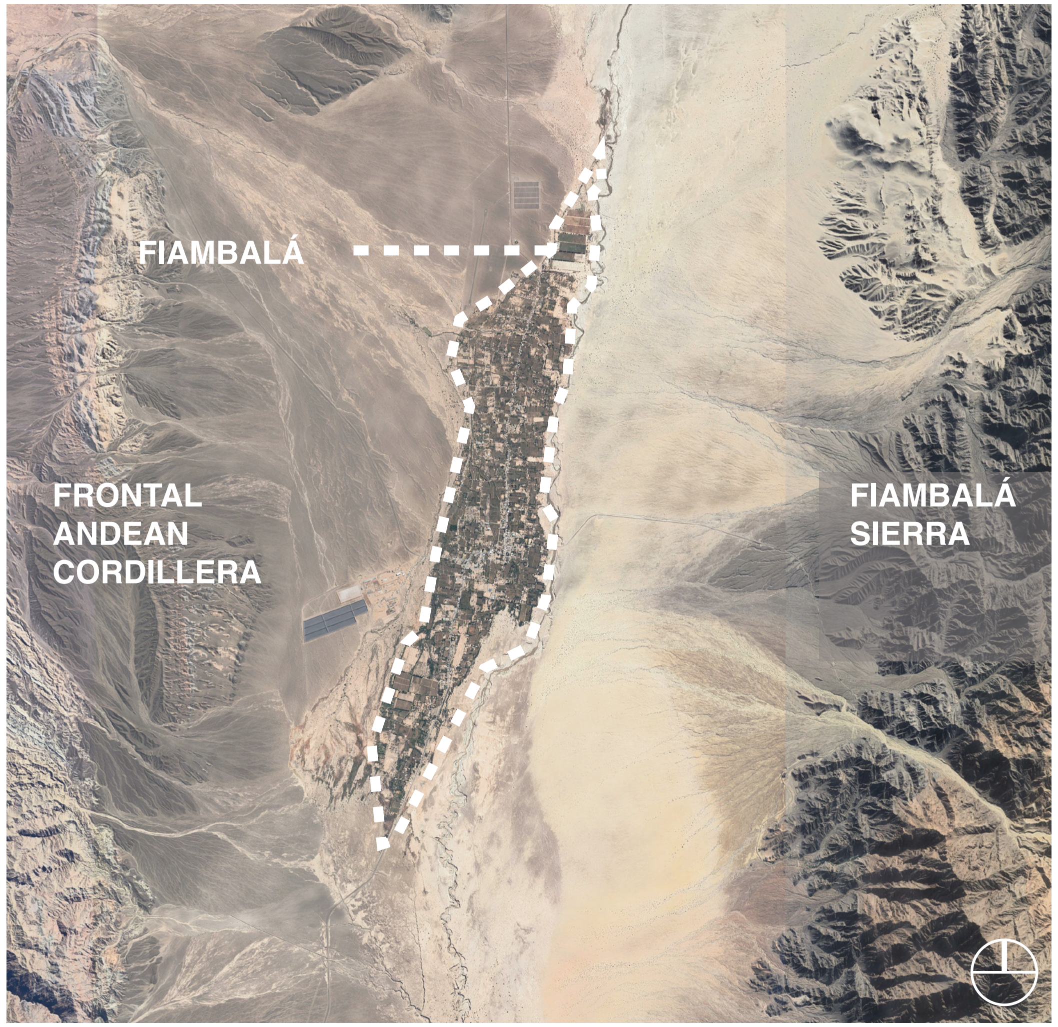


Fig. 7: Google maps, Fiambalá Map, June 2024.

Fiambalá's History

The town was founded as a settlement in 1702 by a Spanish colonizer named Diego Carrizo de Frites. Fiambalá means "wind house/place/pueblo" and comes from the tribe name "Fiambalao" in cacán, the language of the Diaguita native peoples. The Diaguita inhabited the land in Fiambalá and its surroundings, which were brought under Incan rule in 1480. Before Spanish colonization, Watungasta was one of the main towns in the area and was founded circa 500 CE at 23km (14.5 miles) south of Fiambalá (fig. 8-9). The town became part of the Incan empire due to its access to clayey soil, facilitating pottery-making. The settlement was occupied in 1536 by the Spanish and subsequently abandoned in ruins. However, the remaining turret structures in the area reveal a potential indigenous use of mud brick in the walls due to existing assembled stone foundations (fig. 8). In the 21st century, Fiambalá is an agriculture, tourism and mining-centered town that has experienced slowly increasing urban growth since 2023 due to lithium extraction investments.

Fig. 8: Google Street View, Stone foundation ruins of Watungasta, April 2024.

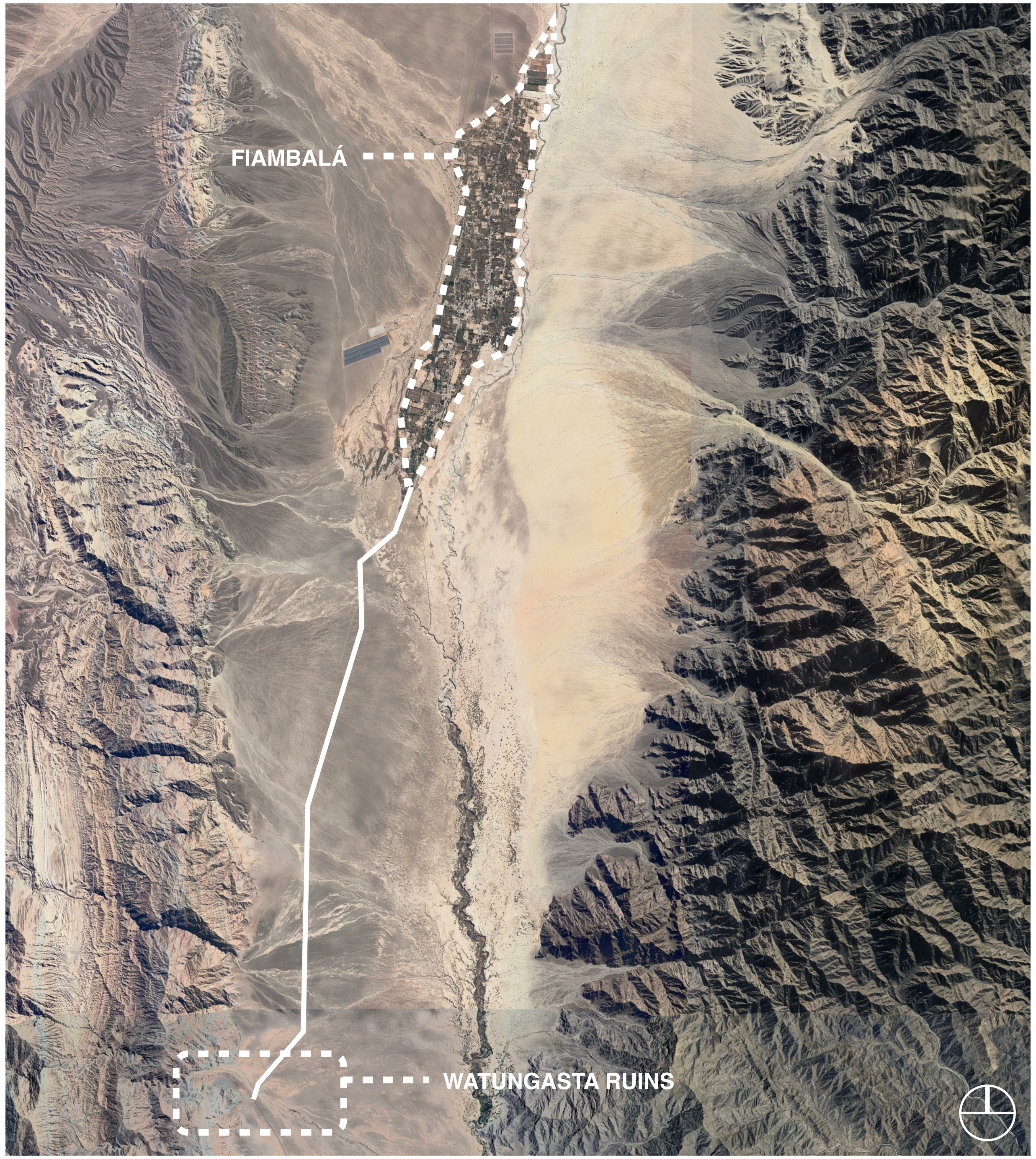
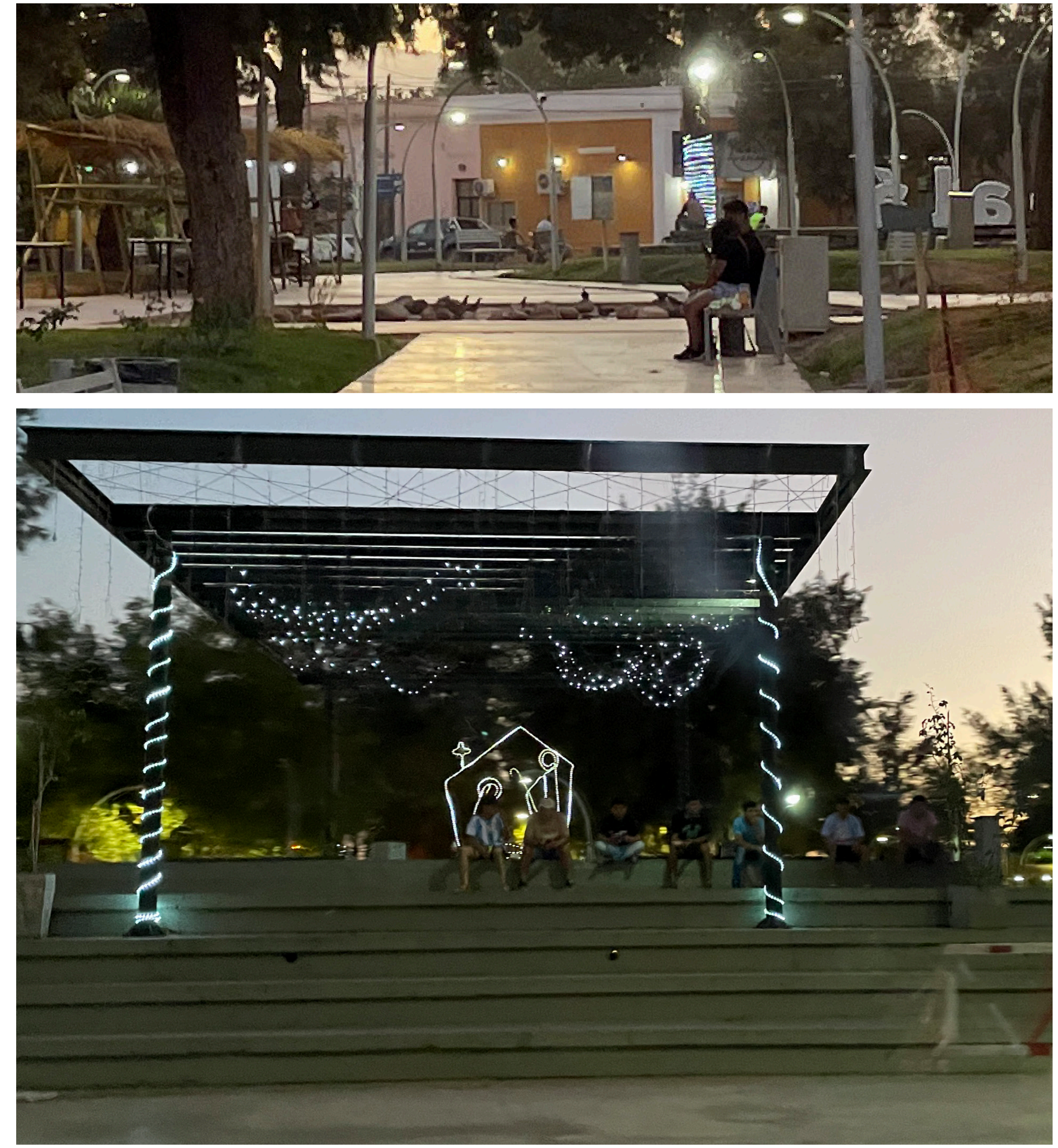


Fig. 9: Google Maps, Watungasta Location, June 2024.

Fiambalá’s Culture

The cultural identity of Fiambalá is embedded in its public art, local construction methods, housing typologies, and use of exterior public spaces. The public art, ranging from murals that oppose the local mining activities to representations of sports and agriculture, reflects the town’s values and traditions. Local masonry construction materials, including concrete blocks, fired hollow bricks, and adobe as infill for reinforced concrete structures, showcasing the town’s unique architectural style (fig. 11). The locals’ high presence and use of Beato Mamerto Esquiú square and its surrounding shops during the field trip’s summer evenings suggest the tight-knit community character of the town’s residents (figs. 12-13). These external statements of the resident’s values, habits, and building materials provide the framework to generate locally rooted design responses that encourage integrating the town’s identified character.

Fig. 11: Modes of Masonry Construction and Materials in Fiambalá, December 2023.



Figs. 12-13 : Summer Evening at Beato Mamero Esquiu Square, December 2023.

Tinogasta's Population

Fiambalá is in Tinogasta, a 25400-people county in the province of Catamarca, Argentina (fig. 14). The county has 3% of its population renting housing which may grow given the potential increase of residents. Due to the growing local lithium mining activity by Zijin company since 2021 in the Tres Quebradas project, the county had an inflow of people living in company housing. Also, Tinogasta's urban centers, including the cities of Tinogasta and Fiambalá, have received native populations who previously inhabited smaller settlements in the county in the last two decades as they searched for job opportunities. The provincial and federal governments fund public housing projects, one of them under the schematic phase in Fiambalá under local architect Oscar Saenz.

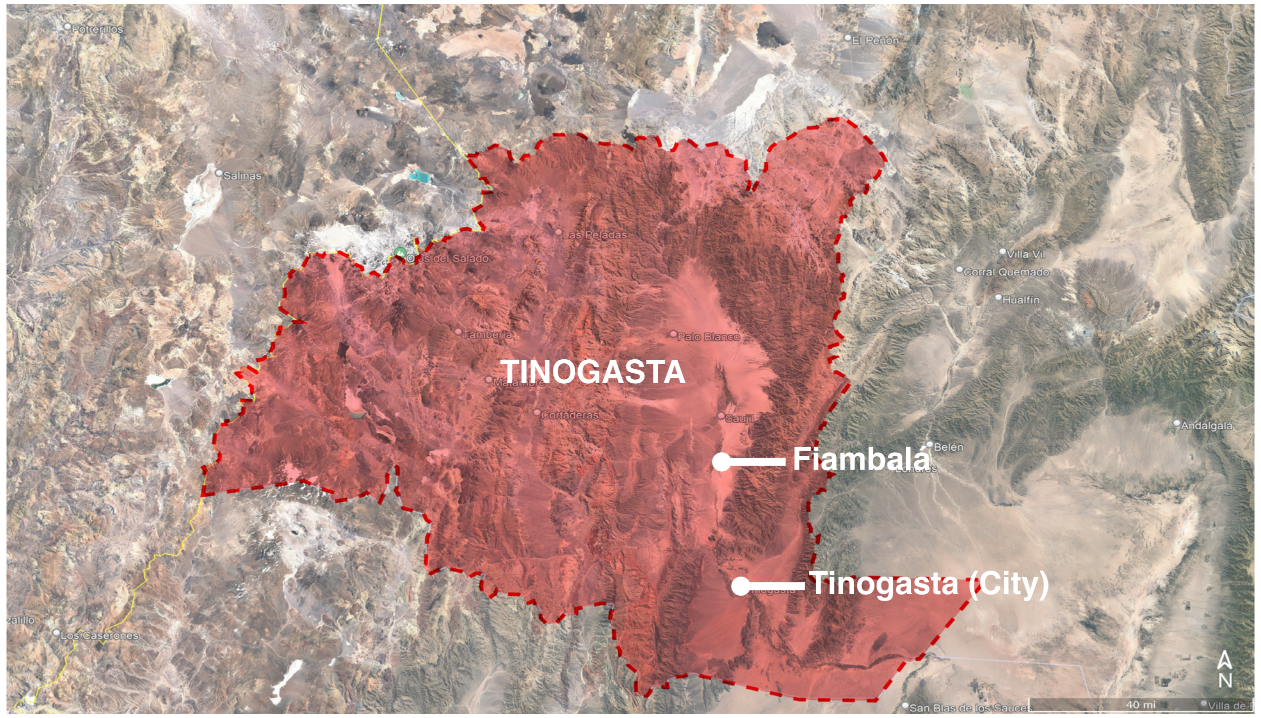


Fig. 14: Google Maps, Tinogasta Map, April 2024.

Regional and Local Challenges

The locality's challenges range from shifting masonry material use to integrated agricultural lands to the urban fabric and county-wide unemployment. Despite no CEB being introduced in the town before, the regional example in the "Hope and Love School No. 3," built in 2013 in Tinogasta, sets a precedent for the material use, durability, and construction cost (fig. 15). The main agricultural activities in the town include grapevine and olive tree crops, which are processed and sold locally or exported. The mix of crops and housing provides the town with a semi-rural landscape and an opportunity to increase groundwater savings when used for irrigation. The high level of self-driven custom additions and built housing projects offer insight into non-architects local interventions in social housing complexes, suggesting a desire for the dweller's identity expression. CEB faces the opportunity to encourage manufacture education certificates, raise employment beyond the existing activities, and engage with Fiambalá's housing addition traditions due to its modular masonry character.

CEB Suitability

Employing CEB for masonry for arid locations is appropriate because it maximizes the material's durability against moisture damage. Fiambalá has a dry Puna climate with low precipitation and flash floods in the late summer. The material's endurance depends on protection from rainwater exposure during seasonal floods and precipitations. Water damage to CEB results in erosion and increases the material's maintenance requirements. Wind during sandstorms also affects exposed CEB as it carries dust that erodes the unprotected blocks. Addressing cost and effort placed into sourcing, production, and manufacturing factors will facilitate its alternative implementation in construction against more polluting industrially made materials. The material's longevity in the context of Fiambalá is assessed through the "Hope and Love" school. The school is built with infill CEB masonry walls in a reinforced concrete frame and hasn't experienced maintenance issues since its opening (figs. 15-17).

"Hope and Love" School No 3

Fig. 15: The Esquiu Newspaper, Exposed CEB Masonry and Rebar Frame, November 2012.

Fig. 16: Exterior Facade, December 2023.

Fig. 17: CEB concealment exterior finish panel, December 2023.

Criteria for Success

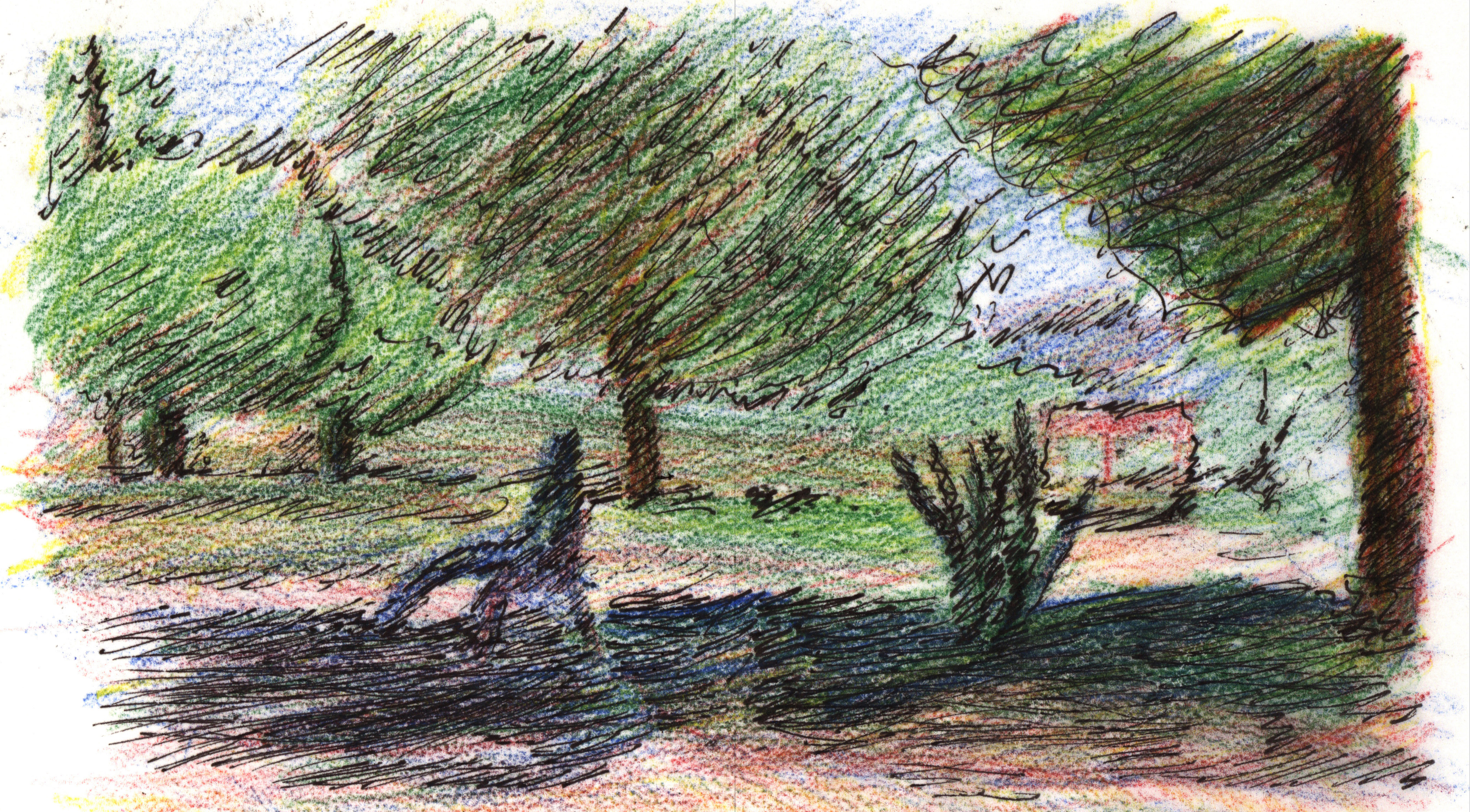
The implementation of CEB as a masonry wall material depends on Fiambalá's residents' acceptance of it, representing the thesis's success. The feasibility of implementation depends on the technology available for production, including sourcing, sifting, mixing, and pressing. Resource availability in the workers and materials categories also facilitates the material's introduction and fabrication (fig. 15). CEB is a viable construction material in Fiambalá due to its culturally responsive character, potential economic advantages, and on-site sourcing capacity. The material's applicability will depend on approval by future home-seeking locals through a community-led approach to the material's embrace which may generate long-term establishment as a predominant standard material. The scope involves the social, economic, and environmental dimensions surrounding CEB implementation to address research, technical, and design scale considerations.

Thesis Assumptions

The cultural and social assumptions applied as thesis's lens are non-professional architecture definitions and mining-caused population growth (fig. 19). This thesis's assumptions stem from my experience growing up in Tucumán, Argentina which helps assess Fiambalá's culture. Examining housing typologies, the logic of residents' additions is inferred without interviewing or visiting their residences but analyzed from photographs taken during the field trip. The subjective criteria that defines non-professional architecture were informal post-construction additions compared to rational housing complex buildings. Contractors were not considered despite the potential for hiring them as Susana Castro, the owner of the cabin where I stayed in Fiambalá, employed them to construct her adobe cabin. Additionally local lithium mining as a cause for future urban sprawl is speculation that partially justifies this thesis's housing complex project, as the focal population addressed is renters and mining workers.

Fig. 18: Fiambalá's Clay Soil and Stone Resources, December 2023.

Fig. 19: Fiambalá's "Tres Quebradas" lithium mining entrance, December 2023.



1. TOWN CULTURE & VISIT OBSERVATIONS

Introduction

The visual articulations of community identity, social issues, urban space uses, agricultural and economic activities are extensions of Fiambalá's cultural landscape. The artistic visualization fragments of the town's identity are in four murals on sidewalk-facing building walls and fences. Also, social problems and agricultural uses are represented in murals while integrated into the town's urban fabric. Observations of public spatial uses by residents provide gathering patterns as the number of people sharing time outdoors changes depending on the time of the day and season of the year. Agricultural endeavors are integrated as patches of land that balance the town's urbanization, providing buffer zones where construction may happen in the future. The conservation of historic constructions emphasize the tourist economy, including museums and remodeled churches that employ adobe as masonry.

