

**raw,
fired,
and in
between**

**कच्चा
पक्का
और
दोनों का मेल**

**Daniel Haselsberger
Doctoral Thesis**

*To Isha
constant companion, tireless encourager,
and the heart of this journey.*

*For the Dalit community in Bahuarwa,
may the children learn in their new school
as much as I have learned from them.*

raw, fired, and in between कच्चा पक्का और दोनों का मेल

on regenerative building materials and
participatory construction in Bahuarwa, India

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Abstract

“Raw, fired, and in between” is the title of a dissertation at the interface of architecture and ethnography. It focuses on the transformation of the building culture of Bahuarwa, a village in the Indian state of Bihar. “Raw” and “fired” are literal translations of the Hindi words *kutchra* and *pukka*, which are commonly used in India to categorize buildings into “strong” ones made of carbon-intensive materials, such as fired bricks, cement, or steel or “fragile” ones made of raw, regenerative materials, such as earth, bamboo, timber or thatch. This binary polarization hinders the use of regenerative building materials, as well as the further development of vernacular building methods.

Relying on a transdisciplinary approach, this research investigates the ways in which regenerative building materials impact the lives of underprivileged people in Bahuarwa. In the first part of the research, the transformations from raw to fired materials are examined in the village, unpacking the interplay between environmental challenges, socio-economic transformations and technological developments. Through interviews with inhabitants, documenting buildings and making observations of the inhabitants’ daily life patterns, the factors influencing the increasing replacement of regenerative building materials with more carbon-intensive ones is then determined. This reveals a multilayered significance of building materials, which are characterized not only by technical properties, but even more importantly, by socio-cultural practices.

Building on these findings, the second part of the dissertation focuses on the participatory design process of a school for underprivileged children in Bahuarwa (Figure 1). A hybrid solution “in between” raw and fired building materials is developed, which allows the integration of regenerative materials into the process without neglecting the aspirations of the target groups. Constructing a public flagship project, as opposed to a private house, means the school promotes the usage of regenerative materials to the broader population, renewing the vernacular canon through technological advances. The participatory building process thus also

Figure 1: Schoolchildren on their way home from the school that was designed and built during this research.

provides further insight into the social acceptance of the hybrid design principles, along with the feasibility of their use, taking both the available infrastructure and skills as well as political and economic framework conditions into account. The construction of the school is less a result than a method of this dissertation. The research is shaped through the participatory construction process, becoming tangible and accessible to the target groups. It engenders conversation with craftspeople, residents, users, and teachers at the school, which are systematically documented in this research through protocols and interviews. Beyond this, the building process also creates a close form of interaction between the researcher and target groups, enabling a deep understanding of the social acceptance but also the feasibility of the developed hybrid. The participatory construction of the school also aims to provide a fair exchange and real benefit for the target groups, legitimizing the engagement and creating a cooperation instead of a one-sided data extraction. The findings of this dissertation are therefore both substantive and methodological. They are as relevant to the context of the researcher's place of origin (Switzerland) as they are to the research context itself; the confrontation with a (building) culture different to one's own brings both into a much sharper view. This dissertation represents the search for a middle ground: one not only between regenerative and more emission-intensive materials, between vernacular and new construction methods – but also, between the Global South and North, science and society, and attempts to bridge boundaries by building together.

Keywords: regenerative materials, socio-cultural building practices, hybrid construction, research by design, transformative research, Bahuarwa, India

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Figure 2 (following page): Local crafts-women creating reliefs on the walls of the classrooms.



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“Despite these promising examples, when considering the needed triple strategy of reducing energy demand, decarbonizing the power supply, and addressing the footprint of construction materials, it is noticeable that building materials are under-addressed in countries’ Nationally Determined Contributions.”