Identity Expressions

Finding the murals as an artistic expression of the locals was an unexpected discovery that facilitated bringing forward themes that matter in the community. Stories about the town and interpretations unfold from the subjects depicted as their meanings change through their interaction with pedestrians. However, the public artwork chosen depicts an identity and environment that may not represent all the residents' preferences. One of the murals presents the "Defenders of Fiambalá Social and Sports Club" emblem and soccer player placed on the sidewalk-facing wall of an athletic club complex (fig. 20). The soccer player's portrayal conveys the excitement for the sport, a generalized shared passion among people from Argentina. Another mural includes the Andean condor flying over the vast valley between the mountain range on another mural, representing a visual connection between the artist, commissioner, and their natural environment (fig. 21).

Fig. 20: Defenders of Fiambala Social and Sports Club mural, December 2023.

Fig. 21: Endemic and Migrating Fauna around Mountain Landscape mural, December 2023.

Local public art depictions of people portray locals engaging with music as an individual, and in protest as a collective indigenous group. The wall painting includes a person playing an instrument next to a grapevine and a vicuña, an endemic relative of llamas (fig. 22). The grapevine is a non-native plant to the town, which the locals have predominantly adopted for farming, spreading through the town. Another example reads, “May life without mining win in Fiambalá,” protesting the extractive lithium mining activities and portraying those behind the protest holding the Wiphala flag, an emblem of Andean Indigenous communities (fig. 23). Also, the mural conveys the sacredness of the land’s resources through the illustration of a mountain entity holding water and earth. The murals embody a portion of the local context, presenting socio-enviro-agricultural symbols and sociocultural-extractive industry clashes.

Fig. 22: Grapevine, Person and Vicuña Mural, December 2023

Fig. 23: Lithium mining protest mural, December 2023

Between the 17th and 18th centuries, Fiambalá went from an Incan clay-source enclave to a Spanish colony, both using adobe due to the suitable resources in the area for construction. San Pedro's church and the "Comandancia de Armas" (colonial military headquarters) are examples of Spanish colonial architecture employing adobe masonry built in 1745 and 1770, respectively (figs. 24-25). Argentina's government declared the church a national cultural heritage site in 1941, and the building underwent restoration in 2021. The buildings are tourist attractions as historic symbols representing the town's beginnings under Spanish control. Wooden trunk beams hold their roof structures, expressing a hybrid combination. However, the town also has abandoned adobe buildings indicating a masonry construction trend moving beyond adobe (fig. 26). The historical significance of the building and expressions of adobe demonstrates a contrast against the locals' generalized pattern shifting away from the material.

Fig. 24: San Pedro's church, December 2023.

Fig. 25: Comandancia de Armas building, December 2023.

Fig. 26: Abandoned adobe building, December 2023.

Local construction practices involve resources from endemic trees and plants for wall, pergola, ceiling, and roof structures. The resources include sparse algarrobo or mesquite forest patches around Fiambalá's Abaucán River, the chañar tree, and caña brava, known as wild cane. Algarrobos provide wood for rustic trunk columns and beams while chañares' tree sap is a waterproofing material (figs. 27-28). Also, caña brava trunks held by metal wire provide panels for interior ceilings and shading roofs for pergolas (figs. 29-30). The construction tradition behind the use of wood in interior roof structures demonstrates continuous use from San Pedro's church to the cabin complex owner's house built between the 2000s and early 2020s (figs. 31-33). The local integration of resources to buildings expresses a construction culture influenced by the environment and co-existing with their imported replacements, setting the background for everyday life.

Fig. 27-30 (clockwise order): Chañar tree, sap, wild cane panel, ceiling and algarrobo beam, Dec. 2023.

Fig. 31: Cabin Complex Killa Qullqi, December 2023.

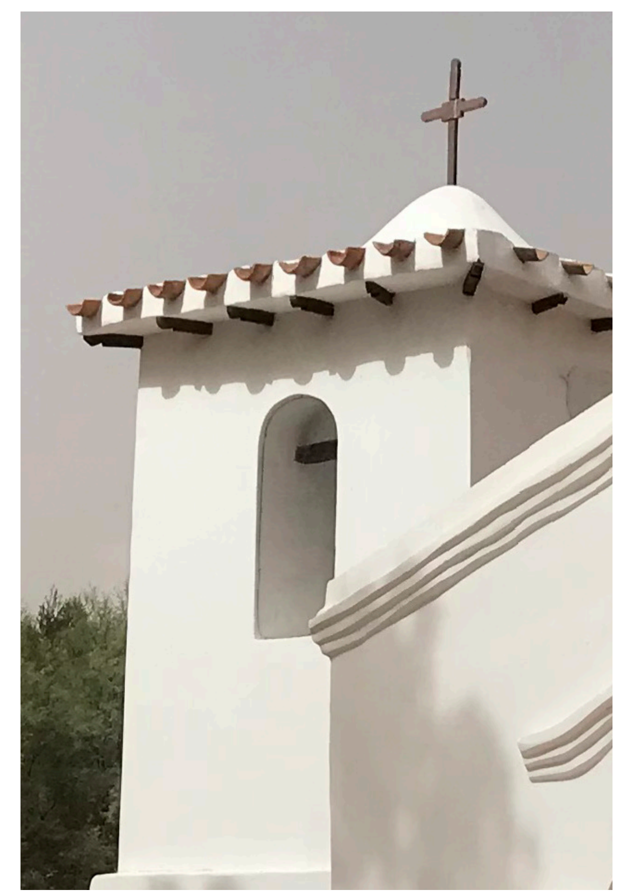


Fig. 32: San Pedro Church bell tower, Dec. 2019.

Fig. 33: Wild cane shading, Dec. 2023.

Town Culture & Visit Observations

The observations of Fiambalá's daily life consist of the people's transition from the private to the public realm. The private realm is the domestic environment, such as people's houses or a tourist's cabin. The semi-public realm includes shops, while the public one includes squares and sidewalks. The Friar Beato Mamerto Esquiú Square is the nexus of community life for locals and tourists. In the summer, around mid-December, few people go to the square during hot sunny days except to sit in the shade. However, in the morning, people buy groceries in surrounding specialty shops and lunch from food trucks (figs. 34-36). From noon to afternoon, temperatures rise, and people shelter in colder areas, such as under the trees (fig. 37). As the evening arrives, residents water their streets to lower the dusty winds' impact, cooling the atmosphere through evaporation (fig. 35). The square becomes lively at night as people come together, neighbors greet each other, and kids play, embodying the community (fig. 39).

Fig. 34-36 (clockwise order): Shops. grocery shopping, deli food truck, December 2023.

Fig. 37: At noon in the shade around Fiambalá's main square, December 2023.

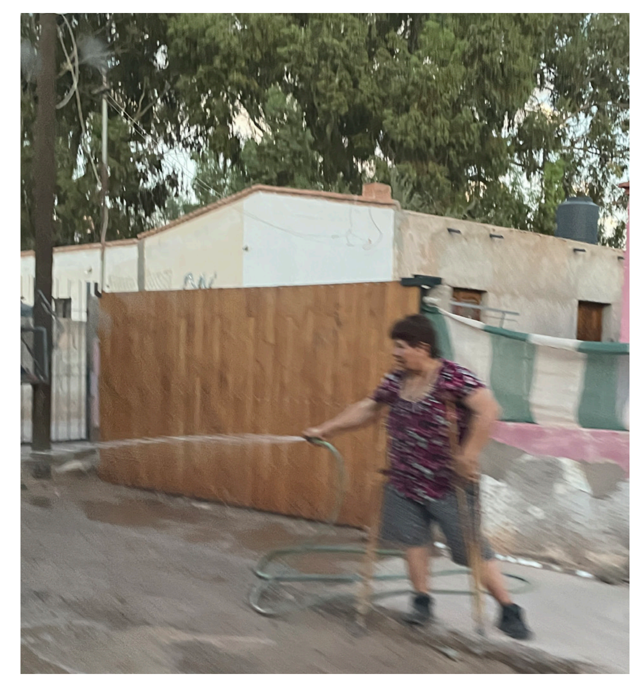


Fig. 38: In the Evening, resident waters the street, Dec. 2023.

Fig. 39: At night, the lively square, Dec. 2019.

Water Significance and Cultural Considerations Outcome

Water shapes the town's culture due to its drought and flood conditions after surrounding rivers carry precipitation from the Fiambalá Sierra (fig. 40). The celebration of the resource emerges in a struggle between its life-supportive and life-threatening character. Floods are catastrophic because of vehicle access obstruction as routes cross at the same level of seasonal rivers (fig. 41). Economic-driven uses include crop irrigation and a hot spring complex called "Termas de Fiambalá" owned by the municipality (fig. 42-43). Additionally, the town's main square has two fountains, which provide a calming atmosphere and cooling against the heat during the summer seasons (fig. 44). Despite the universality of fountains in public squares throughout Argentina and water use worldwide, the community demonstrates awareness of water's precious and ferocious character.

The interrelationship between each identity expression and influence is demonstrated by their mutually exerted impact. One of the murals depicts water in the environment, which supports vegetation and agriculture, and the fountains in the main square, the main place for gathering. The history of water as a survival and potable resource is crucial for continuing life in Fiambalá. A life dependency on water sets it as a priority cultural component, demonstrating its priority in the town's culture. However, the murals consolidate the concerns and celebrations of the residents, while historic buildings are reminders of past generations and reflect construction traditions. Endemic flora provides building materials that shelter people and become their environment for daily life. The society's visual artistic representations, relationship with their environment and history reveal the locals and their setting's multifaceted identity.

Fig. 41: Inforama, Floods in Fiambalá, Jan. 2023.

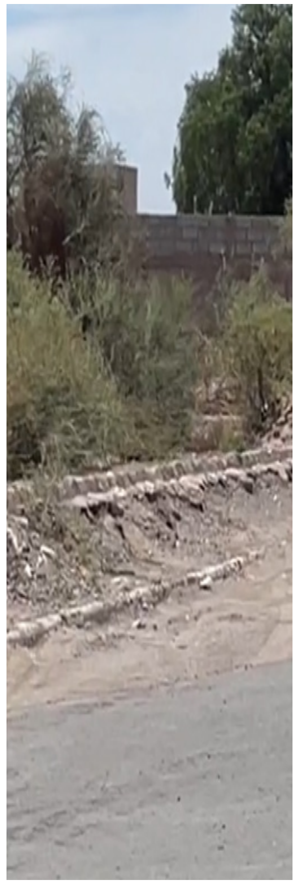


Fig. 42: Fiambalá's Irrigation Acequía, Dec. 2023.

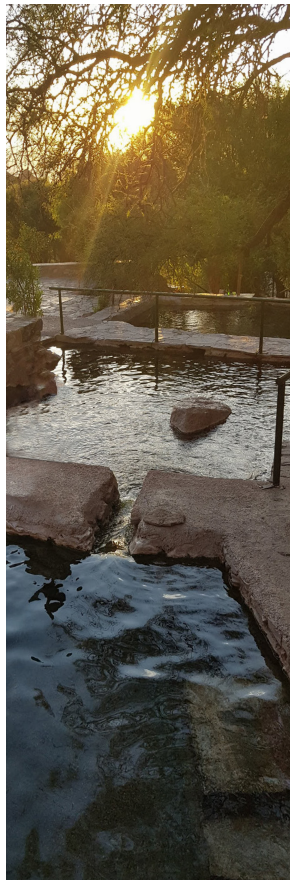


Fig. 43: Fiambalá's Hot springs Complex, Dec. 2019.

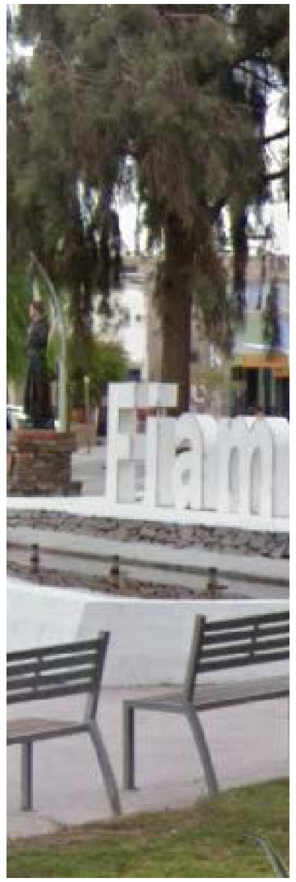
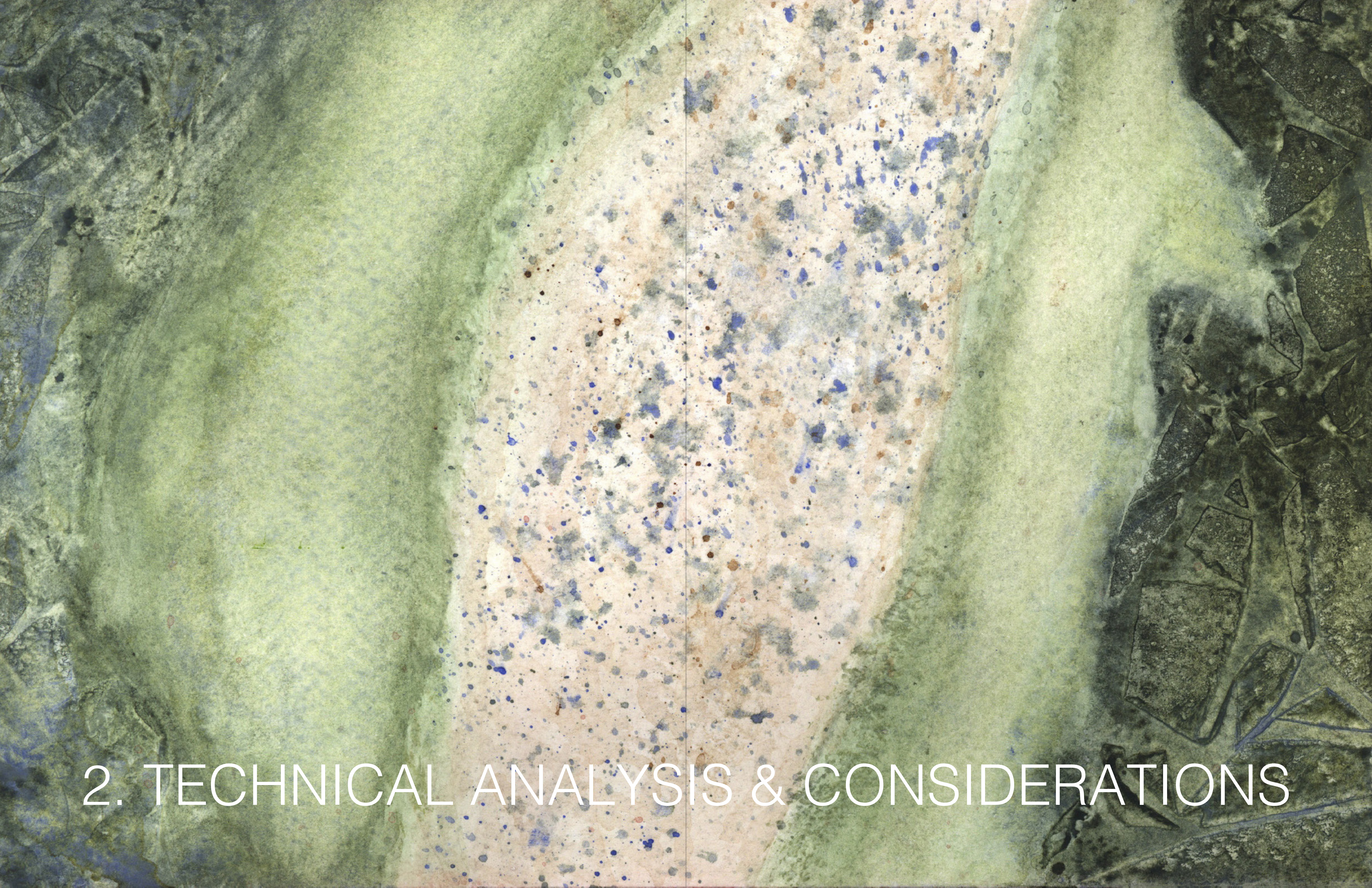


Fig. 44: Google street view, Main square's fountain, April 2024.

Fig. 40: Dry Abaucán River, December 2023.



2. TECHNICAL ANALYSIS & CONSIDERATIONS

Technical Analysis & Considerations

Introduction

Analyzing Fiambalá's environment, population, and construction requires investigating beyond the collected field trip knowledge by pursuing data in four secondary research areas. Climate and groundwater present the natural environment's conditions of the surroundings for survival. Demographic studies of the local population facilitate exploring the people's statistical magnitude, housing, and employment circumstances. The analysis of housing typologies assists in identifying locals' needs, including the active system placement, external spatial and façade configuration. Also, assessing building codes provides guidelines for adequate construction that employs compressed earth block (CEB) and respects minimum standards of living. The development of the research areas for guidelines produces a considerate approach to housing design.

Climate

Fiambalá's valley experiences a dry Puna climate because of its location at the southern border of the Central Andean Puna ecoregion. The town is at -27.83° latitude and -67.83° longitude, where the sun's yearly path passes through the north due to the southern hemisphere location. Also, the land's elevation is 1505 m (4938 ft) above mean sea level. Cloud cover is at its highest in June (31% of the month is overcast) and lowest in November (85% is clear or partially clear). The wettest period spans from late November to April, and the yearly precipitation amounts to 10 mm (0.04 inches). Most wind arrives from the northeast and southwest, while the windiest month is December, with average speeds of 12.8 km/h (8 mph). In contrast, the calmest month of the year is May at 8.5 km/h (5.3 mph). Therefore, cloud cover and sun path inform from window coordinate orientation to shading, while precipitation and wind influence the building envelope.

A 2-hour temperature chart is a tool for defining the human perception of an exterior location's comfort and discomfort levels between heat and cold (fig. 45). The town's chart reveals that late spring to early fall temperatures allow open ventilation between 8 pm and 8 am. During the summer, closed cooling is required between 10 am and 6 pm, while mid to late winter won't have cooling needs.

However, closed heating will be necessary between 10:00 pm and the early morning hours in winter. Most open ventilation occurs during the months of March and November, while the least is in June, July, and August months. Closed heating or cooling is required for 4-hour minimum periods between April and September, as these gradually reduce or increase monthly. Active and passive temperature control systems will be necessary to increase interior comfort levels, counteracting excessive warmth and cooling during peak temperature highs and lows.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
12 midnight	68	67	65	60	56	53	52	53	56	60	64	67
2	66	65	62	58	54	51	50	51	54	58	62	65
4	64	63	60	56	51	48	47	49	51	55	60	63
6	63	62	59	55	50	47	46	47	50	54	58	62
8	66	65	62	57	53	50	49	50	53	57	61	64
10	77	76	74	70	65	62	61	63	67	71	74	76
12 noon	84	83	81	77	72	69	68	71	75	79	82	83
2	87	86	84	81	76	73	72	75	80	83	86	87
4	85	84	82	78	74	71	70	73	77	81	84	85
6	80	79	76	73	68	65	64	66	70	74	77	79
8	74	73	70	66	62	59	58	59	63	67	70	73
10	70	69	67	62	58	55	54	56	59	63	67	69

Fig. 45: Yearly 2-hr temperature chart, April 2023-March 2024. *Closed Cooling* *Closed Heating*

Compressed Earth Block Properties

The thermal properties of CEB as a masonry material depend on wall thicknessl but require an examination to assess the need for additional insulation materials. Thermal insulation, also known as R-value, is the material's capability to impede heat's movement, while Thermal resistance (R) is a material's level of heat flow rejection. Heat conductivity (U-value) is a parameter that facilitates evaluating the efficiency of a material's warmth diffusion and deterrence. The thermal insulation of CEB is low, varying between 0.75 and 1.0 m2xK/W each 25.4 mm (1 inch.). A 30x15x7cm block has an R-value of 8.85-11.8, which is low but appropriate for Fiambalá due to its moderate average yearly maximum and minimum temperatures (fig. 46). However, cooling and heating measures for peak temperature highs of 42°C (107°F) and lows of 1°C (33.8°F) will be necessary through the implementation of active and passive temperature regulating systems.

The material's U-value ranges from 0.11-0.085 W/m²K, calculated as a coefficient of the R-value, which indicates low heat loss. During the construction stage, the block's standard carbon emissions will depend on the place of production (on-site or at a manufacturing facility), transportation method, material extraction methods, machinery implemented, and compression method. The hydraulic block-making presses, whether assembled locally or imported from abroad, will also impact the embodied carbon of the material through its pre-production stage. External to internal, wind, moisture, and water protection layers help enhance the durability of the blocks as damage preventive measures. The resistance of CEB to water absorption and damage depends on the stabilizing material's type and content level, such as cement and lime to lower the block's porosity.

The compression process is accomplished through manual and automatic hydraulic press machines. Fiambala's region employs the manual method that requires pouring the block's mix into the hopper, which contains it until discharging it into the mold. Also, the manual press requires effort when pulling the lever to press the mix into the block and produces 100 blocks per hour, depending on the worker's number, expertise, and block-making role rotation (figs 47-48). The automatic approach also requires the hopper process, but there is no human-based pressing effort. The motorized presses generate 480 blocks per hour; however, these are not located regionally and will require importation (figs 49-50). Local press machine manufacturing efforts would help reduce importation needs and costs.

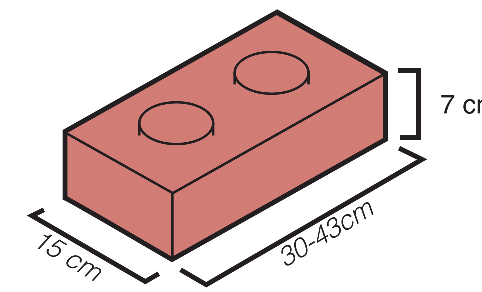


Fig. 46: CEB measurements.

Figs. 47-48 (top to bottom): Rodolfo Rotondaro and Maria Rosa Mandrini,"Compressed Earth Block and Walls: two techniques with load-bearing capacity,"Double manual hydraulic press (top) with CEB (bottom), June 2019.

Figs. 49-50 (top to bottom): ByA Block-makiing machines, Automatic hydraulic press (top) with CEB products (bottom), Jan. 2019.

Groundwater and Superficial Water Resources

Groundwater is water collected below the earth's porous surface through gravity. The groundwater resources in Fiambalá are provided by the Abaucán basin, which stems from the namesake river fed by the Fiambalá and Chaschuil rivers (figs. 51-52). The basin's aquifers are exploited through wells for lithium mining, construction agriculture, and domestic uses. According to a local hydrogeological study by Argentina's Water Institute, groundwater is 35 to 84 meters deep (115-275ft). The water has bicarbonate sodium, salt, nitrate, fluoride, boron, and arsenic between 0.014 and 0.020 milligrams per liter, surpassing the 0.010 mg/l safe value for consumption. However, the water's salt levels are safe for consumption, requiring further assessment of other contents. The groundwater in Fiambalá raises considerations about potability safety and extraction practices, prompting the establishment of filtration and municipal regularization to prevent depletion.

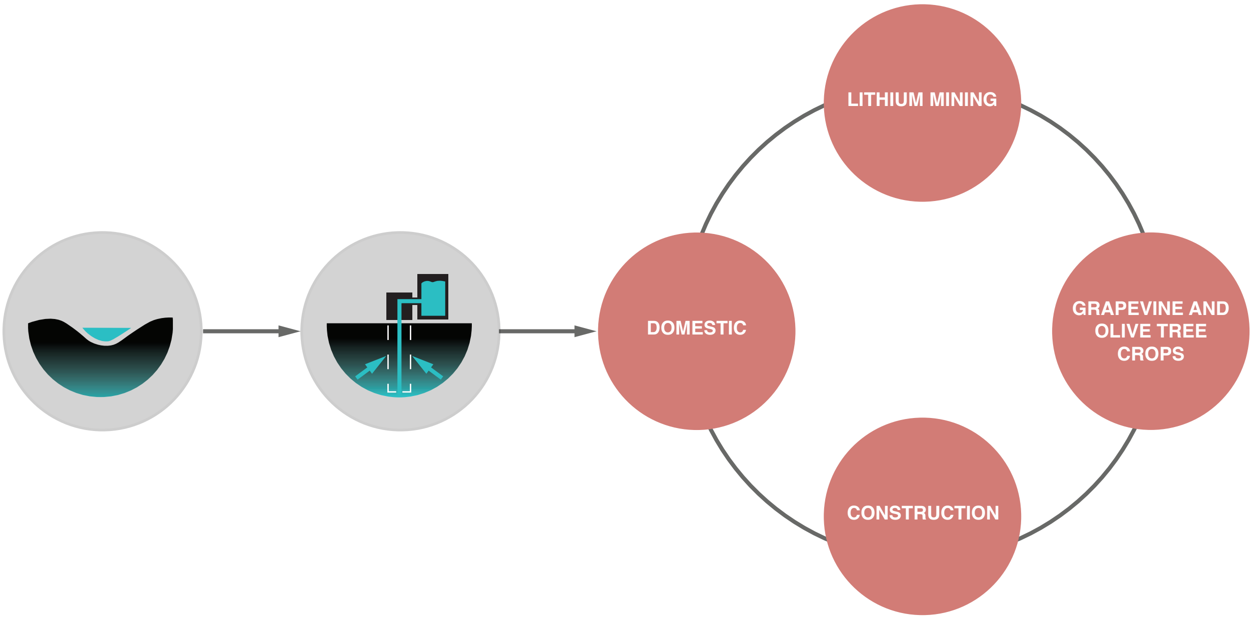


Fig. 51: Groundwater uses diagram..