(UN, 2021, p. 20)

1 Introduction

1.1 Relevance

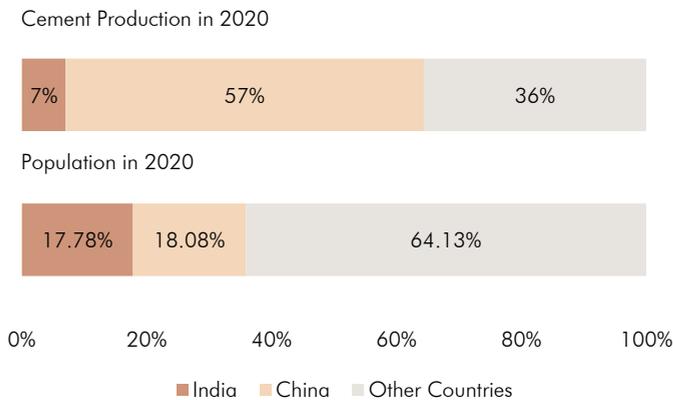
In the Paris Agreement (2015), 196 countries agreed to pursue measures to limit global warming to well below 2° Celsius – preferably a maximum of 1.5° Celsius higher – compared to preindustrial levels. Buildings and the construction sector play a major role in this plan: In 2020 they accounted for 36% of the global energy demand and 37% of energy related carbon emissions (UN, 2021, p. 15). Even though technological progress has led to more sustainable ways of building, the advancements struggle to compensate the increasing carbon emissions and energy demands of a growing population and rising living standards (UN, 2017, p. 15). According to the Global Status Report of the UN (2021, p. 16), buildings as well as building activities must be almost entirely decarbonized by 2050 to reach the goals of the Paris Agreement. At the same time, the building sector will be confronted with an estimated doubling of global energy consumption in buildings and more double the current floor area consumption per capita, mainly due to increased demand in countries of the Global South¹, as a consequence of population growth as well as industrial and infrastructural progress (UN, 2021, p. 16).

In the Nationally Determined Contributions to the Paris Agreement, the building sector is the second most mentioned policy after the use of renewable energy sources in the power sector (UN, 2021, p. 18). However, the implementation of sustainable building codes varies greatly among countries. Especially the footprint of construction materials is inadequately addressed in the triple strategy proposed by the UN (2021, p. 20), which describes the

¹ The terms *Global South* and *Global North* are used instead of categorizations such as industrialized, emerging and developing countries, or countries of the first, second and third world. While such a binary may appear to be against the aim of this dissertation to overcome dichotomies and consider the specific characteristics of every unique context, the pair of terms is nevertheless used due to their widespread understanding and the lack of more appropriate theoretical alternatives at the time of writing.

necessary reduction of energy demand and the decarbonization of the power supply. The use of cement, concrete and steel, which continues to increase, has a major impact on global energy demand and carbon emissions. Further, according to The Global Cement Report (International Cement Review, 2020) of the 4,150 megatons of cement produced worldwide in 2020, China accounted for 57%, followed by India with 7%, as shown in Figure 3. The relatively low contribution of India, whose population exceeded China's in 2023, is projected to increase, contributing to offset China's decline and leading to a further growth in global cement consumption through 2030 (IEA, 2022).

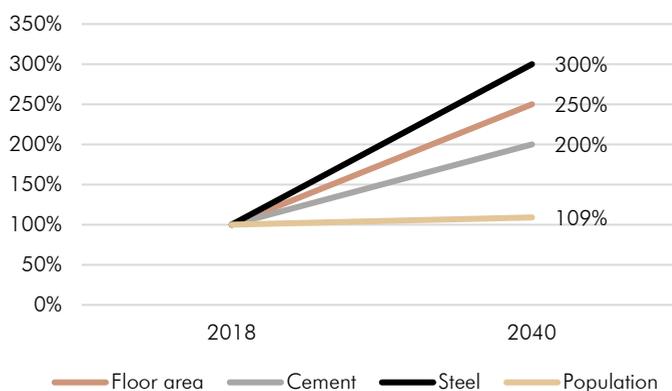
Figure 3: China's and India's share of global cement production and population (Data: International Cement Review, 2020; Population Pyramid 2020).