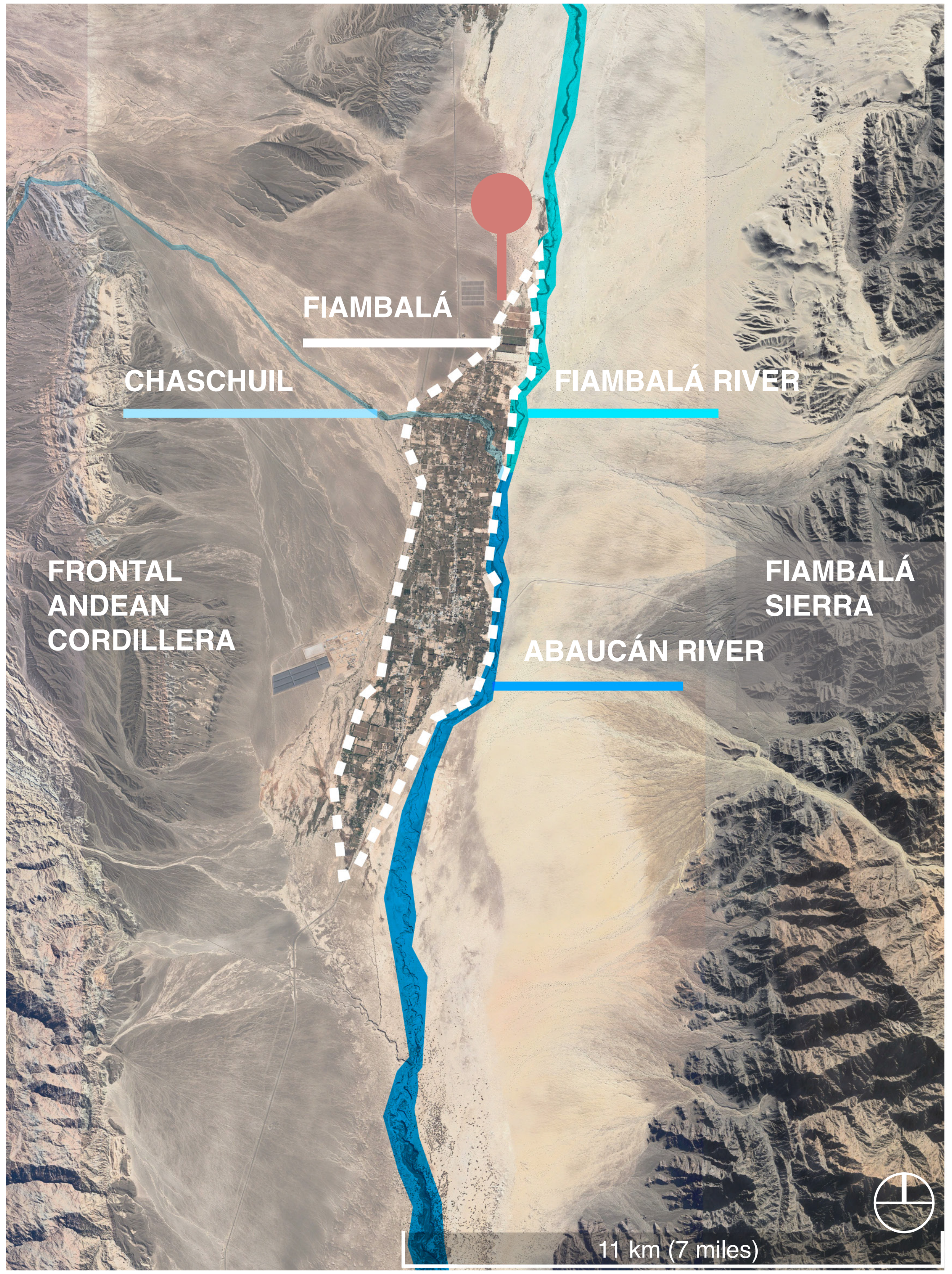


Fig. 52: Google maps, Superficial Water Resources, June 2024.

Population Characteristics

Demographic data is a collection of population statistical information that facilitates learning about people's characteristics, employment, and living conditions to respond to their needs. In Argentina, the census that records population information is updated every decade with the 2-year late exception of the 2020 Covid-19 pandemic. Also, the National Institute of Statistics and Census of Argentina (NISCA or INDEC) carries the census. The country's 2022 Census information is limited to Catamarca province and its counties as of June 2024 because NISCA has not completed the report for full publication. Tinogasta County includes 13 localities beyond Fiambalá, adding to a population of 25300 people (fig. 53). On a more detailed scale, Argentina's 2010 census indicates the municipality of Fiambalá's population as 8000. Additionally, the report indicates that the town of Fiambalá has 4600 people within its namesake municipality.

The thesis's focus population is renters and married couples of Fiambalá under the assumption that they are starting their families experiencing financial difficulties from home rental to ownership. Also, this study focuses on unemployed people as they determine the availability of individuals looking for work to participate in CEB housing construction and manufacturing. Catamarca's public housing program sets the minimum criteria as single Argentinian individuals above 18 years old who are financially independent province residents. The 2010 National census reports that married couples are 34% of the province's population above 20 years old while renters in the 2022 Tinogasta report are 6.7% of the total residents (figs. 54-55). Tinogasta's unemployment is at 7% out of the economically active employable residents, offering opportunities for employment in housing construction (fig. 56). Mining workers are a future speculative population as their 0.25% out of the employed population in the county is under growth expectations as production began in late 2023 (fig. 57). The outcomes are a medium married couple population, low unemployment and housing ownership needs for renters. Despite the results, the study provides prospective applicants and employees to benefit from the project.

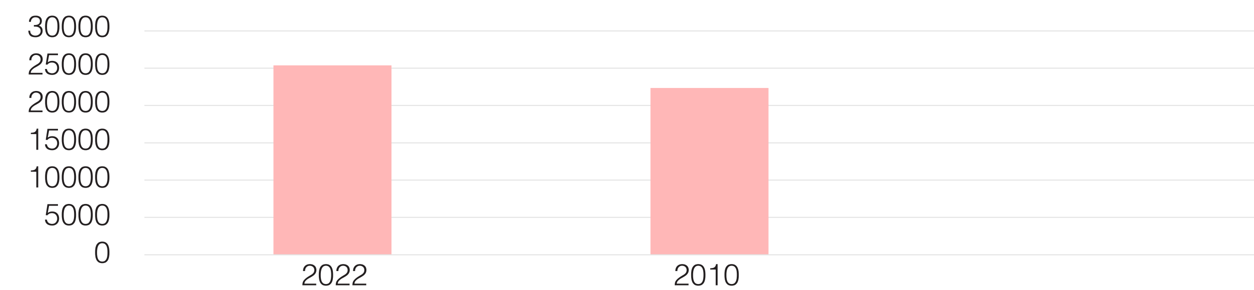


Fig. 53: NISCA, Population Growth comparison in Tinogasta county, 2010-2022.

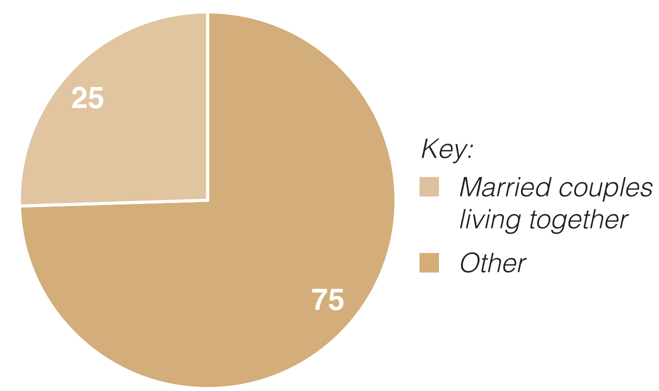


Fig. 54: NISCA, Percentage of co-habiting married population aged 20+ years old in Tinogasta, 2010.

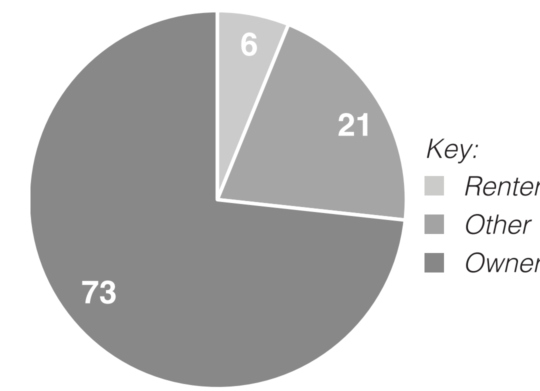


Fig. 55 NISCA, Percentages of housing ownership in Tinogasta, 2022

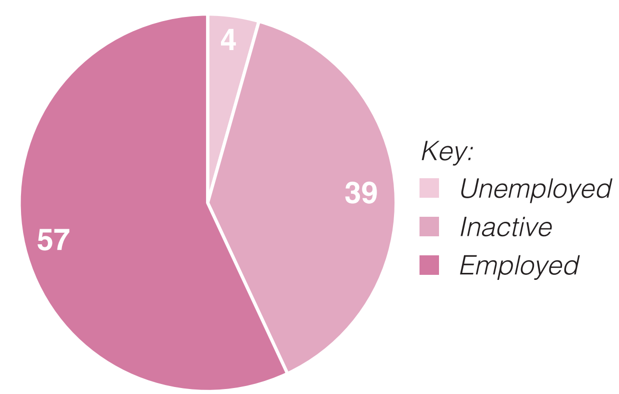


Fig. 56: NISCA, Percentages of employment conditions in Tinogasta, 2022

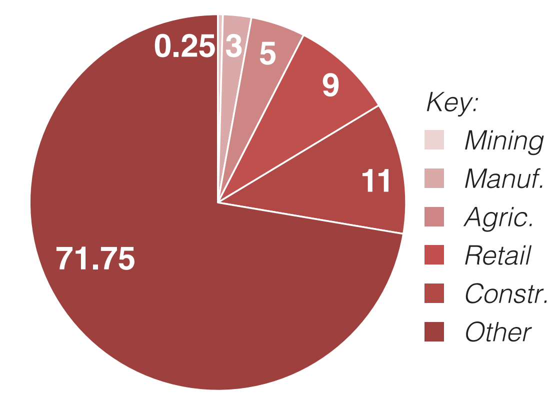


Fig. 57: NISCA, Percentages of employee activities of Tinogasta's population, 2022.

Housing Typologies and Exterior Space Configuration

Exploring housing typologies facilitates responding to existing representations of the locals' needs and standards. The analysis includes 15 housing case studies from the field trip's photographic documentation. Also, the study centers on the morphological exterior facade categories involving wall finish, visible construction material, roof type, window shape, and size. The configuration of each building's exterior reveals the preferences of their owners. The typological examination assesses front yard treatment, parkway, fenestration cover, visible active systems and services (fig. 58). Additionally, the incorporation of exterior elements unfolds a story of modifications in a local housing complex due to the coexistence of the original with the adapted version. The main type of façade components, surrounding elements, and their relationship define the considerations for uncovering the local approach to design and construction (figs. 59-62).

The average outcome of the case studies includes cement stucco as the main wall finish type and adobe as a construction material. Also, the roof types and materials were not visible, while the windows were rectangular and small. Facades engaged directly with sidewalks, and housing buildings had no parkways or visible active systems. However, services were visible in most buildings' exteriors, including power lines and electrical boxes. Water tanks placement is prevalent on structures standing over the roofs to provide minimal water pressure because of the town's low one. Walls conceal the tanks denoting an informal construction stigma associated with their public visibility. Also, the fenestration covers were mostly simple wooden panel shutters to protect from direct heat through window glazing. The analytical outcomes of building character and occupant identity become references to root housing design.

Finish type	Visible construction material	Roof type	Roof Material (if visible)	Window Shape	Window Size	Front Yard Treatment	Parkway	Visible active systems type	Visible services	Fenestration cover
Stucco and cement	Adobe	Not visible	Not visible	Rectangular	Small	Façade engages directly with sidewalk	No	No	Yes	Wooden simple panel shutters

Fig. (58): Typology analysis results chart. (See appendix for complete table and case study images.)

Figs. (59-62): Housing case studies visual analysis, Dec. 2023.

Building Code Examination

Building code is the organized set of rules generally implemented to provide the minimum requirements in construction and design that impact public to private physical spaces in human settlements. Oscar Saenz, an architect in Fiambalá, follows the building code of Catamarca's Capital City because of the absence of a town-specific construction code. The provincial regulation was approved in 1995 and ratified in 2021, including guidelines for construction with reinforced concrete, concrete blocks, and fired bricks. However, the code omits reference to earth construction, including adobe, a historic masonry material in Fiambalá. The Peruvian Building Code is of regional influence in earth construction since its seismic zone considerations provide structural limit guidelines. Perú's code also omits the discussion of minimum instructions for CEB and other earth construction methods.

In Argentina, CEB considerations are incorporated into building codes at the municipal level. In the Paraná municipality (Entre Rios province) the code includes CEB, which provides a national precedent to follow. Argentina allows CEB construction if it adjusts to the building requirements using concrete blocks and fired brick. There are eleven CEB factories in Argentina, mainly in Santa Fe province (eastern Argentina). However, the 2023-2024 economic crisis in Argentina has led to the closure of factories due to currency devaluation, low demand based on the rising cost of living, and the inability to pay employees. According to CEB manufacturers, the limitations on disseminating the material are its unregulated construction system, commercialization, low access to public and private funding, and potential consumer unawareness. The manufacturing barriers include the need for experienced production management staff and quality control of the block's sourced materials and masonry unit.

Technical Analysis Outcome

The emerging findings from the 4 research areas develop the considerations that encourage a context-responsive approach to building in Fiambalá. The considerations begin with the dry climate, flooding risks, and predominantly north solar pattern. A reused timber source is necessary to preserve the scarce Algarrobo trees. Existing groundwater uses encourage its regularization for potability and future conservation through water reuse strategies. Also, the potential applicant population exists in Catamarca, and there is a demand for housing ownership despite low needs. Following the typological domestic approaches to façade pattern and outdoor configuration integrates people's expectations in housing. The absence of a local building code involves navigating regional, provincial, and neighboring municipal ones for CEB construction standards. Adaptation to moderate seismic conditions is necessary to prevent structural failure and preserve the safety of occupants. The analytical outcomes of the studies become technical guidelines that shape housing design, environmental-human interactions, and employment of CEBs.

3. DESIGN RESPONSE & EXPERIENCE

Introduction

Designing buildings in Fiambalá involves the building considerations from technical and on-site studies. The design phase tests the applicability of research outcomes to demonstrate a considerate approach to their integration through the suggestion of a housing complex. An analytical strategy of 3 scales from urban, building to detail facilitates the design proposal exploration as a multi-perspective response. The urban scale represents the conditions of the existing immediate neighborhood, such as building uses, agricultural activity zones, and street-building interactions through configuration. The building scale expresses social sustainable housing through the envelope, climate response, programmatic, and spatial configuration while incorporating locals' housing configuration preferences. The detail scale focuses on the wall assembly and hybrid structure beyond compressed earth blocks.

Social Housing Precedent

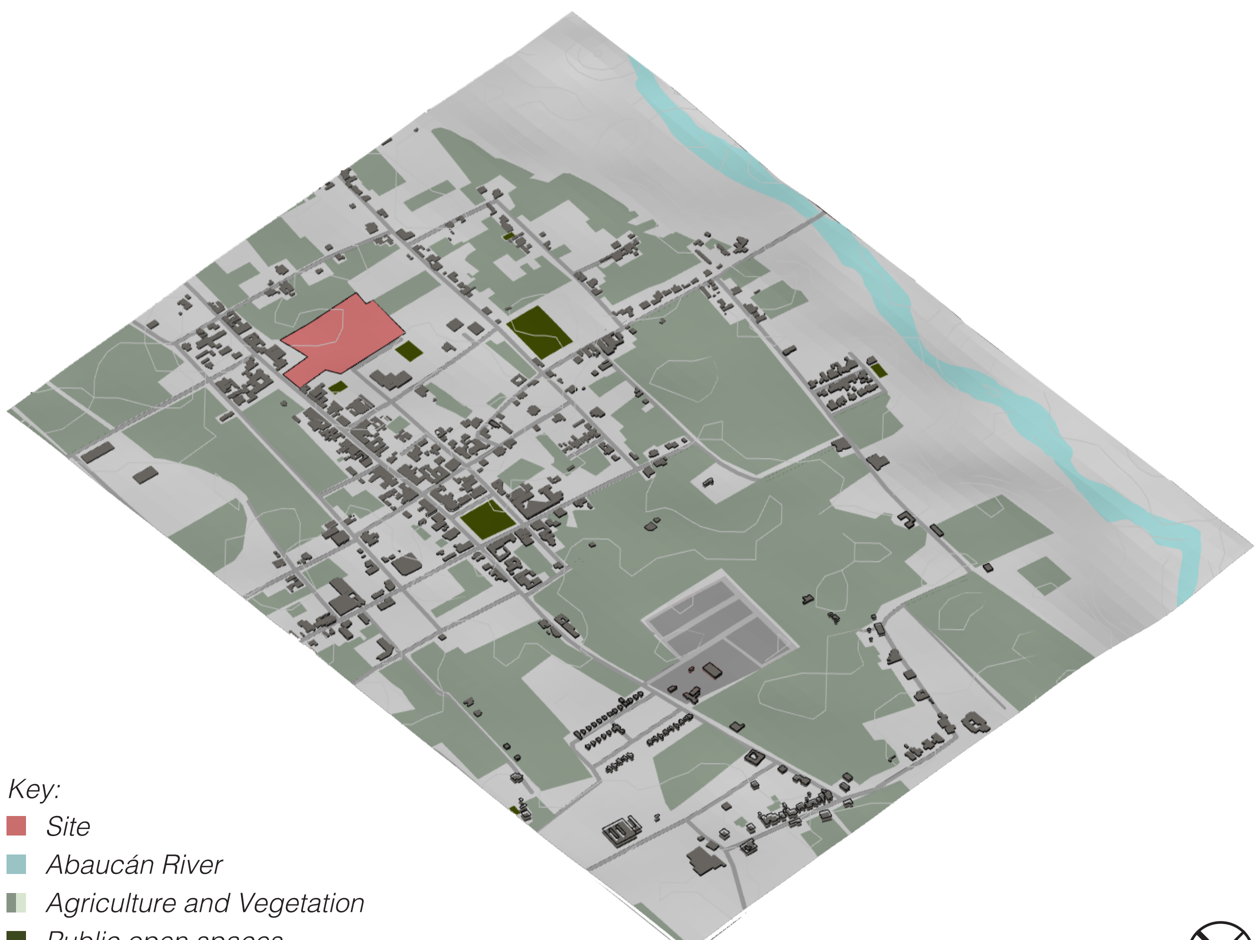
Exploring past social housing complexes responds to revealing typological needs, such as the need for adaptive facades. The site has a high building density and vacant spaces surrounded by grapevine agricultural land and is isolated at the town's margins (fig. 63). Duplex single-family houses in this local complex demonstrate construction additions through time. The standard housing is separate from the sidewalk and has no tree cover. However, there are variations exist with fences that serve as future walls, sidewalk-facade engagement and tree cover (figs. 64-65). Also, modifications include adding satellite dishes and active systems such as heat pumps for split air conditioning units on the house's roof. Façade adaptation includes shop windows or concealment through front gardens with informally handcrafted fences (fig. 66). The contrasting façade redesign represents individuality in a standardized housing neighborhood.. The examples demonstrate the considerations for adaptable modular housing and the residents' willingness to make self-driven modifications.

Fig. 63: Google Maps, Site plan, Jan. 2024.

Figs. 64-66 (top right to bottom): Modifications from standard to resident-reflective social housing, December 2023.

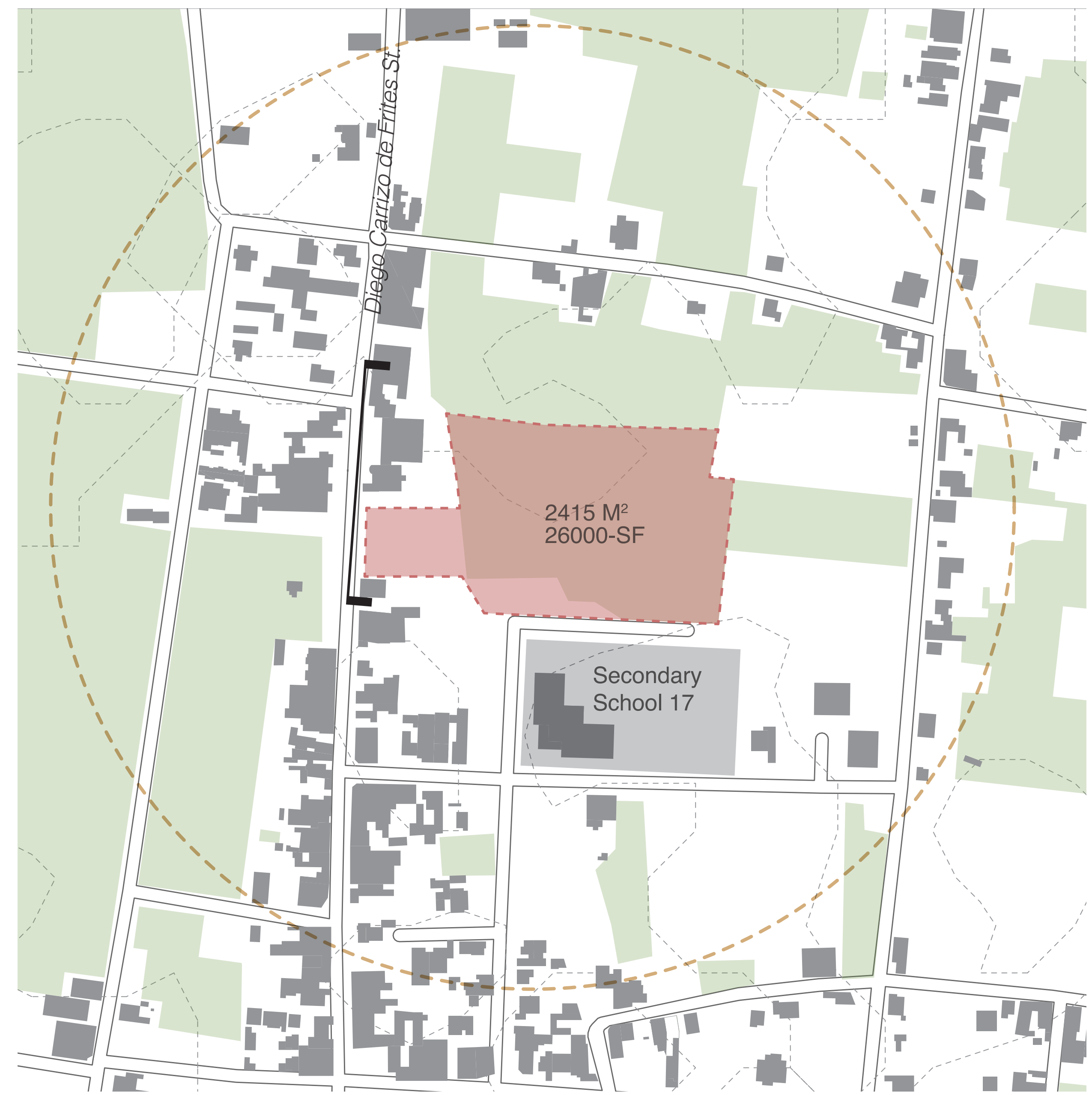
Site Proposal

The isolation of the social housing complex from denser building zones affects Fiambalá's urban fabric by supporting detached suburban expansion. As an alternative, I chose a site by the main commercial strip along Diego Carizo de Frites Street (figs. 67-68). The site choice fosters engagement with existing buildings as an experimental social housing space to develop CEB masonry use. At the urban scale, public spaces are scattered around the area, including the main square and a soccer field. Vineyards and vegetation surround the cluster of buildings around the site, providing existing programmatic and trees that become considerations for conservation.



Key:
- *Site*
- *Abaucán River*
- *Agriculture and Vegetation*
- *Public open spaces*

Fig. 67: Site proposal area and vicinity.



Key:
- *1000-ft Radius*
- *12-ft contour lines (topography)*

Fig. 68: Site plan.

Site Proposal

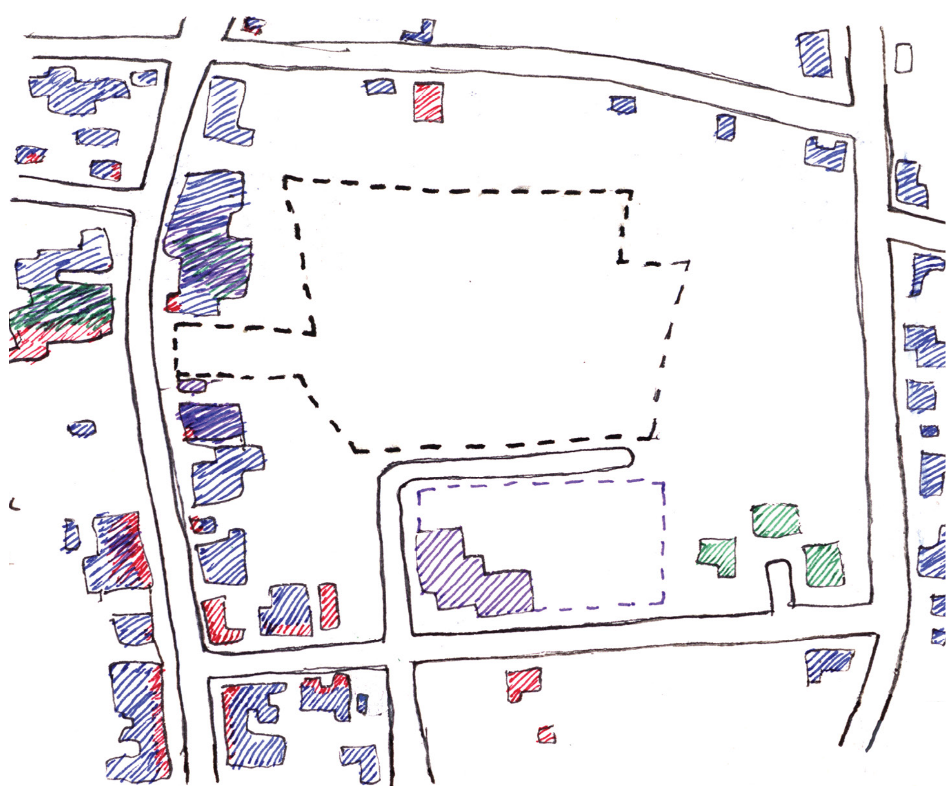
At a closer scale, the site reveals a dead-end street with an extension potential (fig. 69). Also, the site is next to Secondary School 17, which encourages families to settle and grow because of the walkable proximity to education. On-site adobe drying activity provides a continuing endangered local tradition that would revive through on-site CEB manufacture (figs. 70-71).

Figs. 69-71 (clockwise order): Dead end street, adobe drying uses, site section looking east, December 2023.

0 4 8 16 32

Urban Scale Proposal

The main building uses around the site are residential followed by mixed-use, commercial, public and educational (fig. 72). Extending the uses into the housing and open spaces in the site connects to the urban environment (fig. 73). The buildings are in a dense configuration per block to maximize land usage and the street layout continues existing streets. Also, the integration of farming crops preserves the existing ones and offers the opportunity for shared farming and community between neighbors.



Key:

- *Residential*
- *Commercial*
- *Education*
- *Public*

Fig. 72: Analysis of surrounding building's program..

0 20 40 80 160

An existing acequia watercourse runs through the site's western edge for shared irrigation uses in farming. Additionally, open park fields offer flexible gathering places for locals to host community events while preserving existing trees. Implementing two construction phases allows for testing the success of the housing program by measuring the level of engagement it generates with the community.

Fig. 73: Urban Layout and program response.

0 16 32 64 128

Urban Scale Proposal

The first phase involves a 2415 m^2 (26000 SF) area with 2 blocks including 4 adaptable corner and 36 single housing units accommodating couples. A commercial building on the main street draws people into the neighborhood's mixed housing shops (figs. 74-75). The second phase expands the area to 6130 m^2 (66000 SF) and adds 58 single-family houses as well as 11 corner units, while connecting the street layout to the northern and eastern streets. The housing development proposal prevents the erasure of the urban fabric by preserving existing buildings on the site. The focus is on the corner and single-family housing units because of their purpose as the introductory building prototypes for Fiambalá.

Fig. 74: Envisioning the neIghborhood's public life.

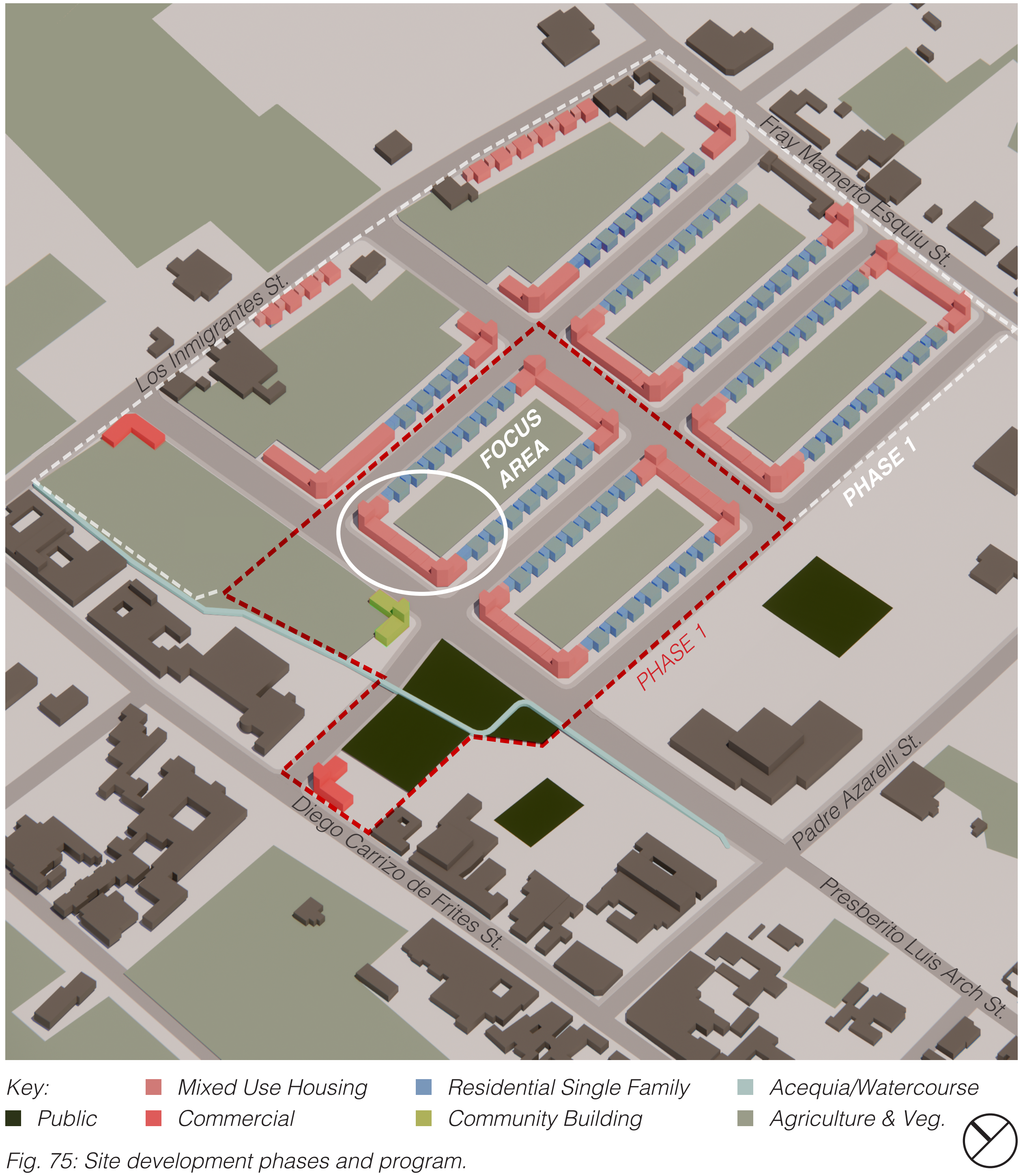


Fig. 75: Site development phases and program.

Program and Iterations

Developing the corner and single-family housing units, the multi-scalar approach to design facilitates unfolding the building's components and character (fig. 76). Corner units reflect two-story buildings around the Beato Mamerto Esquiu square. The building exploration process uncovers CEB's role as a masonry infill material in a reinforced concrete frame. Additionally, the building incorporates wind and solar impact on its envelope to define window size and placement (figs. 77-80) Front gardens with orchards and sun-shading pergolas respond to local implementation based on the existing single-family housing typologies in town. Integrating considerations for future expansion of the housing units facilitates future adaptability to changing user needs (fig. 81). The design influences and treatment of the front yard stem from the housing complex precedent's standard units' potential for modification. .

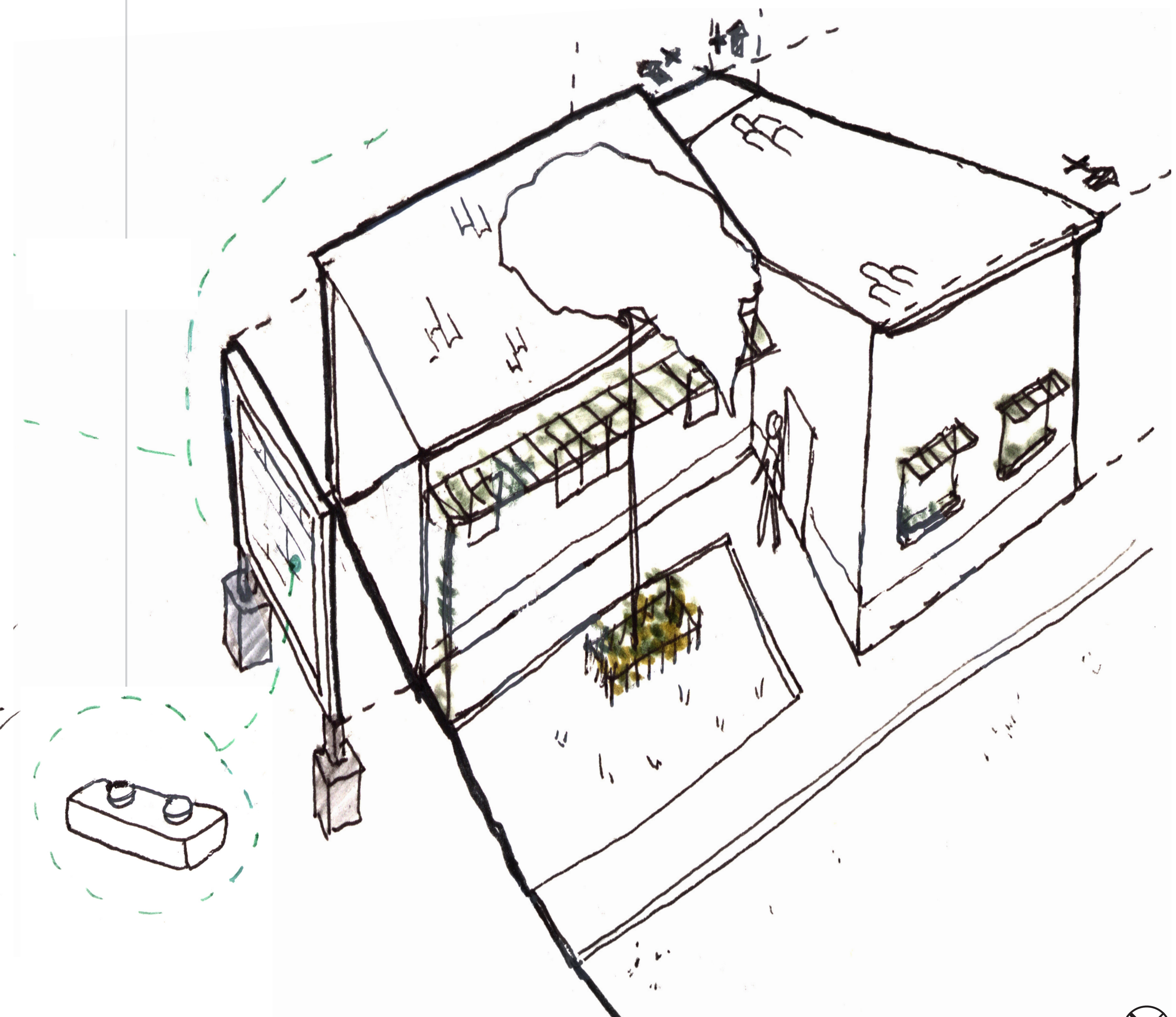


Fig. 76: Building to detail scale-based explorations.

Program and Iterations

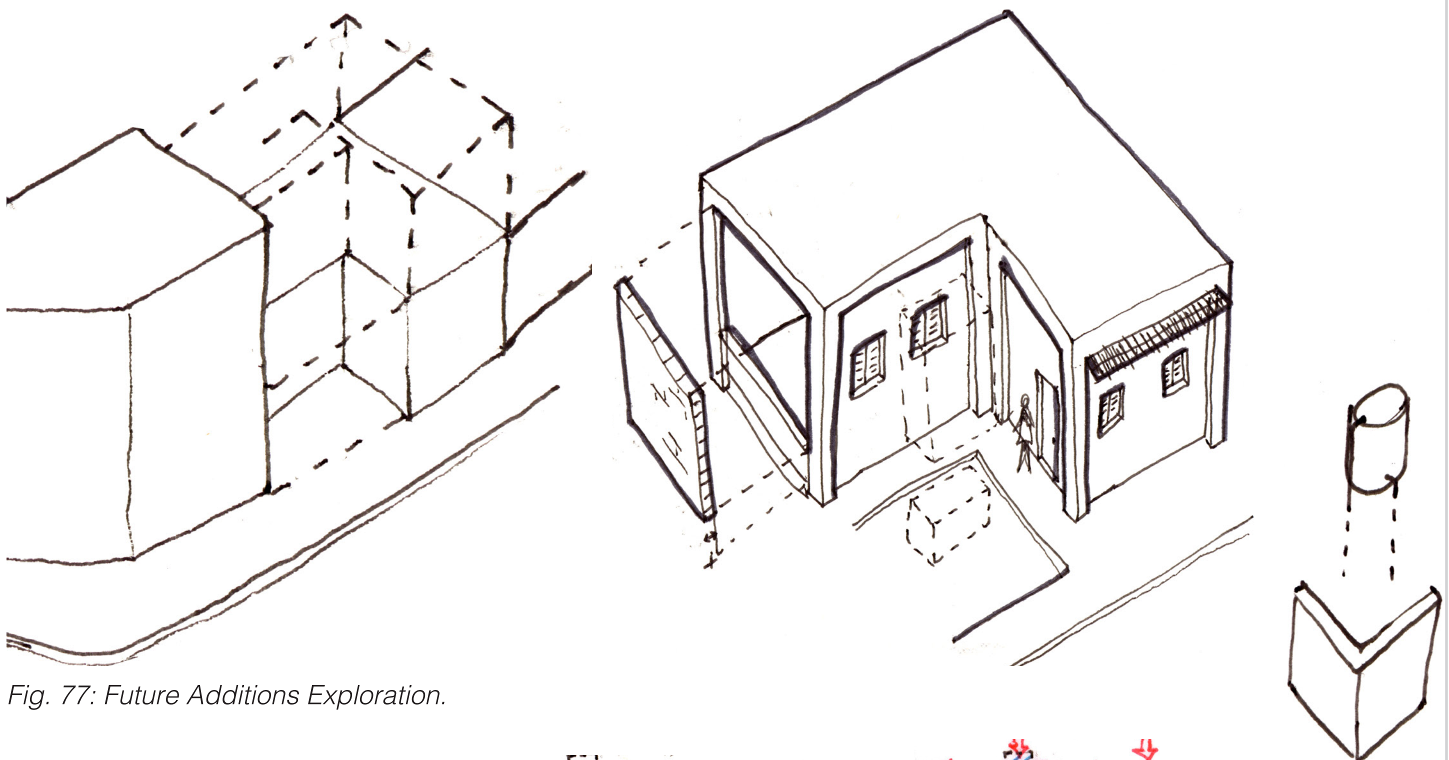
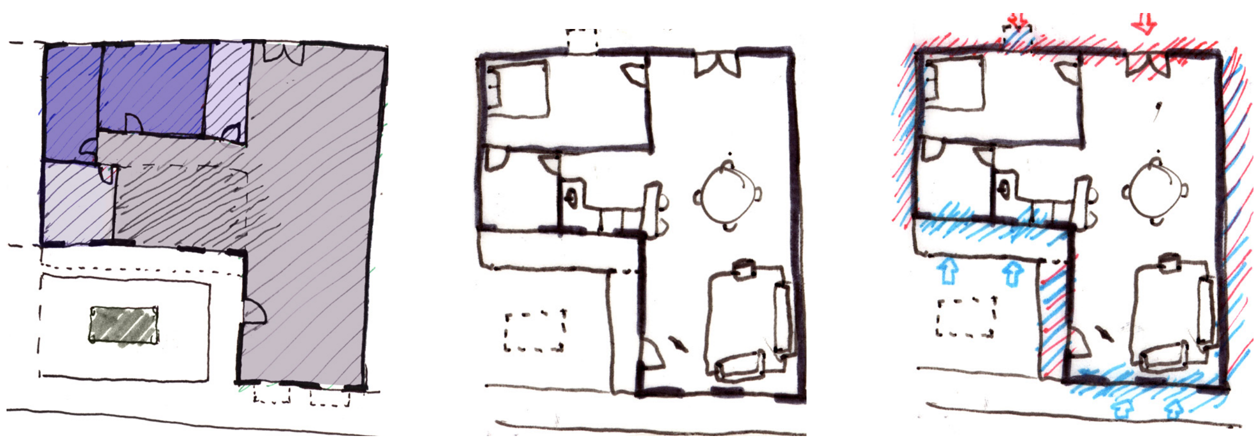


Fig. 77: Future Additions Exploration.



Key:
- *Kitchen + Living + Dining (KLD)*
- *Bedroom*
- *Exterior Coolth / Heat*
- *Bathroom*
- *Orchard*

Figs. 78-80 (left to right): Plan Program and Envelope response development.

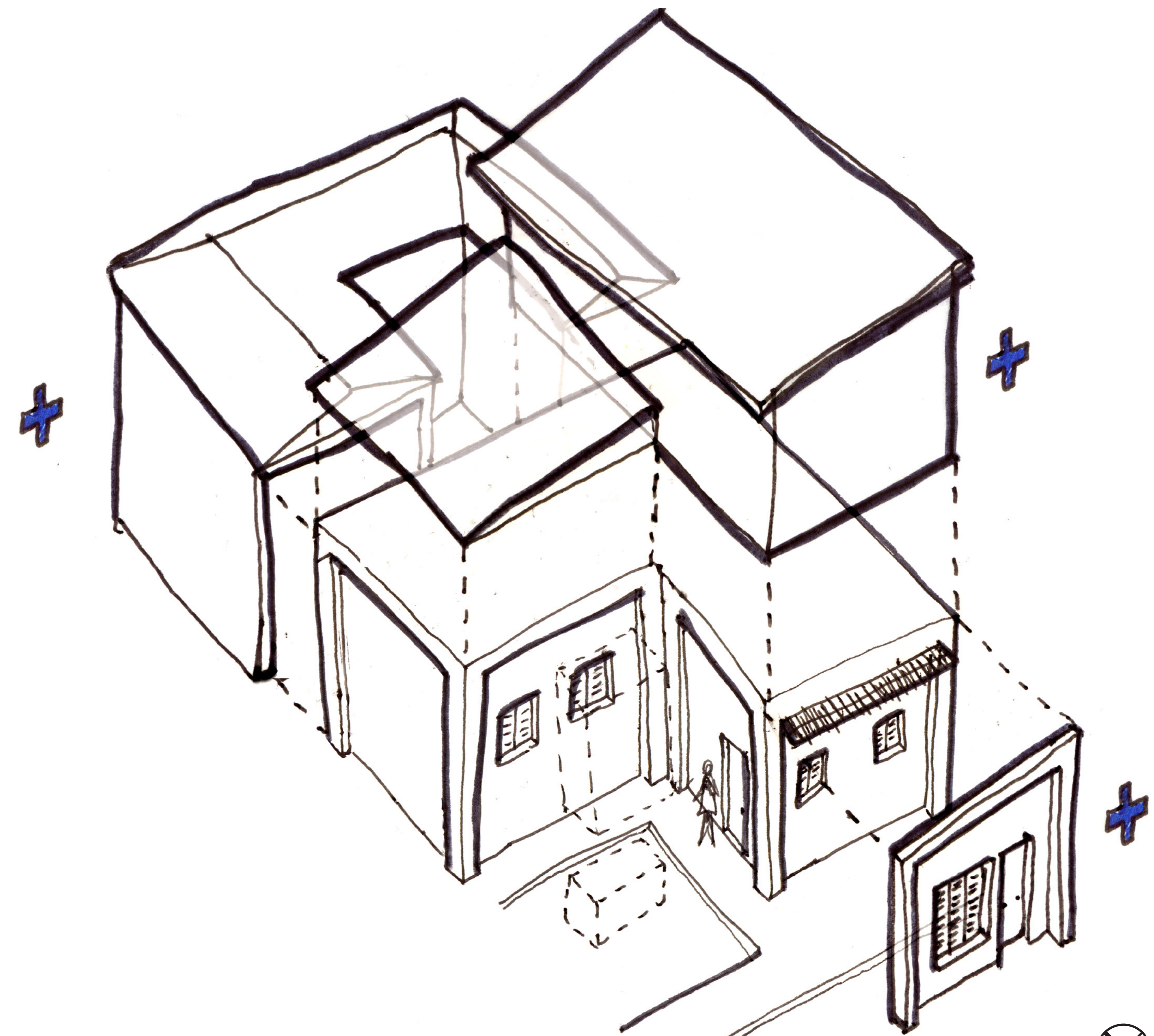
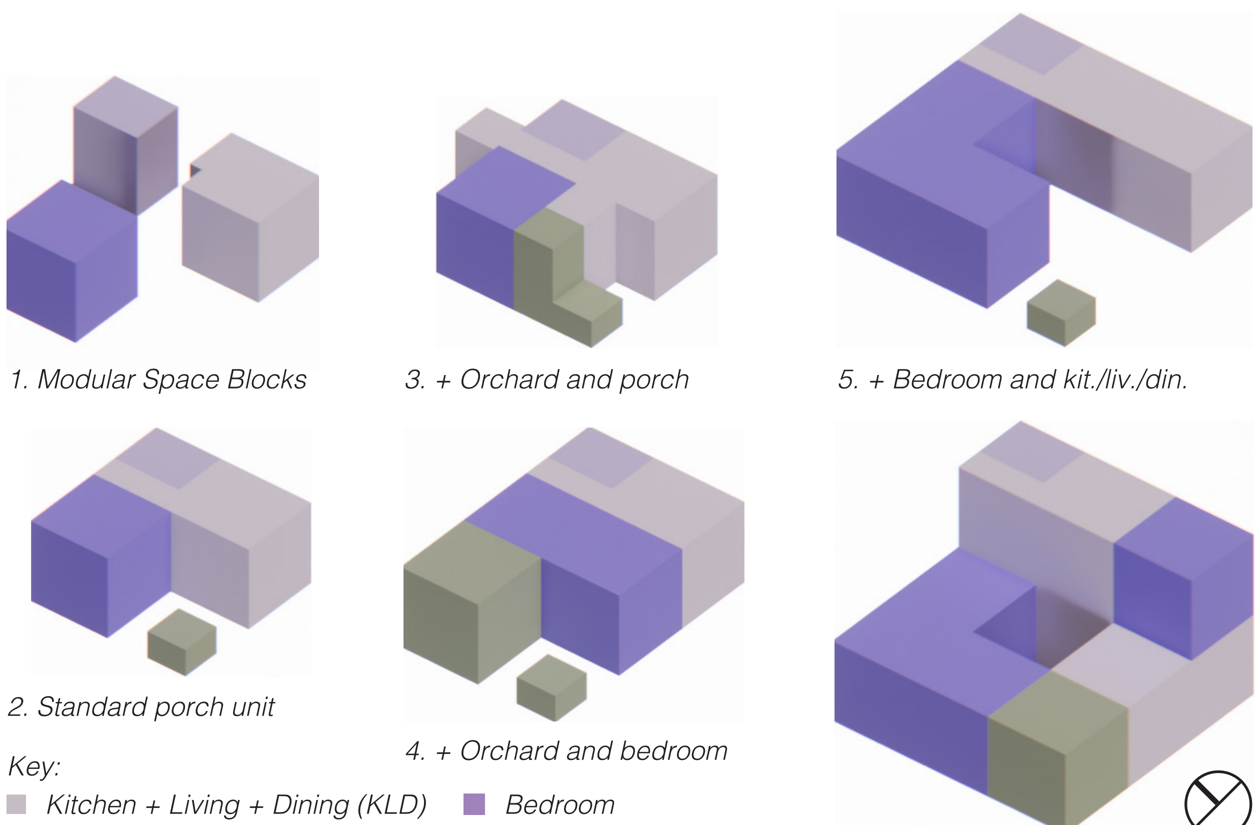


Fig. 81. Future addition and modification options.