Since 1980, India's population has more than doubled, counting over 1.46 billion inhabitants in 2025 (*Population Pyramid, 2025*). This comprises nearly 18% of the global population – meaning that more than one out of six people currently living on this planet is Indian. A population peak is expected in 2060 with around 1.65 billion inhabitants (*World Population Review, 2022*). Despite India's rapid urbanization, its urban population is projected to remain below 50% by 2040 (IEA, 2021, p. 69), well under the UN's forecast (2018, p. 15) of more than 60% for "less developed regions".

Population growth, urbanization and economic development have major consequences for resource and energy demand in the construction and residential sector. The International Energy Agency (IEA, 2021, p. 69) expects the

total residential floor area of India to increase from less than 20 billion square meters in 2020 to more than 50 billion in 2040, which engenders double the demand for cement and almost a triple the demand for steel (Figure 4). In addition to the construction, operating and maintaining existing building stock will lead to a further increase in energy demand and carbon emissions. The IEA (2021, p. 82) underlines three trends that influence the energy demand of buildings in India: construction activities due to an increasing urbanization, a shift from regenerative² to more carbon-intensive materials, and the increasing usage of appliances – mainly air conditioners.



The residential floor area consumption due to population growth in urban areas is further intensified by rising living standards, leading to a total floor area consumption in the residential sector of slightly more than 20 billion square meters in rural parts and 30 billion in urban areas by 2040 (IEA, 2021, p. 83). Besides the quantitative increase of the urban building stock, qualitative changes also contribute to rising CO₂-emissions, energy and resource demands, too. Higher land prices in urban areas and maximizing profits

Figure 4: Predicted increase in percentage of India's population, floor-area-, cement- and steel-demand from 2018 until 2040 (Data: IEA, 2021; World Population Review, 2022).

² In this research, the term regenerative building materials is used. These include both bio-based materials, renewable raw materials produced by organisms in the plant and animal world, such as wood, bamboo or thatch, and geo-based materials such as clay or earth. In the course of this research, however, the extent to which the regenerability of the materials is lost, for example through chemical treatments, will be examined.

have frequently replaced vernacular³ building typologies made of regenerative and locally available materials, trading them for high-rise buildings inspired by examples of the Global North and constructed with concrete, steel and glass (Nugent, 2022). This leads to the third of the aforementioned trends: the increasing demand for air conditioners, as “modern” construction materials and typologies usually do not manage to meet people’s expectations regarding a pleasant interior climate without additional mechanical cooling.

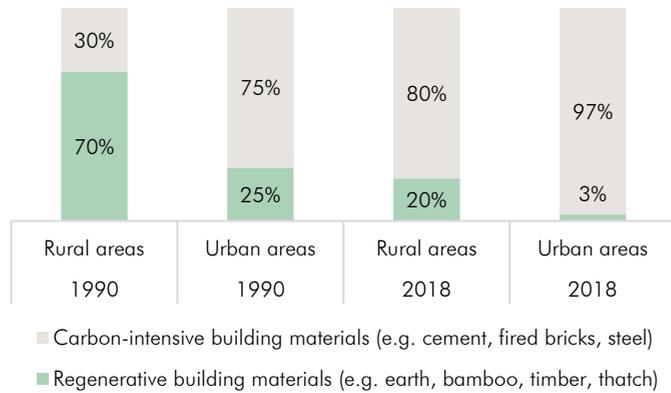
Like many other countries, the government of India does not consider the impact of building materials in its aspirations to reach the goals of the Paris agreement (UN, 2021, p. 20). The replacement of regenerative building materials and vernacular typologies is perceived as an inevitable requirement for development and economic growth. The negative effects on thermal comfort are to be solved with additional technology. Thus, “new” building materials do not only contain multiple factors more embodied energy and CO₂-emissions compared to regenerative, low-processed materials (Shubham & Kolhatkar, 2020, p. 39), they also lead to a multiple factors more energy demand required to ensure thermal comfort (Nugent, 2022). As a result, climate change on a macro-level and the urban heat island effect on a micro-level are intensified, leading to a vicious cycle, wherein the treatment of the symptoms is intensifying the cause of an increasing problem.

The belief in carbon-intensive materials as means of progress is also represented in the country's public housing programs. Promising “housing for all” by 2022, the “Pradhan Mantri Awaas Yojana” project (PMAY-U, 2015) aims to provide a house constructed with “modern” building materials to everyone who is still living in a dwelling made of “traditional” building materials (IEA, 2021, p. 83). Such programs contribute to the increasing abandonment of vernacular building methods. Figure 5 shows that, while 70% of the rural and 25% of the urban buildings were made of

³ In this dissertation vernacular buildings are understood as those that are built mainly from locally available and regenerative materials and by the inhabitants themselves without any involvement of building contractors, architects or civil engineers.

Figure 5: Ratio of buildings made with carbon-intensive and regenerative building materials in rural and urban areas in 1990 and 2018 (Data: IEA, 2021, p. 84).

regenerative building materials in 1990, these shares had decreased to 20% and 3% respectively by 2018 (IEA, 2021, p. 84).



Replacing regenerative building materials with fired bricks, cement and steel, the public housing program entails the next program, the “Indian Cooling Action Plan” (Ministry of Environment, Forest & Climate Change, 2019), which started in 2019. The Indian government further compounded the challenges posed by “housing for all” by 2022 with the promise of “thermal comfort for all” by 2040. Especially in urban areas, where the impacts of global warming are intensified by the heat island effect, the need for air conditioners increases. Whereas the energy demands for cooking and heating are expected to decline, due to more efficient alternatives and global warming, the energy demand and emissions for appliances and cooling are expected to grow, as an increasing amount of people can afford air conditioners and electric devices (IEA, 2021, pp. 84–86). According to forecasts, this will lead to a growth of air conditioner stock from approximately 30 million in 2018 to 670 million by 2040 (IEA, 2021, p. 86). Despite the availability of more energy efficient technologies, the energy demand for cooling is expected to be six times higher than in 2020 (IEA, 2021, p. 86).

The tendencies in India's building sector do not only come along with increasing environmental burdens and deteriorating microclimates, both in building interiors as well as urban contexts; they also contribute to the exploitation of

humans in growing building industries, as shown in a report by Anti-Slavery International and Volunteers for Social Justice (ASIVSJ, 2017). In the more than 100'000⁴ brick kilns currently operating in India, which employ 10-23 million workers, the authors “[...] have found endemic levels of debt-bondage and the worst forms of child labor, despite both being prohibited in the Constitution of India, numerous domestic laws and international law” (2017, p. 2). These common practices in brick kilns perpetuate cycles of poverty and exploitation among the members of marginalized and excluded castes (2017, p. 2). It is therefore questionable whether the promise to provide adequate “housing for all” (PMAY-U, 2015) does inherently pose a contradiction, since it depends on the exploitation of the very people who most urgently need adequate housing.

The increasing use of concrete and cement also requires large quantities of sand and gravel, such that legal and regulated mining of those materials do not manage to meet demand. As a result, sand is increasingly being mined illegally (Bliss, 2017). “Sand mafias” mine what is locally referred to as “gray gold” in rivers and on coasts. People often work under highly dangerous conditions, and at the same time, riparian zones are destroyed; in addition to the destruction of the habitats of many animals it also results in more frequent flooding (Bhadbhade et al., 2020; Bliss, 2017; Narendra, 2023).

The precarious working conditions in Indian brick kilns, the unregulated extraction of sand, increasing energy demands, and carbon emissions related to the firing process of bricks and cement, as well as the resulting dependence on air conditioners to ensure a pleasant interior climate combine with population growth and the impacts of global warming to create a highly problematic and extremely unsustainable building culture. India urgently requires a different approach to the future built environment. Therefore, this doctoral dissertation proposes a solution that closely relates building materials and its construction processes. In doing

⁴ Depending on the source, estimates of the total number of operating brick kilns in India vary between 100,000 and 150,000. Estimates are difficult to make because brick kilns are decentralized and not always registered.

so, it aims to provide insight into social acceptance and practical feasibility of alternative construction methods that integrate regenerative building materials.