Program and Iterations

The field trip and experience living in Argentina informed the program's exploration. Essential interior activity needs include living, cleaning, and resting to support the everyday life of residents. The single-family housing units become a porch typology through their response to solar shading and outdoor sheltered uses. Also, the program complies with minimum standard dimensions of 3mx3m (10x10ft) spaces and 2.5mx2m (7x8ft) for bathroom spaces. A set of modular blocks representing basic housing needs facilitates perceiving the porch unit's future configurations (fig. 82). The porch exterior spaces become a passive cooling tool for the northern façade to facilitate interior thermal comfort (figs. 83-84).



1. Modular Space Blocks
2. Standard porch unit
3. + Orchard and porch
4. + Orchard and bedroom
5. + Bedroom and kit./liv./din.
6. + Second level and Courtyard

Key:
- Kitchen + Living + Dining (KLD)
- Bedroom
- Bathroom
- Orchard

Fig. 82: Program distillation, densification and reconfiguration.

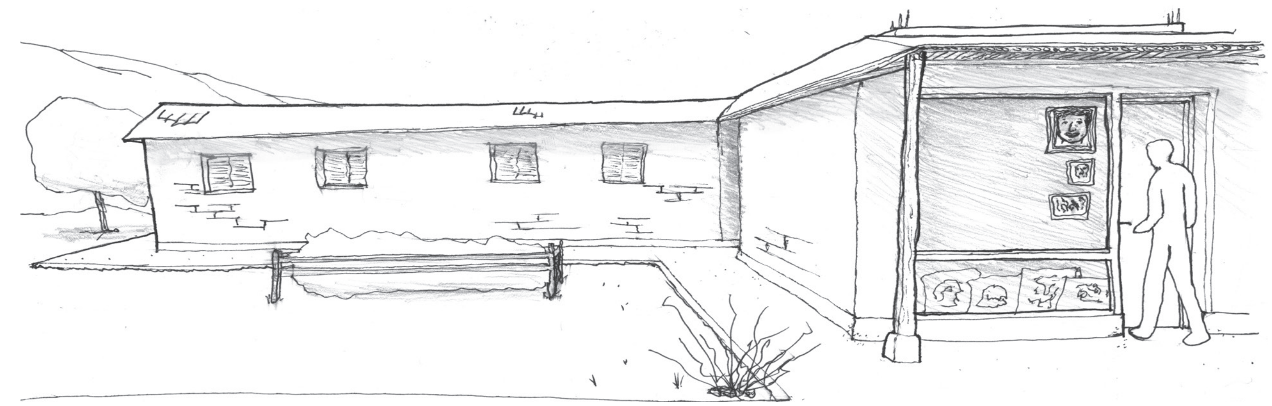


Fig. 83: Shared grapevine farming, direct visual/activity connection.

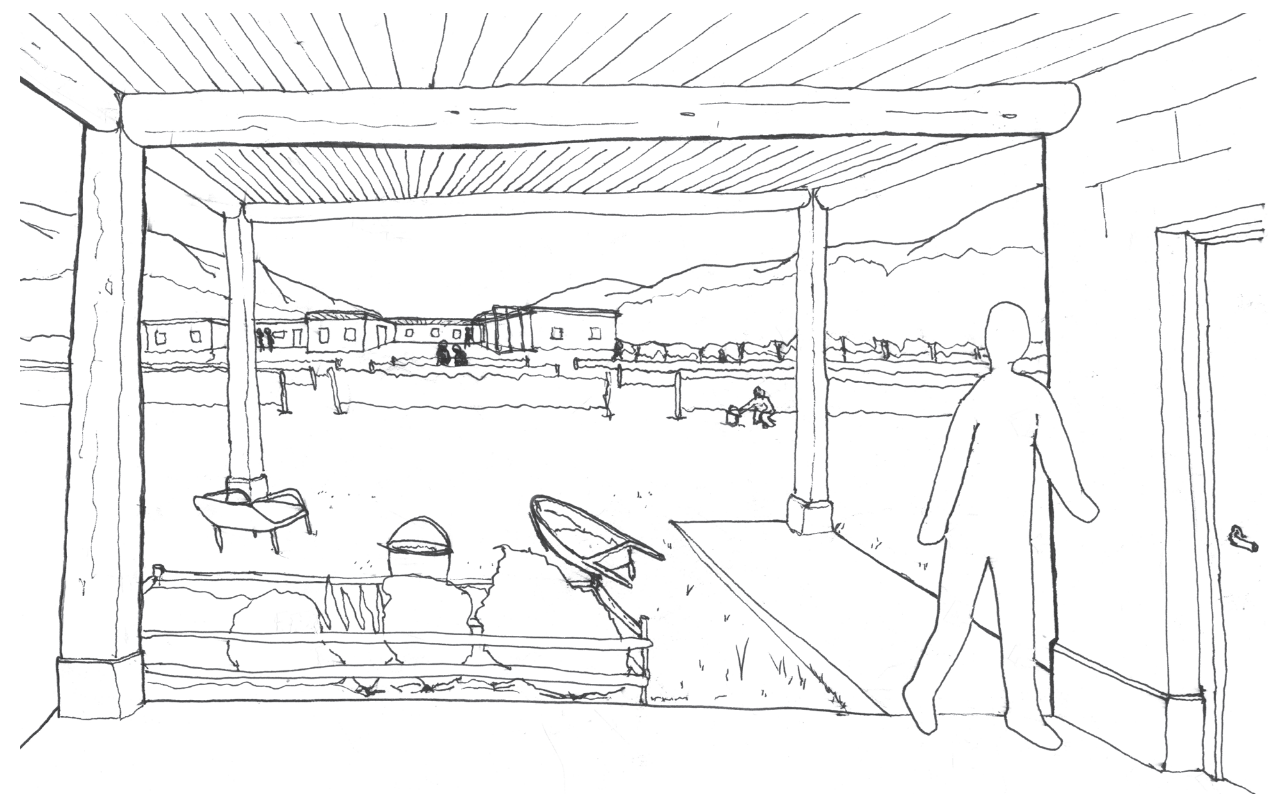


Fig. 84: Envisioning the approach to a shop front-adapted residential building.

Building Scale Typologies: Porch House

The porch units' refinement develops the modular blocks into livable spaces. The lot sizes follow the housing complex precedent at 10x25m (32x82ft). The unit's attributes reflect the local housing construction through the upper pressure water tank incorporation, small rectangular windows, and adaptable character (fig. 85). A moisture-heavy bathroom space with fired brick walls holds the pressure tank, piping, and kitchen sink connections. Building performance considerations include solstice-based shading through the sun-window relationship throughout the year to decrease the building's internal heat loads (fig. 86).The bathroom's fired brick walls prevent CEB from receiving moisture because of its high absorption risk. Implementing water reuse through hand-washing water filtration allows drip irrigation for future front yard vegetation (figs. 87-88). The porch and space size variations demonstrate the reconfigurable layout for adding spaces as the residents' family grows (figs. 89-90).

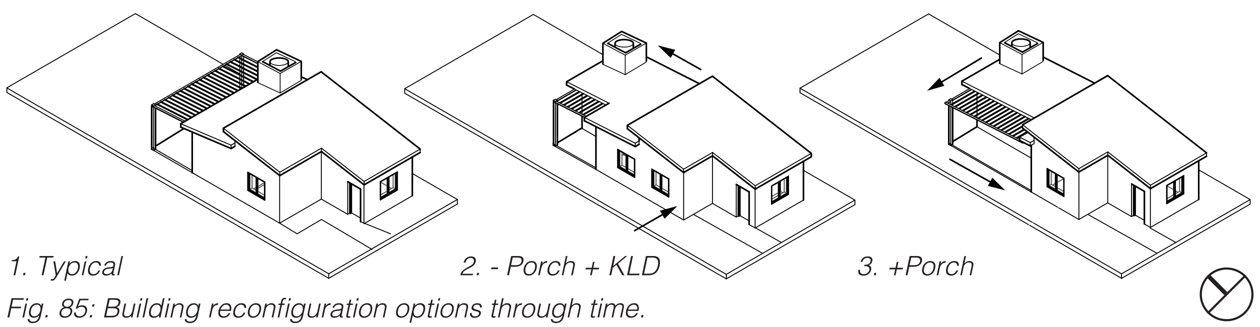


Fig. 85: Building reconfiguration options through time.

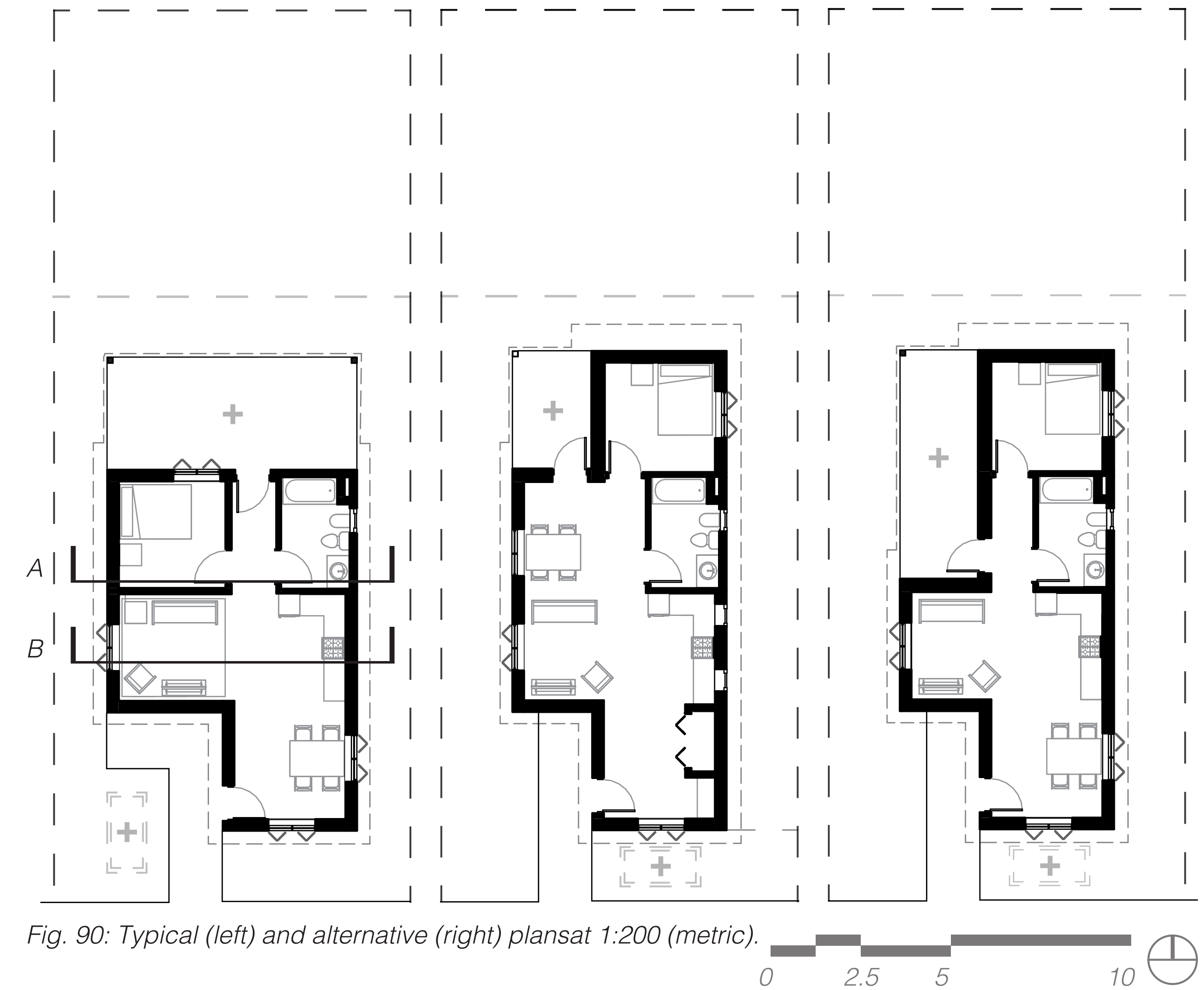
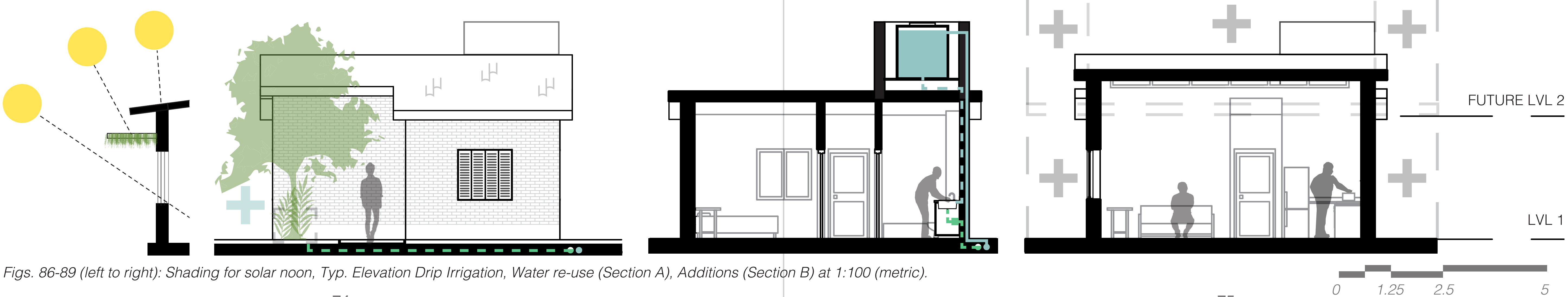


Fig. 90: Typical (left) and alternative (right) plansat 1:200 (metric).



Figs. 86-89 (left to right): Shading for solar noon, Typ. Elevation Drip Irrigation, Water re-use (Section A), Additions (Section B) at 1:100 (metric).

Building Scale Typologies: Corner Zaguan Rowouse

A combination of zaguan and rowhouse with a corner condition defines the weaving configuration of this unit (fig. 91). A zaguan is a housing typology with a central passage providing direct access between the building's entrance and an outdoor space, such as a patio. Zaguan houses are prevalent in the Southwestern United States, Central and South America, including Argentina's northwestern region. The passageway connects the neighboring units, encouraging neighbors to meet for an atmosphere of community (fig. 92). Also, the existing agricultural land offers to share or individually separate crops following the owner's decisions. A north-facing clerestory window allows sunlight in during the winter for passive heating. Also, the attachment adaptability of the single unit offers direct access to the corner shops. The building engages with the sidewalk at the ground level to attract customers, while the upper level serves as a private staff and office space (figs. 93-94).

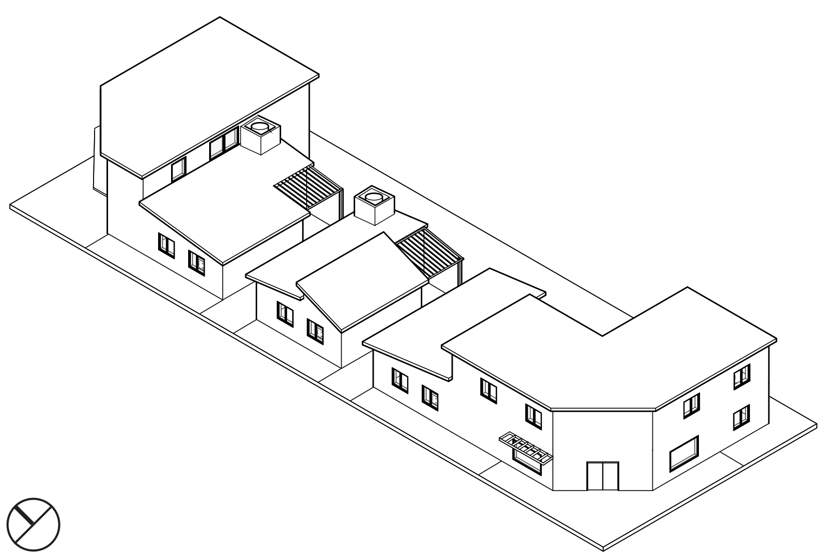


Fig. 91: Building configuration.

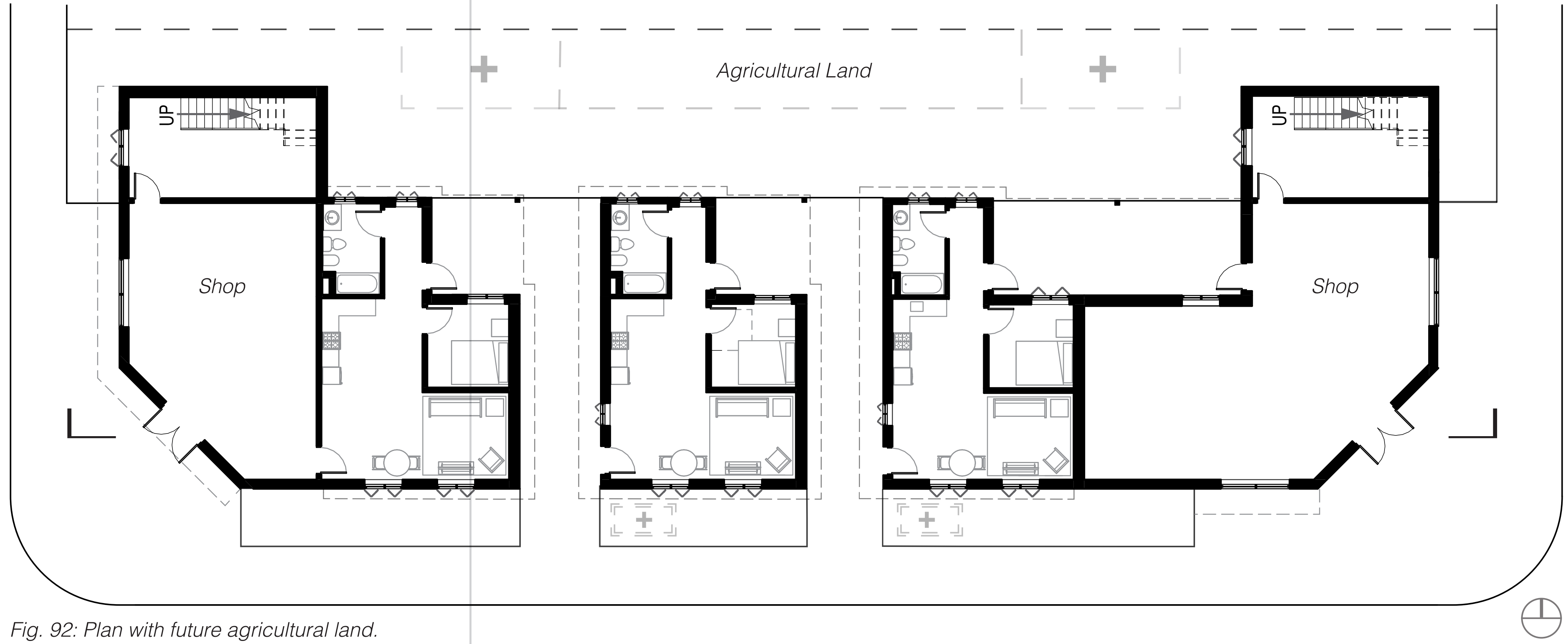


Fig. 92: Plan with future agricultural land.

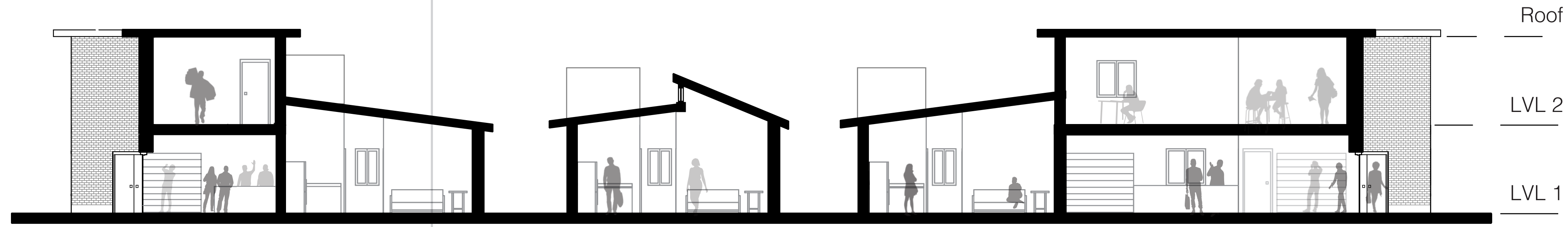


Fig. 93: Activity in section looking North.

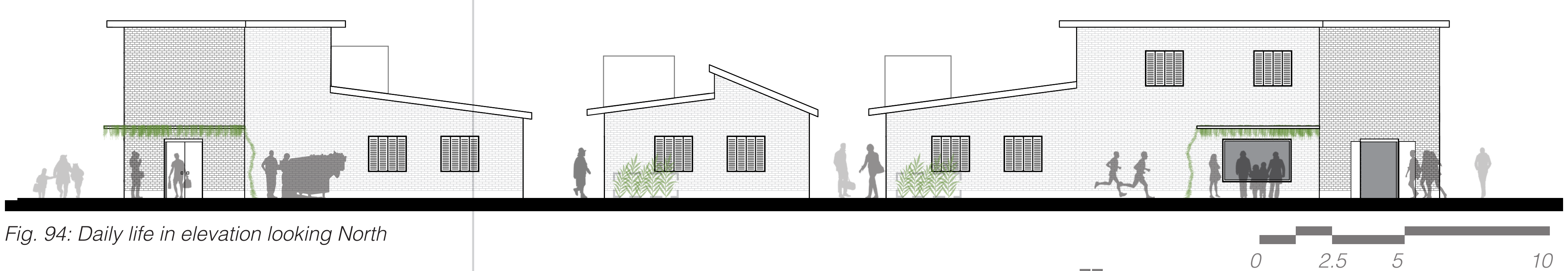


Fig. 94: Daily life in elevation looking North

Detail Scale

The detail scale uncovers the hybrid combination of reinforced concrete, wood, and CEB (fig. 95). Implementing strategies to minimize reinforced concrete lowers the environmental impact caused by its manufacture and material transportation to the site. The strip rubble trench foundation includes local stones due to their availability in Fiambalá. Cement bonds the stones together, providing load-bearing support for the wall. Gravel at the wall's exterior base allows rainwater drainage to protect the wall. Additionally, the protruding foundation protects CEB masonry from direct contact with water at the ground level. The wooden bond beams and framed joists offer an alternative structure to local reinforced concrete framing despite the absence of large surrounding wood sources. Optional materials facilitate owners' decisions on wall, ceiling, and floor finishes, including uncommon insulation. Developing the wall to the upper level and the foundation provides alternatives to existing construction techniques that depend on material importation.