1.2 Objectives

This dissertation aims, first, to analyze the drivers of transformation in the building practices of Bahuarwa by examining the interplay of environmental challenges, socio-economic transformations, and technological developments. Building on this analysis and in close collaboration with the local population, the Bahuarwa Foundation, and craftspeople, the second objective is to conceptualize and test a hybrid construction method that combines regenerative and carbon-intensive materials through the participatory construction of a school for underprivileged⁵ children. The goal is to meet local aspirations for a contemporary building while simultaneously challenging the prevailing kutcha-pukka dichotomy. A third objective is to investigate and critically assess the integration of research by design and participatory action research approaches, with the dual purpose of generating new scientific insights and producing tangible social benefits. This should ensure a fair exchange between the researcher and the target groups. Finally, the dissertation seeks to evaluate the potentials and limitations of regenerative building materials in relation to local aspirations, as well as political, infrastructural and economic frameworks, and to formulate recommendations for possible upscaling strategies that could enhance the use of regenerative materials in Bahuarwa and comparable contexts beyond.

1.3 Research Questions

The needs for the research addressed in this dissertation can be described in relation to the location, the target groups, and the building practices. The research context of Bihar is a blind spot. A low degree of industrialization, a lack of

⁵ Underprivileged refers to individuals or communities experiencing structural social and spatial disadvantages, with limited access to resources (Howe, 2021). In this research, this primarily includes Dalits and members of tribal communities, who are marginalized due to their socio-cultural backgrounds.

tourism, missing infrastructures and high poverty levels come along with a lack of interest in Bihar as a research context. These circumstances, as well as a small number of architectural monuments or preserved vernacular architecture, mean that Bihar in general, but especially in terms of building culture, is a rather unexplored context.

In identifying the target groups for ethnographic research, a significant proportion of the people interviewed and involved in the construction of the school belong to underprivileged population groups. Biharis are known for doing physically demanding work far away from their homes, as their lack of education often does not allow them to do other jobs and they find little work outside the primary sector in the poorly industrialized Bihar. Due to their low level of education, their migrant and working-class background, they are often considered “backward” by residents of other parts of India. This even leads to the term “Bihari” being used as a slur (Tripathi & Das, 2024, p. 226). Many are *Dalits*⁶: a population group that is excluded from the Hindu caste system and forms the lowest layer of the cultural and socio-economic hierarchy. Their designation as “untouchables” underlines their low social status and distance from other castes. This study aims to give a voice to members of this underprivileged social class.

However, the central gap of the research relates to the lack of efforts to address the prevailing dichotomy of regenerative and more carbon-intensive materials, vernacular and new construction methods, which is further reinforced by government housing programs and the growing influence of construction industries. Roychowdhury et al. (2022, pp. 95–99) call for a more intense engagement with the potential of vernacular architecture, to develop and promote hybrid solutions of vernacular and new construction

⁶ There are four main castes in the Hindu caste system: the priests (Brahmin) form the highest caste, followed by the knights and higher officials (Kshatriyas), the traders and merchants (Vaishyas) and the farmers and craftspeople (Shudras). Excluded from the four castes are the Dalits, also known as Harijans or untouchables. Together with tribal communities they form the lowest layer of the Hindu caste system and are the target groups of this dissertation (Encyclopaedia Britannica).

methods. The polarization between *kutchā*⁷ houses made of local and regenerative building materials and *pukka*⁸ houses made of fired bricks, concrete, and steel is therefore questioned in this dissertation. The research investigates the following three questions:

What factors shape the transition from vernacular to new building practices – from kutchā to pukka houses – in Bahuarwa?

To what extent can a hybrid construction method that combines regenerative and carbon-intensive materials challenge the prevailing dichotomy of kutchā and pukka houses in Bahuarwa?

How does the construction of a school for underprivileged children contribute to the dual production of scientific knowledge and local social benefits?

The first question aims at developing a contextual understanding that allows for a more nuanced comprehension of the multiple factors behind the changing building practices. This question is primarily addressed in the first ethnographic part of the dissertation.