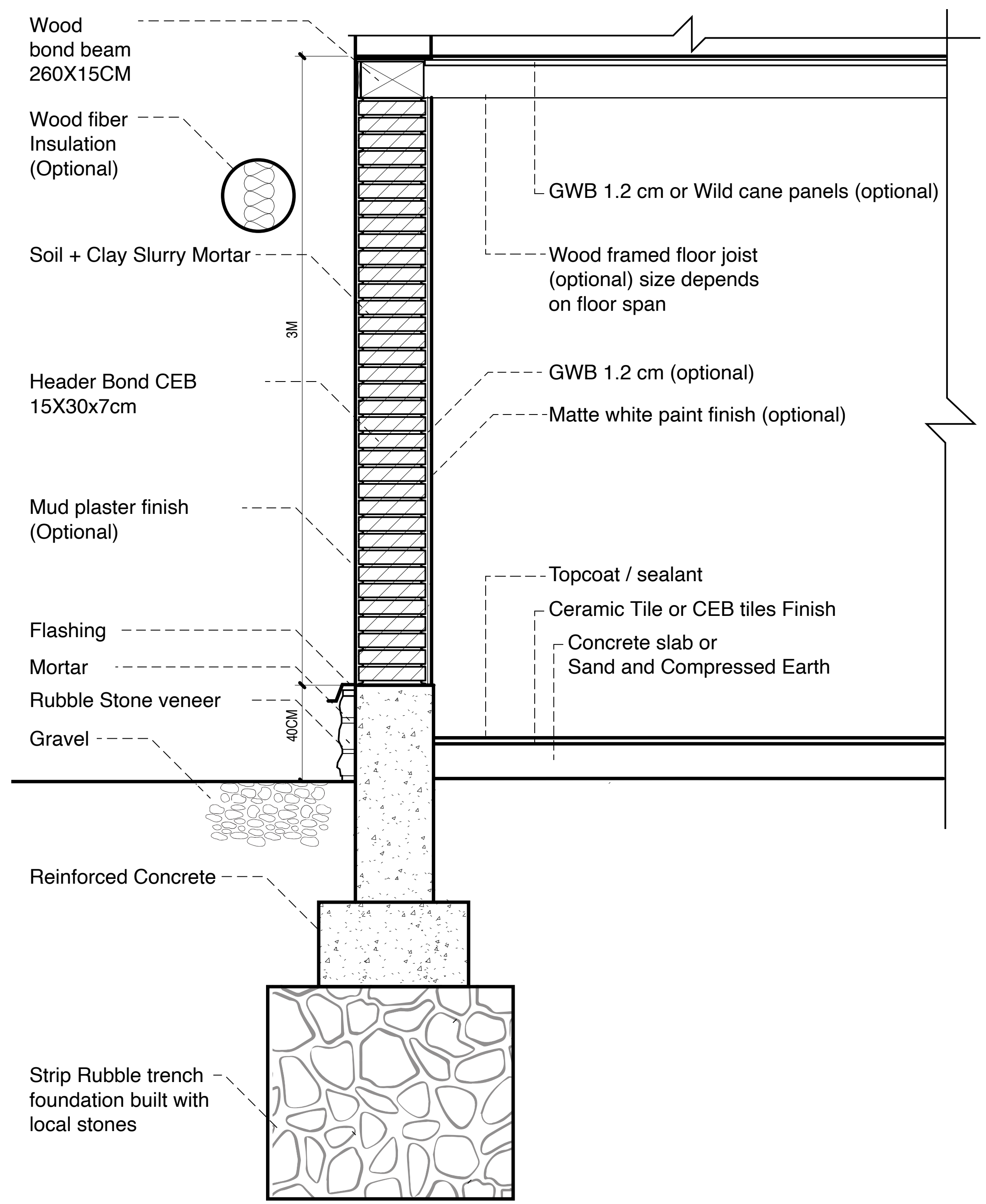
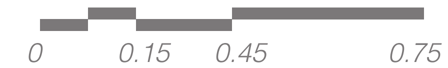


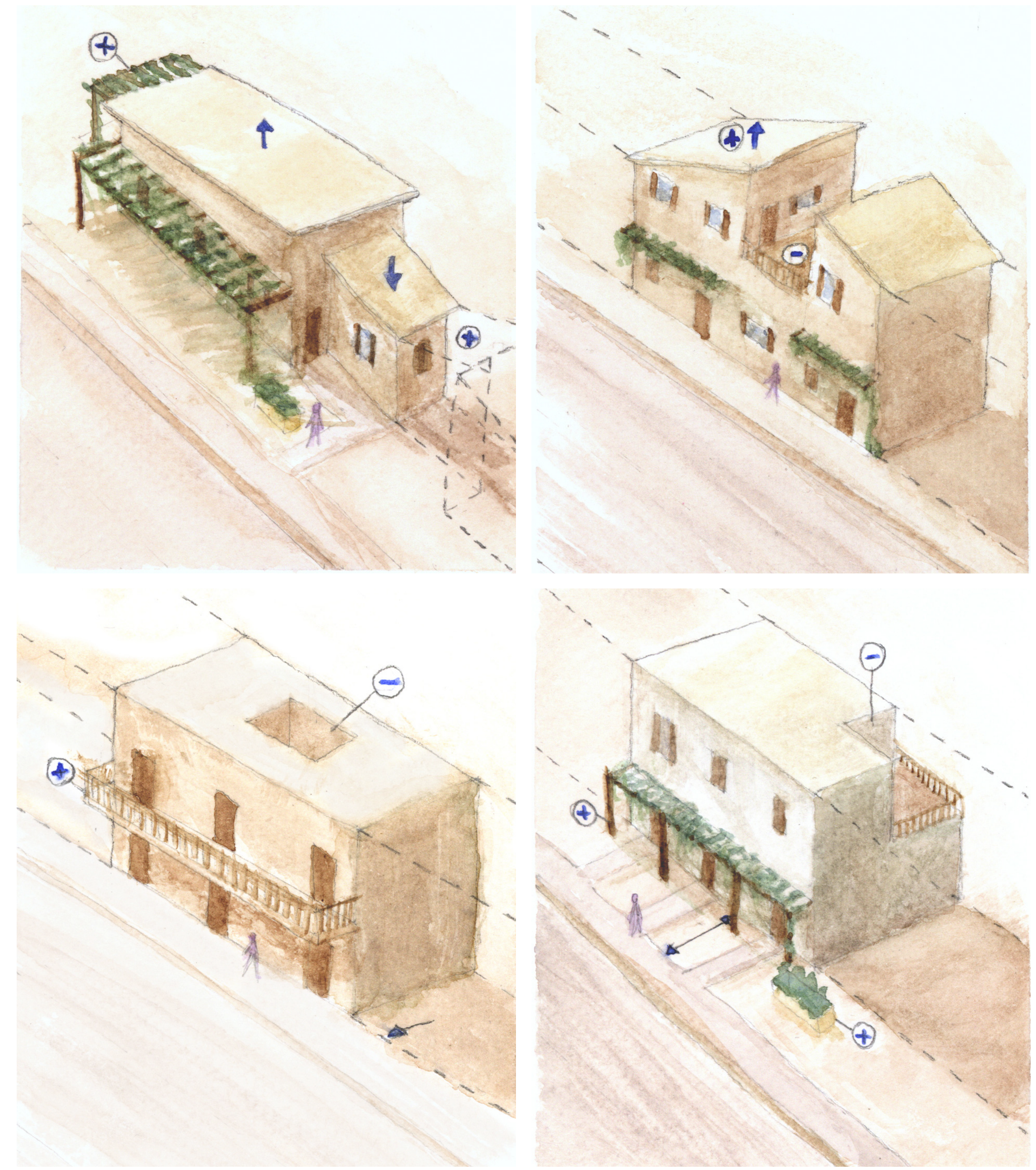
Fig. 95: Foundation-Floor-to-Wall Detail Section at 1:15 (metric).



Design Outcome

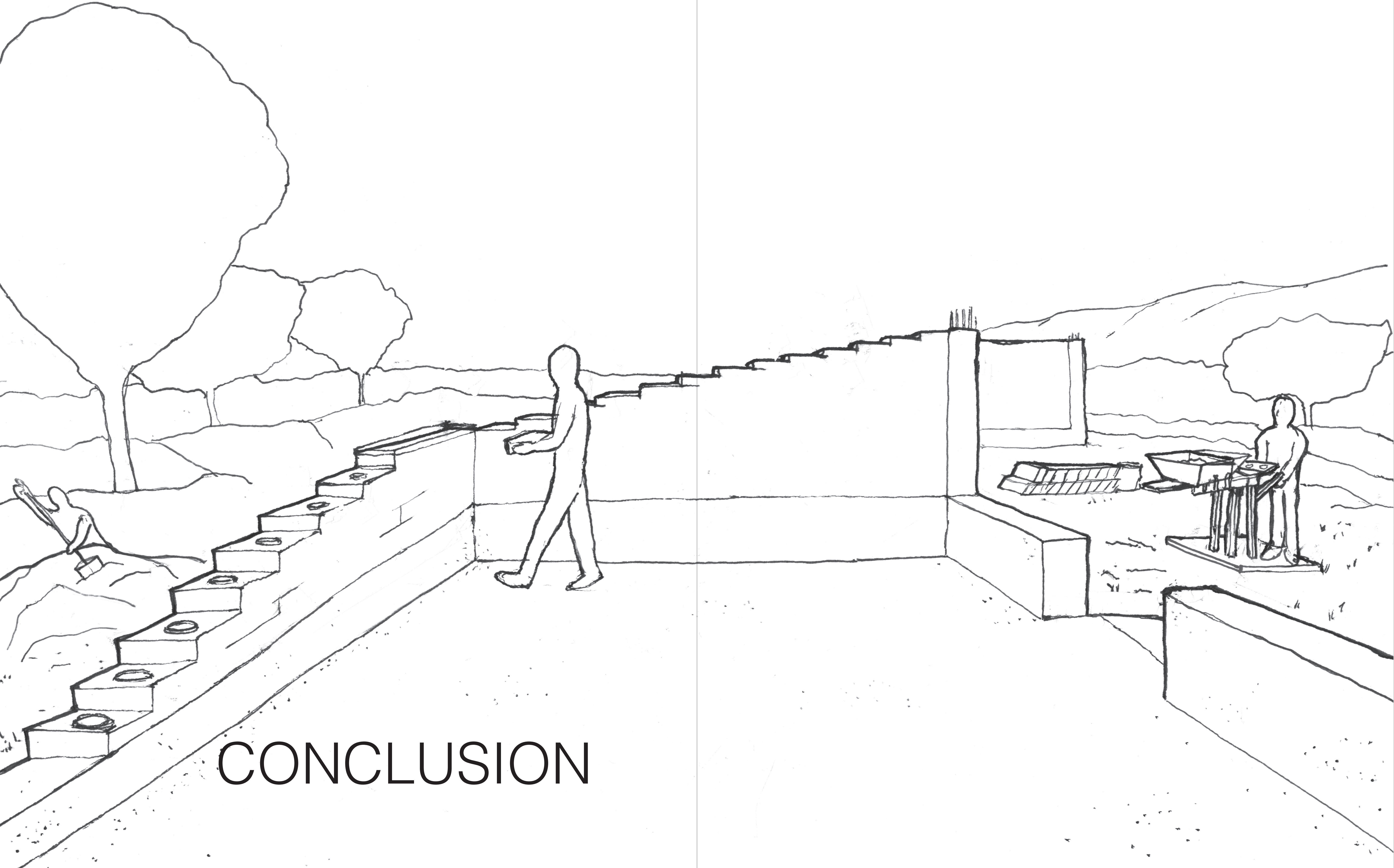
The applications of CEB through housing design facilitate visualizing outcome incorporation through the 3-scale development approach. From urban to detail scale, the multi-faceted study shapes the opportunities for locals to have a context-responsive proposal to implement CEB. The housing complex precedent informs the density in the blocks of the urban expansion plan. Preserving existing vineyards fosters the continuation of site uses that encourage communal farming. Also, CEB is integrated to the housing units as a contemporary alternative masonry wall material. Strategic phased planning allows testing that includes mixed-use, residential, commercial, and community buildings. The porch and corner-zaguan-rowhouse buildings offer reconfigurable and future alternative layouts with the integration of contextual considerations, such as buildings around Beato Mamerto Esquiu square (fig. 96). Alternatives to local structural construction invite opportunities for future homeowners and architects to assess cement reduction strategies involving CEB, wood, and stone (figs. 97-100). The design phase consolidates the vision for the context-rooted employment of CEB in Fiambalá.

Fig. 96: Approach to Beato Mamerto Esquiu Square.



Figs. 97-100 (in clockwise order): Future alternative single and multi-family housing configurations.

CONCLUSION



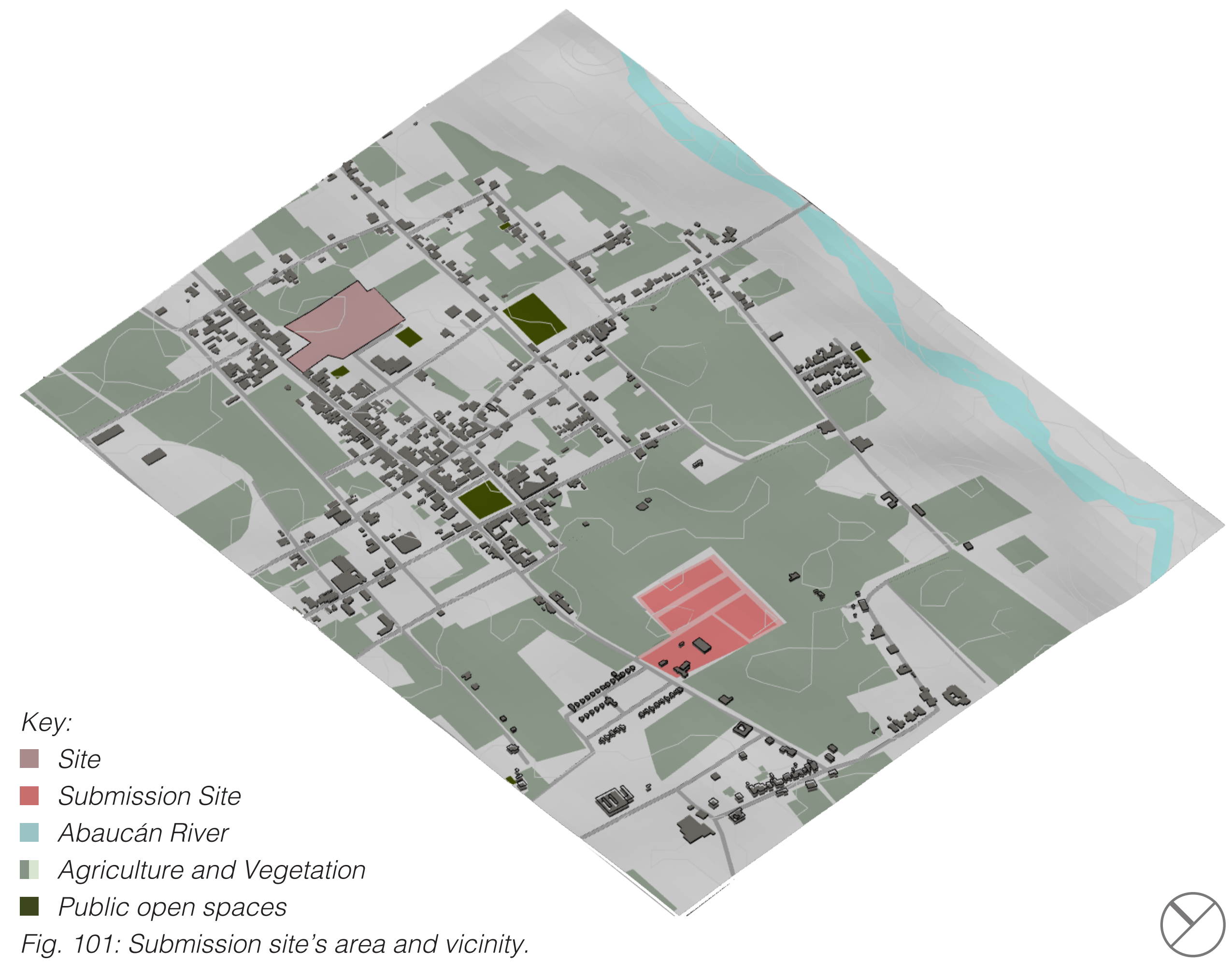
Conclusion

Reflection

Envisioning CEB for Fiambalá is the preliminary base for the material's adoption that challenges local construction transition trends away from traditional adobe. However, the proposal has limitations as its acceptance among the municipal government, architects, and residents depends on their engagement with the material as an economic driver. The comprehensive study approach develops a response based on place-based considerations, establishing a body of research work to support building design serving residents needs. Sustainable social housing provides the opportunities to implement CEB as an alternative masonry material. Additionally, strategies to foster community around the residents in the urban plan focus on the collectivization of agricultural land through shared crops. The connections made through the field trip establish future possibilities for work collaboration that strive to continue building on the thesis outcomes.

Moving Forward

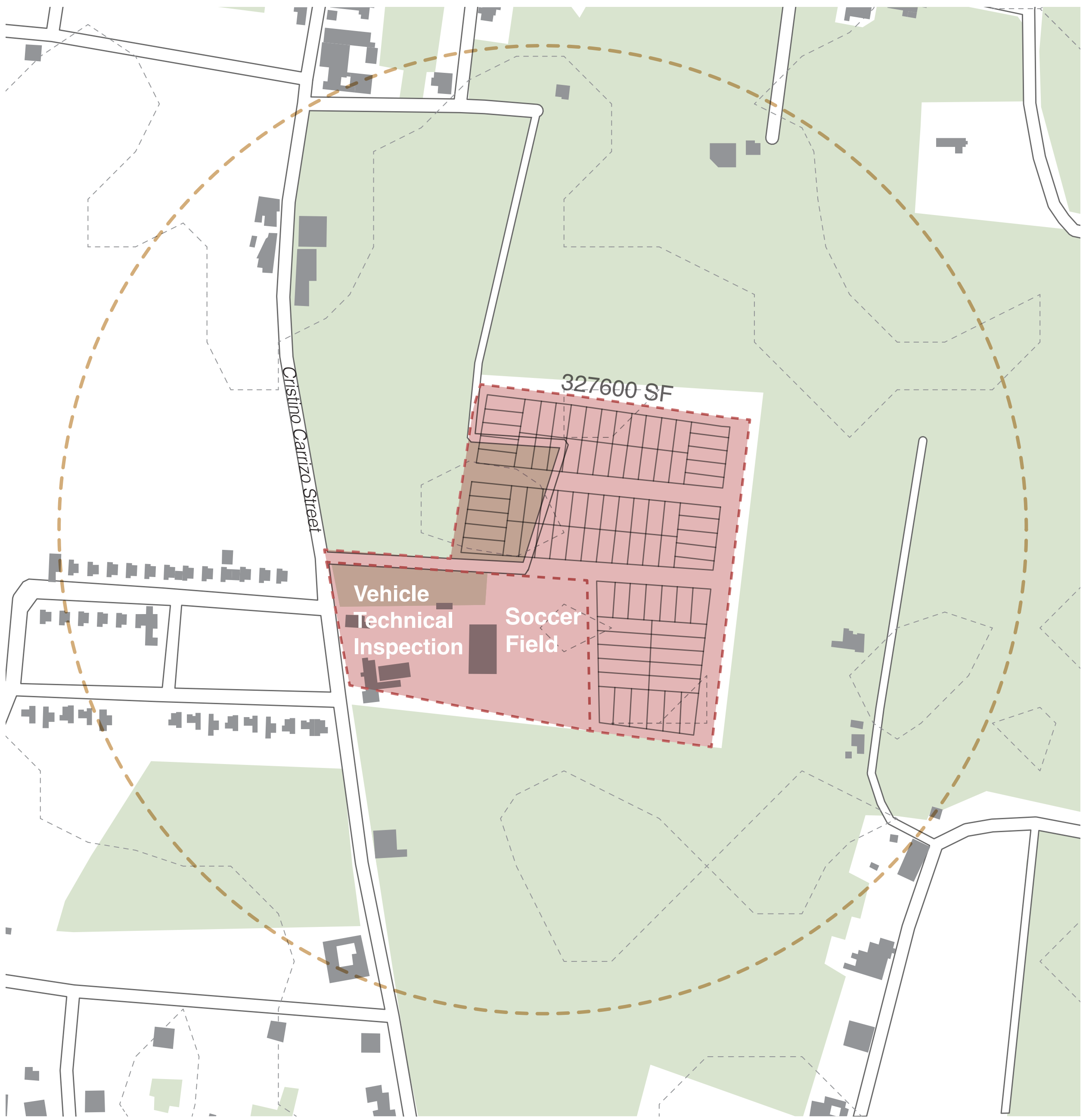
The next steps are to submit the thesis to a housing project's architect, conduct future research on the town's social makeup, and establish CEB factories with learning programs to engage the youth population. Also, developing the proposed housing by consolidating a CEB factory and estimating the construction material's cost will assist the architect's submission to the government. The housing's structural research would address seismic concerns, and the building lifecycle assessment would facilitate the CEB reuse potential to identify its environmental impacts. Catamarca's government funds the ongoing sustainable housing project south of the proposal site (figs. 101-104). Oscar Saenz, who I met on my visit to the town, specializes in designing and leading the construction of the housing project. During our meeting, Saenz mentioned his preference for lower construction costs, including wall masonry materials. Also, determining a quantitative cost advantage over imported alternatives would encourage CEB's local adoption. The path towards accomplishing the visualization of CEB in Fiambalá is to accomplish these steps and question them further through conversations with Saenz and the stakeholders, building them into reality.



Key:
Site
Submission Site
Abaucán River
Agriculture and Vegetation
Public open spaces

Fig. 101: Submission site's area and vicinity.

Moving Forward



Key:
- 1000-ft Radius
- 12-ft contour lines
- Site
- Agriculture and Vegetation

0 20 40 80 160

Fig. 102: Site submission plan.

Fig. 103: Soccer field by the site.

Fig. 104: Approach to the site looking east.

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Note: The figure captions that do not mention the author's name indicate that this thesis' author has produced the image.

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Conclusion

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CEB and Earth Construction in Catamarca - Data Collection Summary

Introduction

Fiambalá is a town located in the province of Catamarca, within the Argentinian northwest and a population of approximately 4700 people. A field trip to collect photographic evidence and get to know locals that would inform the thesis project was carried out between December 12th and 17th, 2023. The lenses through which this paper looks at Fiambalá include local economic activity, identity expression, local earth construction history, feasibility of a CEB social housing project and production infrastructure development. This paper is a summary of the observations and meetings acting as empiric and survey evidence. The main goal is to inform and orient research development within the project to engage in-depth perceptions of the multiple contextual conditions of the project.

Field-trip Observations

In Fiambalá, the identity of the town expresses itself through public art, industrial extractive, and agricultural activities as well as the local biodiversity. Also, the town's character is conveyed through historic and contemporary buildings, construction materials, exterior finishes, and organization of public spaces. Murals depict the indigenous community, collective soccer culture, viticulture, and endemic animals while statues emerge as monuments to women and agricultural field workers. There is also a mural against mining, stating "Let life without mining win in Fiambalá," revealing increasing resource extraction. Zijin Mining Group, a Chinese multinational state-owned corporation, has been carrying lithium mining exploration since 2021 in the Tres Quebradas salt flat. Zijin's extractive operations began in late 2023, expecting to produce 20000 tons of battery-grade lithium carbonate per year.

Neo-lithium, a Canadian corporation founded in 2016, was responsible for finding lithium extraction potential through exploration around Fiambalá and would later be acquired by Zijin Mining Group. However, the town's main economic activity supporting residents has been grape and olive production for export while there are a few wineries and olive oil processing businesses. Endemic flora includes deciduous chañar trees (Geoffroea decorticans), wild cane (caña brava, Arundo donax or Gynerium sagittatum) and algarrobo trees (Prosopis Chilensis).

The wildlife in Fiambalá site spotted during the field trip included Andean foxes, mountain lions, vicuñas, and condors. Also, insects appeared inside adobe cabins, including the "kissing bug" (Triatoma infestans, locally known as vinchuca) which transmits the Chagas disease. Therefore, Fiambalá's character and population are multi-faceted with global extractive economy issues.

Meetings

Pablo Dorado holds a doctorate in Architecture and is an expert in CEB construction in Argentina.

  3 meetings total.

Santiago Pedro Cabrera holds a doctorate in engineering and is a civil engineer focused on earth and lime construction, specializing in CEB.

  1 meeting.

Sergio Palleroni is an architecture professor at the University of Oregon specializing in Public Interest design working with underserved communities. Also, Palleroni works with UNESCO, connecting First Nations to facilitate international collaboration.

  1 meeting.

Daniel Oscar Saenz is a local architect in Fiambalá experienced in designing and leading construction with adobe who was the town's secretary of public works until 2021.

  1 meeting and constant communication through messages.

Maria Gabriela Watkins is an architect in the Capital city of Catamarca province, a professor at the University of Catamarca, bioclimatic design expert with CEB experience.

  1 meeting, Watkins expressed interest in further meetings.

Erika Walter is an architect in the Capital city of Catamarca province with extensive experience building with CEB and indigenous people's communities.

  1 meeting, Walter was interested in sharing photographic process of CEB construction.

Amira Yarbouh is a technical school instructor and an architect in Tinogasta with a hydraulic press for CEB production. Yarbouh worked on an olive oil factory shed using CEB in Tinogasta.

1 meeting, Yarbouh is willing to provide help as needed.

Mariela Soto is the school principal at the CEB-built school in Tinogasta.

1 meeting and constant communication through messages.

Martin Irazú, tourism secretary in Tinogasta, manages the “La Aguadita” thermal complex.

1 meeting only, Irazú is willing to provide help as needed.

Erika Andrea Peralta is an architect in Tinogasta and its secretary of public works.

1 meeting, Peralta is also willing to provide help as required.

Susana Castro is a local resident of Fiambalá and owns an artisanal shop and short-term rentable cabins in her adobe house’s complex.

1 meeting, Castro has shown interest in giving help as necessary.

Meeting Notes

Pablo Dorado

The conversation centered on earth construction regulations, CEB material production industry, and social housing prototype challenges. Other topics covered in the meeting were social-centered building technologies and contextual thesis factors. Dorado discussed the need for municipal earth construction regulation as there are none at any local level. Peru’s building regulations serves as a regional example since it has similar high seismic conditions to Fiambalá. Also, Dorado proposed a CEB manufacture model involving the connection of the material source and manufacture chain while incorporating the consumers as workers. Also, the inclusion of training facilities for production and sourcing would benefit workers, providing a social technology. Dorado mentioned that cooperative business models do not work in Argentina due to the corruption of governmental and larger construction companies.

The social housing prototype challenges included contextual factors such as construction logistics, local resources and CEB factory infrastructure.

Another challenge posed by Dorado is to work without cement and reinforced concrete to help stabilize CEB. Dorado suggested that external factors such as political, social, and economic would help analyze the feasibility of local development through an adaptable prototype along with material manufacture and construction infrastructure. In addition, the consideration of the changing political context will help understand its impact on public-oriented built infrastructure using earth materials. The meeting with Dorado helped examine considerations of earth construction and the thesis’s boundaries in relation to contextual problems, while it also helped organize the future objectives of the thesis and the data compilation presentation.

Santiago Cabrera

The discussion focused on CEB in Argentina, its stabilization, processes, and production cost including negative and positive aspects. Other topics included the seismic resistance of stabilized and non-stabilized CEB compared to fired brick and cement blocks. The discussion also focused on the business model’s feasibility in Argentina and moving beyond CEB for low carbon outcomes. Cabrera mentioned that cement addition to the CEB mixture for the least carbon impact is 2.5% of the whole mix, which withstands 3 to 5 megapascals which measures the pressure and tensile resistance. Other specifications include the 14-inch threshold for thermal comfort and an 18-inch thick CEB wall in a house. Also, Cabrera was critical of using lime to stabilize CEB due to its similar impact to cement’s production process.

As for the CEB business model, Cabrera emphasized the need to establish the criteria in manufacture and construction and the cheaper cost of fired brick due to its informal production. Another factor in the failure of CEB is the for-profit business model because of the fluctuating need of the mixed public-private market. Cabrera establishes that a viable alternative is a housebuilding (construction/material production) cooperative where, for example, 100 landowners in a housing plot agree to build with the same material. The business model provides work self-sufficiency as material production begins when internal construction demand requires it. Cabrera suggests including an integral construction system which expands the industrialized and lower embodied carbon of CEB as the masonry material compared to fired brick and adobe.

Sergio Palleroni

The meeting focused on the outcome summary pamphlet to engage Fiambalá locals and precedents of organizations that work with earth construction and communities. Palleroni suggested analyzing local values and reviewing manuals of construction that incorporate CEB technology. Another suggestion was a cartoon-style pamphlet format to convey the essential graphic message. Palleroni recommended the Auroville Earth Institute in India which has trained and helped people building their dwellings through earth construction. Another recommendation was thinking at a systemic level that reveals the potential failures of the proposed CEB construction infrastructure. The boundaries of the thesis were also discussed, including its potential development phases, analyzing local architecture, engaging in soil studies for sourcing CEB manufacture materials and including an economic plan to implement the required building infrastructure.

Daniel Oscar Saenz

The conversation included the eco-sustainable housing project in Fiambalá including a plan of 81 lots. Other topics were adobe's traditional seismic-resistance techniques, its dwindling construction use, and the locally followed building code. Oscar was open to using CEB in the project's construction and recommended sending him the pamphlet so that he could share it with the people in the project. The local seismic-resistant adobe techniques include thicker walls above 3ft while allowing the concrete in rebar frames to weld both materials. However, adobe availability as a construction material is decreasing due to less local adobe makers and cheaper purchase of industrially produced alternatives. The town's construction usually follows the building code of the capital city in the province of Catamarca which does not address earth construction.

Maria Gabriela Watkins

The discussion included community-centered design options, approaches to introducing CEB to locals and organizing the manufacture as well as the construction infrastructure in Fiambalá. Also, Watkins revealed the process for local construction and its interaction with the municipal government.

The construction of a community hub such as a club for collective activities in an adaptable social housing complex with a shared water tower would strengthen the ties among the generations of residents. The development of CEB practices has to be gradual and in collaboration with non-governmental organizations that have experience training and building with non-traditional materials. The permit process requires presenting a construction plan intent letter to the municipal administration due to the absence of technical personnel to control the building drawings.

Erika Walter

The main topics included CEB construction and regulation in Catamarca through precedents and working experience. Walter emphasized the need for earth construction local to national regulation while revealing that some provinces have their regulations, such as Mendoza and Salta. Moreover, there are municipal building regulations such as in Catamarca's capital city, but these do not cover earth construction. Walter has worked with the Interamerican Bank of Development which has funded her school building projects in villages surrounding Fiambalá, including one in Antofagasta de la Sierra. In Walter's experience, the internal humidity prone walls in bathrooms or kitchens include water-resistant materials. Currently, she works on a K-2 through K-5 building in Antofalla, collaborating with the chief and local indigenous community producing a CEB construction.

Amira Yarbouh

The discussion was about workforce and construction with CEB and its implementation in communities that have experience with adobe. Yarbouh led the construction of an olive processing factory's CEB shed, during which she encountered problems with the workforce. The main problem that concerns Yarbouh is construction workers using mud plaster between interlocking CEB, mimicking techniques used in adobe buildings which were unexpected during the building phase. Also, she emphasized the need to find an adequate construction group due to misunderstandings that she dealt with which jeopardized the building's process. Yarbouh compared implementing CEB to Argentina's gradual adoption of reinforced concrete in the 1970s, revealing that acceptance of a new material takes time.

Erika Andrea Peralta

Peralta recommended looking at the “Escuela de Amor y Esperanza” since it is an example of CEB in the region, specifically in the town of Tinogasta. Peralta suggested looking at the “La Aguadita” thermal complex and a school in the village of Taton because of their CEB construction. Also, Peralta revealed that the building code that the municipality of Tinogasta, south of Fiambalá, looks at for earth construction is the one used in Peru. Amira Yarbouh was recommended as a contact by Peralta, as she has a small CEB building and manufacturing studio using a hydraulic press to make the construction material. The red pro-tierra was another source discussed that would help expand the network of professionals that could collaborate as consultants for the thesis.

Non-architecture professionals and Locals:

Martin Irazú

The meeting consisted of a tour through the “La Aguadita” thermal complex including 4 earth-based cabins built between 2006 and 2007 in Tinogasta. Irazú discussed the complex’s unavailable cabins and maintenance issues. The main problem in the cabins is the inefficient thermal insulation ceiling, which requires an assembly that prevents wind and sun from seeping through. Also, there is interior moisture damage given the need for the roof’s water insulation to prevent water from getting to the walls. The cabins’ structures have a small number of beams supporting their loft floors requiring a structural engineer’s inspection. Irazú revealed that tourists come to the complex in the summer due to its cooler water (63°F-70°F), while Fiambalá’s are predominantly in the winter and more international visitors.

Mariela Soto

The focus of the discussion was on the conditions and maintenance experience at the “Hope and Love Number 3” school for children with special needs. The school includes CEB masonry in most of its lower walls and is located in Tinogasta, a southern neighboring city of Fiambalá. Soto mentioned accessible circulation, cross-ventilation, and ceiling height design aspects of the building. Also, Soto discussed the corrugated steel roof’s water filtrations and the usage of drywall in the school’s ceiling, which eventually fell and a membrane insulation replaced it.

During the last seismic event in 2023, Soto recalled that the only structural issues were cracks in a party wall with a neighboring building and an exposed steel column disconnected from CEB masonry.

Susana Castro

The discussion with Susana Castro, who owns and runs the adobe-built cabin complex called “Killa Qullqi,” involved earth construction processes in Fiambalá and her cabins. Also, the conversation addressed the quick process of modernization that Fiambalá underwent from a local point of view and the changing climate. Castro has lived in Fiambalá for 17 years, when she arrived, local jobs were under the municipal government and in vineyards. She stated that many people living in Fiambalá came from its surrounding mountain range. Also, Fiambalá has not experienced a proper transfer of building traditions between generations that underwent the local modernization process. The town’s social and economic status is reflected in the built material, as wealthier families build with imported ones that convey permanence and power.

Castro described quincha as a drywall alternative that is economic and easy to make, where the work effort is lower when compared to adobe. Quincha involves a construction system using cane that forms a framework wrapped in mud and plaster. Castro has used the quincha for two of her cabins, one internal wall and all the walls of a cabin which has external cracks. The traditional roofing system assembly that Castro uses includes from top to bottom a layer of concrete, mud, plastic, cardboard and for the ceiling, wild cane (gynerium sagittatum). Before construction begins, Castro usually hires a truck that transports around 400 adobe bricks and workers, where the price of the bricks is approximately equal to both the truck and the workers.

Groundwater Management Infrastructures: Public Policy and Applications

Introduction

Groundwater is water collected below the earth's porous surface through gravity and acts as a critical resource that supports life and human-led agricultural activities in dry-climate areas that do not have access to surface freshwater bodies. Arid landscapes include low-precipitation and dry ecosystems where terrestrial, seasonal riparian, and aquatic species thrive on storage and highly competitive access to water. Water resource management infrastructures combine the regulation and movement of resources, organizational structures, and facilities required to maximize the beneficial uses of water for non-human and human species. Mitigation strategies and planning contribute to preventing depletive groundwater extraction practices for arid regions. The infrastructure for groundwater management includes governmental, corporate, and community-led regulation of public policies on extraction facilities and preservation methods.

Rural and urban environments in arid regions rely on groundwater for survival. The accurate management of this resource becomes crucial to prevent ecosystem, societal, and agricultural failure. According to the U.S. Environmental Protection Agency (EPA), there are green infrastructure applications in semi-arid to arid climates that lead to socioeconomic and environmental benefits, including groundwater recharge. Applications of water collection, filtration, and reclaim strategies include rainwater harvesting, swales, porous pavement, and grey-water reuse for irrigation. This research paper explores and compares case studies on groundwater management infrastructure to prevent the overuse of scarce water resources in arid regions. Also, this research contributes to the Master of Architecture thesis I am pursuing, focusing on Fiambalá, a 4600-people urban settlement dependent on groundwater in Argentina's dry-Puna region (fig. 1).

This paper explores four case studies on groundwater infrastructure application performance, including Crete, India, Saudi Arabia, and the Caplina Aquifer in the Atacama Desert shared by Perú and Chile. The paper's structure includes the analysis and description of each case study to summarize and frame them under their approach to improving groundwater systems.

The comparison and discussion of the case studies follow to convey the implementation success level of each conservation method in reducing human-activity impacts in arid regions. The juxtaposition will reveal similarities and differences between all the case studies that will contribute to understanding the impact level of each of the country's groundwater preservation approaches.

Fiambalá's Underground Hydrological Conditions

The groundwater resources in Fiambalá are provided by the Abaucán basin, which stems from the namesake river fed by the Fiambalá and Chaschuil rivers. Also, the surface water sources depend on snow precipitation in surrounding mountain ranges. The basin's aquifers are exploited through wells for lithium mining, viticulture, oleiculture, and domestic uses. According to a local hydrogeological study by Argentina's Water Institute, groundwater is 35 to 84 meters deep (115-275ft). The water has bicarbonate sodium, salt, nitrate, fluoride, boron, and arsenic between 0.014 and 0.020 milligrams per liter, surpassing the 0.010 mg/l safe value for consumption. However, the water's salt levels are safe for consumption, requiring further assessment of other contents. The groundwater in Fiambalá raises considerations about potability safety and extraction practices, prompting the establishment of filtration and regularization.

Case Study #1: Messara Valley in the Geropotamos Basin, Crete, Greece

This study focuses on the planning, performance examination, and future suitability of groundwater recharge in the Geropotamos Basin of the Greek island of Crete. The island is in the Mediterranean Sea with a semi-arid climate, dry summers, and intensive agriculture, which over-exploits and decreases groundwater in the local basin for irrigation. The island's government sets groundwater stabilization measures that hinder water extraction and prevent new perforation for water-supplying wells. The exploitation of water below the surface will continue to be sponsored by the state, causing the spreading Managed Aquifer Recharge (MAR) strategy to be suggested for the source's preservation and recovery. MAR is a tool that helps mitigate groundwater issues, including over-extraction and contamination.

The MAR method's efficacy is dependent on aquifer storage capacity for groundwater, adequate recharge water accessibility, and better water quality than the existing one below the surface. The case study provides the structure to facilitate the implementation of MAR strategies around the Geropotamos Basin, using a Geographic Information System (GIS) multi-criteria decision analysis (MCDA) for site selection. The findings included four site suitability scenarios considering hydrogeology, rainfall, groundwater level, slope, soil, land use, and distance to surface water. Despite the study not producing a direct physical intervention for groundwater, the outcome includes a framework methodology for recharge location selection. Also, the study provides visualization that has the potential to encourage state authorities to include MAR in groundwater-level improvement planning and management methods.

The Messara Valley MAR case study addresses the need to replenish groundwater to satisfy dry summer water extraction needs and contribute to the development of existing underground hydrogeological systems. Consolidating a visual tool through the site selection GSI-MCDA analysis will help Crete's government make groundwater recharge MAR placement decisions. Examining each scenario promotes a direct understanding of favorable areas for recharge measures. Also, the impact of implementing the MAR application facilitation method has the potential to accelerate the recovery of the decreasing levels of groundwater in the study area's aquifers. The benefits of a faster groundwater resource recovery are water access, socioeconomic and agricultural activities security. This case study provides MAR and its application framework strategy as groundwater infrastructure that engages local water administrative authorities.

Case Study #2: Indus Valley, India, South Asia

This study centers on policy and community-led action recommendations for improving groundwater management in India, Pakistan, and Bangladesh within South Asia. Also, the study offers examples of locations requiring groundwater recharge, specifically those impacted by the large farmers' overexploitation of the resource and the negative effect on marginal farmers.

Some locations include the states of Rajasthan and Gujarat in Western India around the Indus Valley, which are subject to an arid climate that further restricts water recharge. As the extraction of water increases, farmers with low economic resources are displaced and forced to migrate to cities to find new jobs. The study suggests multiple groundwater conservation strategies that address the resource's supply, demand, forms of participatory and co-dependent management. Another suggestion includes changing agriculture practices to encourage groundwater extraction reduction.

The main challenges to improving groundwater management include supporting the survival of expanding populations struggling against climatic-led socioeconomic change. The study identifies the need to engage stakeholders across the incorporation of multiple approaches to groundwater management that consider existing energy and food-sourcing required conditions. The strategies to increase supply include integrated watershed management programs, underground transfer of floods for irrigation, and managed aquifer recharge (MAR). Methods for managing groundwater demand include policy, regulatory, and agronomy measures. Also, the study encourages irrigation efficiency through micro-irrigation, piped distribution networks, and conservation agriculture due to improving supply resilience. The participatory approaches to the resource's control include village-level intervention and farmer groundwater systems. The study recommends solar irrigation and food support tactics to develop co-dependent sector supervision.

The performance of each strategy was measured by the level of efficiency that contributed to the increase of groundwater available. The management methods form the infrastructure to reduce the agricultural systems dependent on over-depletion while adapting to climate change-caused stress on groundwater. Some efficient implementations include MAR in Gujarat, which encouraged installing check dam structures and a community-based groundwater recharge that increased the resource's availability. Also, the study revealed that the Indian government's promotion of low groundwater use irrigation tools such as sprinklers and the drip method decreased excessive extraction to two-thirds. The strategies for fostering conservation and reduced usage provide the instruments that facilitate infrastructure implementation.

Case Study #3: Saudi Arabia

In the Arabian Shield around the Red Sea, underground water resources exist among porous extensive sedimentary basins and Precambrian (4.6 million years ago) crystalline rocks. The Arabian Shelf is another extensive region in Saudi Arabia that has sedimentary aquifers out of limestone and sandstone on top of the Shield's rock foundation. The study focuses on fossil groundwater extraction management in Saudi Arabian shelf and shield aquifers. The paper supports management policies for socio-economic development through support for drought-prone groundwater resources. Also, the study examines the implementation of government-sponsored regulations, including corrective demand control. According to the author Walid Abderrahman, controlling the demand depends on establishing modifications in the financial support of agricultural practices to facilitate the regeneration of underground water for increased availability.

The distribution of agricultural land disregarding water availability led to intensive groundwater extraction after the 1980s. The study's groundwater policies include decreasing irrigation water and supply network leakage to diminish losses. Also, the resource management strategies involve increased demand control, surface water from wastewater and desalination. Agricultural underground water removal involves wells, pumps, sprinkler and drip irrigation systems in rural areas. The government implemented the reduction of irrigation water employed in crops for wheat fields by modifying its price support policy, reducing their cultivation to local necessities. The governmental strategy of wastewater reuse involves the subsurface irrigation of crops from sewage effluents recycled through treatment plants. The acceptability in the local agriculture world has remained between 1-2% in the last two decades.

The desalination processes support 60% of local domestic and industrial sectors water demands. The process involves high electric energy in filtering saline water through thermal distillation (evaporating water through heat) or reverse osmosis (applying pressure forcing water through a filter). The water is post-treated to adjust its mineral contents and increase its potability. The performance of the government-planned groundwater management policies has decreased the use of non-renewable fossil underground water resources.

The policies facilitate the recharge and augmentation of resources to prevent depletion by encouraging a reduction in intensive usage. Surface water availability increases and agricultural use reductions through economic deterrents depend on state action and would require local initiatives from the people through education programs to prevent setbacks in the groundwater infrastructure development.

Case Study #4: Caplina Aquifer, Atacama Desert, Peru

The main groundwater systems in South America are the Caplina and Guarani aquifers. The study examines the impact of the Caplina aquifer's management policies and analyzes the government's implementation of resource control tools. Assessing the contributions of groundwater management strategies allows for facilitating aquifer water increase with responsive decision-making. The groundwater resources are in the Caplina basin within the Peruvian Tacna region and northern Chile, facing the Pacific Ocean. The low annual accumulated precipitation recorded from 3 to 7 cm, seawater intrusion, and overexploitation of groundwater resources deplete the aquifer's fresh water. Climate change also intervenes in the groundwater levels as previously non-recorded precipitations began to occur within the basin. The control policy is the Peruvian Water Resources (PWR) law, which fosters governmental and participatory management.

The governmental approach to depletion mitigation measures is based on the aquifer's compromised status due to state-sponsored prevention issues, wells' salinization, and over-pumping. The scarce availability of groundwater for agricultural and domestic users in Tacna encourages excessive extraction that is 5 times greater than the recharge capacity of the aquifer. The regulation framework of the PWR law has an extraction permit requirement that has legal impact if violated through unregulated uses. However, farmers and households continue groundwater exploitation through informal wells because of low state-community collaboration, educational outreach, and regulation enforcement to users. In order to counteract the future collapse scenario in the study, the alternative measures include reuse and desalination. Implementing aquifer recharge through hydraulic barriers as groundwater flow boundaries lowers marine intrusive contamination.

The study proposes that disseminating groundwater preservation techniques among users and investing in conservation tools will benefit the aquifer's endurance beyond increasing water supply infrastructure to meet regional demand. The study reveals regulatory application difficulties that encourage the modification of procedures for conservation measures Also, the study suggests that the transition to testing and implementing from structural to non-structural guidelines will facilitate the recovery of groundwater levels. Planning for the resource's extraction control, reuse, and salination prevention measures increases aquifer crisis awareness, restrained uses and decontamination of groundwater. Community state-sponsored engagement for farmers and domestic users on management tools provides potential long-lasting preservation efforts.

Discussion

The case studies focused on the promotion of infrastructure applications for groundwater management to provide recommendations for their implementation. Also, the first and second studies underscore MAR as a strategy to prevent over-extraction of groundwater resources. These studies also highlight stakeholder engagement and policy interventions as crucial elements for sustainable groundwater management. The first study primarily encourages visual tools and governmental measures to address groundwater issues, providing a comprehensive framework for recharge location selection. Similarly, the second, third, and fourth studies adopt a more expansive approach, advocating for multiple strategies and policies at a community and governmental level.

There are differences in the strategies proposed, as the first case study includes implementing GIS-MCDA tools as a framework for selecting MAR application areas. On the other hand, the second and fourth case studies center on the groundwater increase strategies' post-application effectiveness. Moreover, there are climate conditions differences between studies, with the first in a semi-arid location, the second in seasonally dry to wet while the third and fourth are in arid regions. The first study emphasizes visual tools and government-sponsored initiatives, while the second, third and fourth include community participatory approaches, co-dependent sector supervision for energy, water, and food-sourcing security.

Also, the second study highlights the displacement of marginalized farmers and suggests village engagement in groundwater management. Therefore, the studies advocate for groundwater availability to increase within their geographic context, an analysis of the implementation stage, and the number of strategies offered to address the multifaceted challenges of management.

Conclusion

In conclusion, the case studies' analysis reveals tactical measures for groundwater management promotion and installation. The contributions of the case studies include recommendations and community-to-government engagement to reduce groundwater exploitation. However, the suggested strategies and performance examination require geographic, climatic, and ecosystem adaptation. The case studies contrast in demonstrating pre- to post-application procedures and the performance of groundwater management infrastructure, respectively. The case studies provide the considerations, methods, and tests to develop an initial guide for groundwater infrastructure tools. The strategies assessed will facilitate their implementation in a resource control recommendation framework for the arid region of Fiambalá.

Population Characteristics Tables of Tinogasta County

Note: This thesis's author translated the following tables, for their original version refer to the works cited.

Population Structure per County

Table 1.3. Province of Catamarca. Total population, absolute variation and relative variation, by department. Years 2010 and 2022

Code	Department (County)	Population 2010	Population 2022	Absolute Variation	Relative Variation (%)
10	**Total**	**367,828**	**429,562**	**61,734**	**16.8**
10007	Ambato	4,463	5,129	666	14.9
10014	Ancasti	2,917	3,302	385	13.2
10021	Andalgalá	18,132	19,678	1,546	8.5
10028	Antofagasta de la Sierra	1,436	2,022	586	40.8
10035	Belén	27,843	30,569	2,726	9.8
10042	Capayán	16,085	19,885	3,800	23.6
10049	Capital	159,703	186,947	27,244	17.1
10056	El Alto	3,570	4,375	805	22.5
10063	Fray Mamerto Esquiú	11,896	14,625	2,729	22.9
10070	La Paz	22,638	26,370	3,732	16.5
10077	Paclín	4,185	4,725	540	12.9
10084	Pomán	10,776	12,260	1,484	13.8
10091	Santa María	22,548	26,929	4,381	19.4
10098	Santa Rosa	12,034	13,322	1,288	10.7
10105	Tinogasta	22,360	25,395	3,035	13.6
10112	Valle Viejo	27,242	34,029	6,787	24.9

Source: INDEC, National Census of Population, Households and Housing 2022. Final results.