The second question addresses the potential of a hybrid construction method that combines regenerative and carbon-intensive materials. It explores to what extent such a strategy can reconcile the various design requirements resulting from the previously analyzed factors for the changing building practices while also challenging the rigid dichotomy between vernacular and new practices. It forms the guiding question of the second part of the research.

The third question examines the methodological dimension of the research, asking how the integration of research by design and participatory action research methodologies contributes to both knowledge production and tangible local benefits. Through the construction of a school as both a

⁷ derived from Hindi *kaccā* for raw, uncooked, unripe, immature (dictionary.com, 2022a).

⁸ derived from Hindi *pakkā* for cooked, ripe, mature (dictionary.com, 2022b).

research methodology and a social intervention, the dissertation reflects on how transformative research can generate academic insights while ensuring fair collaboration with local communities in a non-extractive manner.

1.4 Structure of the Dissertation

The main body of this research is divided into two parts: An ethnographic analysis of the building transformations in Bahuarwa (chapter 4) and a participatory construction process of a school for underprivileged children in this village (chapter 5). The findings on the building transformations in Bahuarwa served as a basis for the development and application of the hybrid solution balancing regenerative and more carbon-intensive materials, vernacular and new construction methods.

The initial ethnographic analysis consists of three chapters, each of which examines the material transitions and building transformations from a different perspective. The first chapter (4.1) examines how the inhabitants of Bahuarwa deal with the influences of the natural environment. The challenges posed by village fires, floods, earthquakes, and insects are presented and analyzed in relation to adaptations of the buildings.

The second chapter (4.2) explores changes of buildings in connection with socio-economic transformations. The effects of increasing mobility and digitalization are changing the concept of a desirable home. New sources of income and changing family structures result in transformations that are expressed in floor plan typologies and choice of materials. The connections between state-subsidized housing programs, globally expanding construction industries and the structural changes in Bahuarwa are also explained in this chapter.

In the third chapter (4.3), the transformations of building methods will be placed in the context of technological developments. The aim is to show how the construction process changes with the development and introduction of new building methods and products. This includes aspects such as the length of the construction process, the division of labor along occupational lines and gender, supply chains and transport distances. The transition from vernacular self-

construction to informal and incremental construction processes will be illustrated.

The findings in connection with the building transformations were used to build a school for underprivileged children in Bahuarwa, which is documented and reflected on in the second part (chapter 5) of the book in three chapters. The first chapter (5.1) attempts to translate the ethnographic analysis into design factors that are relevant to the inhabitants of Bahuarwa and should form the base for the development of a hybrid solution of vernacular and new construction methods, integrating regenerative and more carbon-intensive materials. This chapter also serves to illustrate considerations for individual parts of the building. The aim is to show how the development of a hybrid solution resembles the negotiation of a compromise, which often leads to contradictions and conflicts between different design factors. The design decisions, which should do justice to both a high level of social acceptance and the integration of regenerative building materials, are presented along this negotiation process.

The second chapter (5.2) explains the building process, the materials used, and the construction in detail. It provides a step-by-step account of how the school was built, including design decisions, material sourcing, and the role of local craftspeople. It can be read independently of the other chapters as a construction manual for similar projects.

The third chapter (5.3) serves as an evaluation of the construction process based on the design factors derived from the ethnographic analysis. It assesses how the identified environmental, socio-economic, and technological considerations were addressed during the design and building phases. Particular attention is given to the alignment with user needs, and the challenges encountered in practice. This evaluation thus provides critical reflections that link the building process back to the ethnographic research of the dissertation.

“The assumption that there is a problem in other (developing) countries that can only be solved with our expertise is related to the attitude that our own social models are not questioned. This gets in the way of the basic structures of development cooperation and, first and foremost, requires a change.”