Housing Conditions

Table 6.3. Province of Catamarca. Population in private housing, by land tenure status and regularity of ownership for own housing, according to department. Year 2022

Code	Department (County)	Population in Private Housing (¹)	Land tenure status and regularity of ownership for own housing: Owner					Rented	Ceded due to work	Borrowed	Other situation
			Total	Deed	Purchase contract	Other docummentation	Does not have documentation				
10	**Catamarca**	**427,625**	**349,739**	**167,780**	**58,581**	**75,156**	**48,222**	**34,951**	**2,161**	**20,726**	**20,048**
10007	Ambato	5,087	4,171	1,913	747	974	537	159	106	409	242
10014	Ancasti	3,282	2,955	963	283	646	1,063	88	38	145	56
10021	Andalgalá	19,545	16,486	7,622	3,086	3,722	2,056	1,108	183	933	835
10028	Antofagasta de la Sierra	1,822	1,546	895	147	217	287	131	9	83	53
10035	Belén	30,353	24,744	10,953	3,690	6,526	3,575	2,548	86	1,742	1,233
10042	Capayán	19,471	17,013	6,481	2,772	4,942	2,818	741	140	886	691
10049	Capital	186,466	149,391	78,561	21,454	29,914	19,462	19,510	393	7,303	9,869
10056	El Alto	4,375	3,749	1,281	769	872	827	193	82	177	174
10063	Fray Mamerto Esquiú	14,624	12,448	6,893	1,712	2,551	1,292	683	83	619	791
10070	La Paz	26,341	22,183	8,309	3,962	6,255	3,657	1,882	293	1,273	710
10077	Paclín	4,696	3,974	1,728	700	1,020	526	192	55	238	237
10084	Pomán	12,219	10,370	3,845	2,171	2,652	1,702	820	88	553	388
10091	Santa María	26,822	20,661	10,983	4,527	3,508	1,643	2,488	133	1,816	1,724
10098	Santa Rosa	13,317	11,242	4,517	2,848	2,332	1,545	673	184	729	489
10105	Tinogasta	25,254	20,172	8,808	3,313	4,348	3,703	1,691	107	2,274	1,010
10112	Valle Viejo	33,951	28,634	14,028	6,400	4,677	3,529	2,044	181	1,546	1,546

(¹) Homeless people are not included in this study.

Source: INDEC, National Census of Population, Households and Housing 2022. Final results.

Population Structure per Locality

Table 12.4 Catamarca Province according to Locality. Population according to age group. Year 2001

Locality	Total Population	Age Groups: 0	1-4	5	6-9	10-12	13	14	15-17	18-19
Total	**334,568**	**7,886**	**30,837**	**8,077**	**30,862**	**21,784**	**7,003**	**6,967**	**19,922**	**12,070**
Gran San Fernando del Valle de Catamarca	171,923	3,966	15,008	3,899	14,816	10,615	3,441	3,420	9,943	6,380
San Fernando del Valle de Catamarca	140,741	3,218	12,148	3,141	11,899	8,702	2,797	2,830	8,124	5,217
San Isidro	22,173	555	2,058	549	2,068	1,372	483	434	1,328	816
San José	9,009	193	802	209	849	541	161	156	491	347
Andalgalá	11,411	253	1,137	253	1,059	746	221	242	726	443
Tinogasta	11,257	285	974	285	1,084	714	253	226	679	375
Belén	11,003	192	936	247	1,090	753	252	258	739	362
Santa María	10,800	240	1,042	307	1,027	686	245	228	722	350
Recreo	10,147	243	1,030	256	1,085	741	176	208	590	346
Fiambalá	4,585	117	483	140	510	343	105	90	280	124
Chumbicha	4,029	108	417	106	425	326	84	85	231	157
Los Altos	3,207	100	329	75	326	230	75	79	210	143
San José	2,845	66	258	75	272	226	59	62	189	89
Pomán	2,259	67	222	51	210	151	34	44	126	71
Huillapima	2,139	54	239	62	225	145	54	50	150	92
Londres	2,134	37	202	39	203	148	39	50	150	66
Localities with less than 2000 people	59,844	1,523	5,878	1,576	5,887	4,133	1,358	1,333	3,602	2,110
Scattered rural population	26,985	635	2,682	706	2,643	1,827	607	592	1,585	962

Locality	Age Groups: 20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	Age Groups: 65-69	70-74	75-79	80-84	85 y más
Total	**30,191**	**24,962**	**21,149**	**19,163**	**18,333**	**16,562**	**14,701**	**10,967**	**9,004**	**7,725**	**6,715**	**4,609**	**2,809**	**2,270**
Gran San Fernando del Valle de Catamarca	16,549	13,756	11,491	10,442	9,829	9,031	7,990	5,702	4,436	3,706	3,174	2,167	1,211	951
San Fernando del Valle de Catamarca	13,691	11,239	9,348	8,532	8,139	7,452	6,654	4,718	3,636	3,106	2,604	1,812	980	754
San Isidro	1,994	1,782	1,525	1,372	1,214	1,111	961	691	573	390	367	232	151	147
San José	864	735	618	538	476	468	375	293	227	210	203	123	80	50
Andalgalá	985	753	698	685	603	585	493	376	309	257	240	169	108	70
Tinogasta	948	848	699	587	629	520	510	392	314	278	265	174	116	102
Belén	879	907	676	627	586	555	465	333	300	263	219	155	125	84
Santa María	967	749	695	619	590	532	442	345	283	222	205	124	100	80
Recreo	936	823	711	638	550	452	387	279	198	186	137	87	55	33
Fiambalá	357	323	264	216	242	160	190	133	126	111	111	69	48	43
Chumbicha	393	270	247	220	181	188	148	115	93	72	66	51	25	21
Los Altos	296	199	196	174	194	146	138	79	68	57	45	22	16	10
San José	237	204	139	136	146	106	109	90	96	72	88	56	34	36
Pomán	171	164	175	128	122	105	93	76	59	59	52	34	22	23
Huillapima	190	131	129	117	85	88	78	66	54	39	34	25	13	19
Londres	152	141	126	108	115	104	88	73	75	60	69	42	24	23
Localities with less than 2000 people	4,891	4,010	3,480	3,180	3,155	2,760	2,417	1,902	1,682	1,570	1,351	974	598	474
Scattered rural population	2,240	1,684	1,423	1,286	1,306	1,230	1,153	1,006	911	773	659	460	314	301

Source: INDEC. National Census of Population, Households and Housing

Employment Conditions

Table 1.3. Province of Catamarca. Population of 14 years and older in private homes, by condition of economic activity, according to department. Year 2022

Code	Department (County)	Population of 14 years and above in private housing	Economic activity condition			
			Economically active population			Economically inactive population
			Total	Employed	Unemployed	
10	**Catamarca**	**339,304**	**213,900**	**197,548**	**16,352**	**125,404**
10007	Ambato	4,216	2,654	2,550	104	1,562
10014	Ancasti	2,652	1,372	1,307	65	1,280
10021	Andalgalá	15,605	9,707	9,037	670	5,898
10028	Antofagasta de la Sierra	1,406	1,011	965	46	395
10035	Belén	23,818	15,045	14,171	874	8,773
10042	Capayán	15,179	8,852	8,284	568	6,327
10049	Capital	149,266	97,104	88,668	8,436	52,162
10056	El Alto	3,388	1,811	1,721	90	1,577
10063	Fray Mamerto Esquiú	11,547	7,618	7,086	532	3,929
10070	La Paz	20,348	11,560	10,646	914	8,788
10077	Paclín	3,788	2,222	2,086	136	1,566
10084	Pomán	9,529	5,841	5,531	310	3,688
10091	Santa María	21,206	13,565	12,534	1,031	7,641
10098	Santa Rosa	10,484	5,701	5,183	518	4,783
10105	Tinogasta	20,020	12,284	11,405	879	7,736
10112	Valle Viejo	26,852	17,553	16,374	1,179	9,299

Note: in accordance with the evaluation of quality and consistency of the final results, and to comply with the statistical quality standards required by INDEC.
Source: INDEC, National Census of Population, Households and Housing 2022. Final results.

Employment Activities and Types

Table 6.3.15. Province of Catamarca, department of Tinogasta. Employed population aged 14 or over in private homes by occupational category, according to

Sex registered at birth and grouped branch of economic activity	Employed population aged 14 and over	Occupational category					
		Domestic services	Employee or worker	Self-employe ed	Patron or Employer	Family worker	Ignored
Total	**11,405**	**1,004**	**6,247**	**3,131**	**259**	**344**	**420**
Agriculture, livestock, hunting, forestry and fishing	657	///	292	307	16	36	6
Exploitation of mines and quarries	29	///	27	1	1	-	-
Manufacturing industry	372	///	152	187	6	24	3
Supply of electricity, gas, steam and air conditioning	13	///	12	1	-	-	-
Water supply; sewers; waste management, materials recovery and public sanitation	44	///	37	5	1	1	-
Construction	1,184	///	706	423	19	26	10
Wholesale and Retail; repair of motor vehicles and motorcycles	1,404	///	551	710	75	52	16
Transportation and storage service	181	///	91	75	6	6	3
Accommodation and food services	355	///	208	111	12	21	3
Information and communications	29	///	17	11	-	-	1
Financial intermediation and insurance services	33	///	26	2	1	-	4
Real estate services	3	///	-	3	-	-	-
Professional services, scientists and technicians	63	///	27	32	3	1	-
Administrative activities and support services	177	///	132	33	3	8	1
Public administration, defense and mandatory social security	1,046	///	975	38	14	6	13
Teaching	896	///	792	51	9	9	35
Human health and social services	264	///	194	57	8	2	3
Artistic, cultural, sports and leisure services	42	///	18	23	1	-	-
Association services and personal services	127	///	26	90	3	4	4
Activities of households as employers of domestic staff; household activities as producers of goods or services for own use	1,005	1,004	-	1	-	-	-
Services of extraterritorial organizations and bodies	-	///	-	-	-	-	-
No response	2,002	///	948	612	58	109	275
Insufficient information to code	1,479	///	1,016	358	23	39	43

Source: INDEC, National Census of Population, Households and Housing 2022. Final results.

Partner and Co-habiting Conditions

Table P25-P. Catamarca Province. Population aged 14 years and over by legal marital status and cohabitation as a couple, according to sex and age group. Year 2010

Sex recorded at birth and age group	Population aged 14 years and over	Legal Marital Status and Cohabitation as a couple									
		Single		Married		Divorced / Legally Separated		Widow / Widower		Ignored	
		With Partner	No Partner	With Partner	No Partner	With Partner	No Partner	With Partner	No Partner	With Partner	No Partner
Total	**263,242**	**49,209**	**108,655**	**74,873**	**4,789**	**3,937**	**8,176**	**1,332**	**11,884**	**263**	**124**
14	7,959	148	7,793	10	2	1	2	-	-	-	3
15-19	36,931	2,866	33,789	181	27	3	6	1	43	9	6
20-24	28,807	7,596	19,965	1,073	56	16	39	9	8	43	2
25-29	27,312	9,888	13,161	3,755	221	53	185	2	12	35	-
30-34	27,943	10,025	9,339	7,550	319	180	418	14	35	57	6
35-39	23,845	6,728	5,897	9,190	496	552	789	30	126	27	10
40-44	19,530	4,238	3,987	9,028	415	639	934	68	201	17	3
45-49	18,174	2,584	3,229	9,345	609	793	1,209	112	258	18	17
50-54	16,700	2,064	2,798	8,453	693	652	1,323	141	541	22	13
55-59	15,301	1,259	2,297	8,263	666	459	1,143	179	1,009	18	8
60-64	12,489	841	2,026	6,501	451	296	877	197	1,277	13	10
65-69	9,460	437	1,438	4,566	381	174	591	193	1,653	4	23
70-74	6,799	241	1,077	3,166	198	56	300	111	1,649	-	1
75-79	5,609	189	860	2,080	149	39	222	150	1,899	-	21
80-84	3,634	76	605	1,172	60	21	78	72	1,549	-	1
85 and over	2,749	29	394	540	46	3	60	53	1,624	-	-

Note: this study includes homeless people.
The data published here arise from the expanded questionnaire, which was applied to a part of the population. The values obtained are estimates of a sample and therefore include the so-called "sampling error".

Source: INDEC, National Census of Population, Households and Housing 2010

Housing Typology & Exterior Space Analysis of Fiambalá

Category	Finish type	Visible construction material	Roof type	Roof Material (if visible)	Window Shape	Window Size	Front Yard Treatment	Parkway	Visible active systems type	Visible services	Fenestration cover
Case study 1	Mud plaster	Adobe, mass timber, corrugated steel	Gabled	Wild cane, plastic and mud	Rectangular Bricked up	Medium	Unkept, Building materials and vehicle parts scattered, clear parkway, two large plants	Yes	No	No	N/A
Case study 2	White and dark red painted stucco on cement	Adobe	Not visible	Not visible	Rectangular	Medium to small	N/A, Facades engage directly with sidewalk, Religious symbol on top of entry door and Mailbox on secondary façade.	No	Yes (AC unit wall mounted)	Yes (electrical power line at corner and box)	Wooden simple panel shutters
Case study 3	Pastel orange, stucco and cement	Not visible	Not visible	Not visible	Rectangular	Medium to small	N/A, Façade engages directly with the sidewalk, Religious symbol next to the entry door, sunflower plant on the sidewalk, and yard on one side.	No	No	Yes (water tank, satellite television dish, and power line)	Steel and wood simple panel shutters and window bars
Case study 4	Mud plaster	Adobe	Not visible	Not visible	Rectangular	Small	Lower adobe wall, empty transitional space and piled mud bricks	Yes	Yes (heat pump, pipes, tubes and drainage)	Yes (electric power line rod and box)	Wood and steel movable and fixed shutters
Case study 5	Mud plaster and cement	Adobe and wood	Not visible	Not visible	Rectangular	Small	N/A, Façade engages directly with sidewalk and has a fenced yard on one side.	No	No	No	Wooden simple panel shutters
Case study 6	Stucco and cement	Adobe	Not visible	Not visible	Rectangular	Small	Façade engages directly with sidewalk	No	No	No	Wooden simple panel shutters
Case study 7	Mud plaster and cement	Adobe	Not visible	Not visible	Rectangular	Small	Façade engages directly with sidewalk	No	No	Yes (electric power line rod and box)	Wooden simple panel shutters
Case study 8	Cement and stucco	Adobe, wood and reinforced concrete	Slanted	Wild cane and mud	Rectangular almost square	Small	N/A, Façade engages directly with sidewalk and stands on top of reinforced concrete foundation.	Yes with garage	No	Yes (electric power rod and box)	Wooden louvered and simple panel shutters
Case study 9	Stucco, bare and cement	Concrete blocks	Gabled	Ceramic Tile	Rectangular	Small	Fenced, private with gate	No	Yes (heat pump, drain, pipes, and water tank heater)	Yes (power line, satellite dish, and septic tank exhaust pipe	No
Case study 10	Stucco and cement	Concrete block and wood	Gabled	Ceramic Tile	Square	Small	Open, growing trees, plants, cacti. Also, stored building materials.	Yes	Yes (kitchen exhaust pipes)	Yes (power line, box, satellite dish and water tank)	Interior curtains
Case study 11	Pastel blue stucco	Concrete and concrete block, and rebar	Split gabled	Not visible	Rectangular	Small	Open with unfinished rebar structures and stored building materials	Yes	Yes (heat pump)	Yes (satellite dish and water tank.)	Interior curtains
Case study 12	Stucco	Concrete block	Not visible	Not visible	Rectangular	Small	Fenced flower garden with non-native plants and stored building materials	Yes	No	Yes (antenna, satellite dish and water tank.)	Wooden louvered and panel shutters
Case study 13	Fired Brick and dark green painted stucco	Wood, fired brick and reinforced concrete	Split Gabled	Corrugated steel	Square	Small	Fenced with wild cane and wood columns. Also includes fenced garden.	Yes	No	Yes (power line, powerline box, and security camera)	Wooden louvered panel shutters
Case study 14	White painted stucco	Not visible	Not visible	Not visible	Square	Small	Fenced flower garden and religious figure placed on the door surface.	Yes	No	Yes (Satellite dish)	Wooden louvered panel shutters
Case study 15	Mud plaster and cement-based stucco	Adobe and reinforced concrete	Split gabled	Not visible	Rectangular Bricked up with garage	Medium with garage	Fenced with wire, has vynil above ground pool and grapevines on pergola.	Yes with garage	No	Yes (water tank)	Not visible
Average	Stucco and cement	Adobe	Not visible	Not visible	Rectangular	Small	Façade engages directly with sidewalk	No	No	Yes	Wooden simple panel shutters

Table 1: Housing case studies comparison.

Housing case studies: #1 (top), #2 (middle), #3 (bottom left), and #4 (bottom right). Dec. 2023.

Housing case studies: #5 (top), #6 (middle left), #7 (middle right), and #8 (bottom). Dec. 2023.

Housing case studies: #9 (top), #10 (top right), #11 (middle left), #12 (middle right), and #13 (bottom). Dec. 2023.

Housing case studies: #14 (top) and #15 (bottom). Dec. 2023.

CEB Building Code, Material, & Implementation Infrastructure

Introduction

This paper explores existing literature on compressed earth block (CEB) in the Global South with a focus on the town of Fiambalá, Catamarca province, Argentina. Examining the CEB's building code and implementation globally and regionally facilitates contextualizing its proposal for local construction. Also, the building code analysis is centered on Catamarca's capital due to usage in the housing project design by local architect Oscar Daniel Saenz in Fiambalá. Perú and Egypt's articles reveal the extent of the inclusion of CEB considerations providing earth construction guidelines for seismic areas.
Source Summary and Analysis (725 words)

Building code is the organized set of rules generally implemented to provide the minimum requirements in construction and design that impact public to private physical spaces in human settlements. The local building code of Catamarca's Capital City, approved in 1995 and ratified in 2021, includes guidelines for construction with reinforced concrete, concrete blocks, and fired bricks. However, the code omits reference to earth construction, including adobe, an extensively used masonry material in towns such as Fiambalá. The Peruvian Building Code is of regional influence in earth construction due to its seismic zone considerations for structural limit guidelines. Perú's code also omits the discussion of minimum instructions for CEB or other earth construction methods. The authors of "The Peruvian Building Code for Earthen Buildings" reveal low code adoption due to its reduced dissemination among users.

Using booklets as educational tools is critical to spreading information about structurally safe Adobe construction strategies. According to Hisham Hafez in "Barriers and Enablers for Scaled-up Adoption of Compressed Earth Blocks in Egypt," the Egyptian building code expands on requirements for CEB construction. Also, the article discusses the technical, economic, and social barriers and enablers that prevent and encourage CEB usage in construction. The categories of the article are based on a survey study among architects, academics, and experts in CEB. The social category included CEB clients with poor material perception, poor aesthetics, and durability prejudice.

The economic barriers include machinery, material, and transportation costs, and the technical ones are availability, maintenance, and production speed of press machines, skilled workers, and materials. The enablers for CEB construction and implementation include addressing durability concerns through CEB stabilization, permanent and movable CEB production, and raising awareness of building codes.

In Argentina, CEB considerations are incorporated into building codes at the municipal level. In the Paraná municipality (Entre Rios province) the code includes CEB, which provides a national precedent to follow. Argentina allows CEB construction if it adjusts to the building requirements using concrete blocks and fired brick. There are eleven CEB factories in Argentina, mainly in Santa Fe province (eastern Argentina). The 2023-2024 economic crisis in Argentina has led to the closure of factories due to currency devaluation, low demand based on the rising cost of living, and the inability to pay employees. According to CEB manufacturers, the limitations on disseminating the material are its unregulated construction system, commercialization, low access to public and private funding, and potential consumer unawareness. The manufacturing barriers include the need for experienced production management staff and quality control of the block's sourced materials and masonry unit.

The application of CEB manufacturing infrastructure in highly seismic zones such as Nepal is executed through a cooperative model factory for the post-2015 seismic catastrophe reconstruction of the town of Nuwakot in the Bagmati province of the country. According to Masso Ros in the article "CEB Factory for seismic resistant earth architecture design in Nepal," the development of CEB seismic resistant earth construction is demonstrated in a Nepalese 2016 classroom prototype built with a bamboo roof structure and CEB load-bearing walls. The CEB factory infrastructure implementation supported the project by incorporating local workers through machine control training programs and material production. Following the first employment and training stages, the authors state that workers have the potential to engage in self-house building and self-management of profit and efficiency. However, developing the factory to improve its workers lives would rely on continued financial gains and public demand for CEBs.

Masso Ros's article discusses CEB block dimensions and the decrease in manufacturing costs due to locally building press machines in Nepal. The CEB manufacturing machines were built in local metal factories based on cooperation with the Nepalese architecture firm ABARI to access a free press model. The process of building CEB manufacturing infrastructure locally included laboratory tests of earth and bamboo seismic-resistant structures. The tests were done in collaboration with the Universities of Kathmandu and Pulchowk, demonstrating high academic involvement. The seismic resistance experiments were crucial in generating building and design recommendations. Some structural suggestions for CEB include using symmetrical floorplans and rings of two to three brick courses encased by wire mesh for reinforced thicker horizontal joints. Nonetheless, the article overlooks potential infrastructure failure scenarios and contention plans, focusing primarily on celebrating the effectiveness of the factory and its structural experiments.

Conclusion

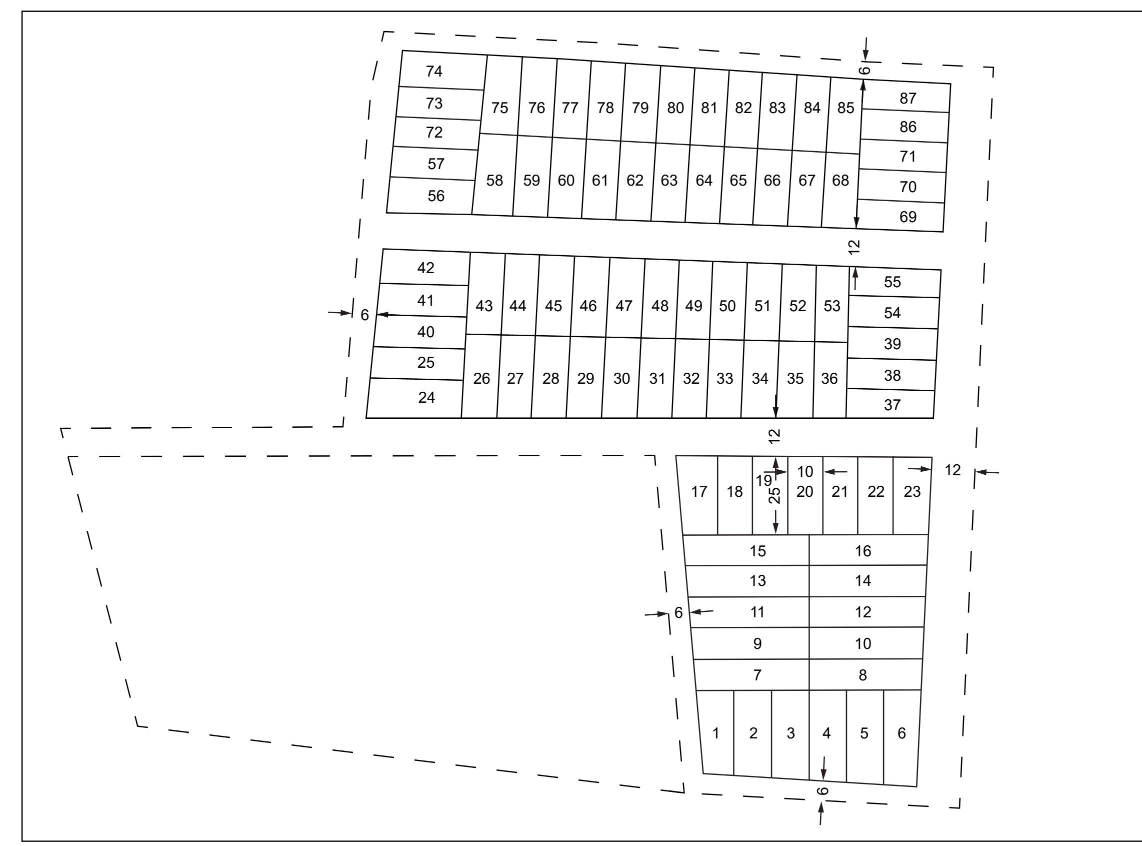
The analysis of CEB through its production implementation and construction rules facilitates distilling criteria encouraging the acceptance of the material. The criteria include designing prototypes and generating manufacture guidelines for CEB based on adjusted global, regional, and municipal building code that considers earth construction materials. Also, the criteria acknowledge the probability of collapse and barriers to enacting long-term alternative material uses compared to the standard fired brick and concrete block. Government-supported self-management groups collaborating with the education sector and local communities will contribute as strategies to demonstrate the local community's need for using the material.

Preliminary Urban Project for Fiambalá Document

Note: The author of this thesis has translated and digitally traced this document from an image sent in December 2023 by Oscar Saenz, the architect from Fiambalá.

PRELIMINARY URBAN PROJECT FIAMBALÁ

CADASTRAL REGISTRATION: 15-26-35-3228
SURFACE:3.41 Hectares (Ha)
FIAMBALÁ - TINOGASTA
Total subdivision- 87 lots of 250 m2 approximately



Ministry of Labor, Human Resources and Planning Government of Catamarca | **Secretary of Planning** | **Provincial Department of Planning** | **Department of Land Bank and Territorial Development**