(Pawlicki et al., 2023, p. 68)

2 Research Design

2.1 Positionality

Working as a Swiss researcher in a context of the Global South and with an underprivileged population group requires decolonizing a Western and Eurocentric understanding of conducting research and interpreting the results. However, the naming of research and decolonization in the same sentence already proves to be paradoxical, as “[t]he ways in which scientific research is implicated in the worst excesses of colonialism remains a powerful remembered history for many of the world's colonized peoples” (Smith, 2008, p. 1). To resolve this contradiction Igwe et al. (2022, p. 454) suggest that cooperation with communities should become an integral part of the research: research questions, objectives, and appropriate methods should be determined in consultation with the affected community. To ensure a positive impact on the target groups and to consider relevant technical aspects, this dissertation was based on a cooperation of several partners (Table 1). These collaborations led not only to the consideration of additional voices and perspectives (R. Roy & Uekusa, 2020), thus expanding the scope of data sources, but also formed the basis for a fair, meaningful and engaged research approach (Kolinjivadi et al., 2020).

My wife, Isha Haselsberger, who is also an architect and has grown up and lived in India until the age of 24, played an indispensable role in the project, contributing both to the data collection through interviews and household visits and to the realization of the school. Her personal network, her translations, and her mediation between me and the target groups were crucial in bridging cultural and linguistic gaps. Without her involvement, neither the research nor the construction of the school could have been successfully carried out.

Priyadarshan Kumar, head, and founder of the *Bahuarwa Foundation*⁹, is the local partner for the future operation of the school. He acted as a mediator and translator between me and the local community. His close relationship to the target groups ensured careful consideration of their needs and the development of appropriate design measures for the school. Through him and my wife eventual language barriers and cultural gaps were overcome and a participatory design approach with the local community assured. The *Center for Indian Bamboo Resource and Technology*¹⁰ (CIBART) was the partner for technical questions. Being experts for an innovative use of bamboo, the craftspeople of CIBART played a crucial role for the implementation of the school.

“Decolonizing research should focus on the question of ‘how’ can the research benefit the Global South, minority groups and Indigenous communities and promote diversity?” (Igwe et al., 2022, p. 462). This claim had consequences for the methods and the objectives of this research. In close exchange with the Bahuarwa Foundation, the construction of a school was seen as the best option to have a positive impact on the livelihood of the target groups, because less than 50% of the Dalit children in this region start school, and only around a fourth of those enrolled complete it.

Officially, there is a public school in Bahuarwa run by the government, which is supposed to provide education to underprivileged children. However, it is rarely in operation, such that wealthier parents send their children to private schools. Since this is not an option for members of the Dalit and tribal communities, the children help at home or in the fields instead of going to school.

Table 1: Partners and their roles in the research process and its four phases: (1) analyzing, (2) visioning, (3) implementing and (4) evaluating. The phases are explained in the following chapters on methodology and methods.

⁹ The Bahuarwa Foundation is committed to improving the living conditions of underprivileged people – mainly Dalits and members of tribal communities. The NGO's focus is on promoting the education of children and young people (Bahuarwa Foundation).

¹⁰ Partner organization for the implementation of the school. CIBART is a non-profit company, founded in 2002. Its work includes bamboo research and development in India, and it has operations in Gujarat, Uttar Pradesh, Uttarakhand, Himachal Pradesh, Bihar, and Jharkhand (Centre for Indian Bamboo Resource and Technology).

Partners	Roles	Research Phases			
		1	2	3	4
Priyadarshan Kumar: Founder and head of the Bahuarwa Foundation, partner for the operation of the school	community expert	x	x	x	x
	interview partner	x	x	x	x
	translator	x	x	x	x
	mediator	x	x	x	x
Local community of Bahuarwa: Primarily Dalits and members of tribal Communities	target group	x	x	x	x
	interview partners	x	x	x	x
	daily life experts	x	x	x	x
	construction workers		x	x	
Centre for Indian Bamboo Resource and Technology: Partner for the implementation of the school	technical experts		x	x	
	interview partners		x	x	
	instructors			x	
	construction workers			x	
Isha Haselsberger: Architect and founder of the NPO Arch Aid	translator	x	x	x	x
	mediator	x	x	x	x
	co-designer		x	x	
	construction supervisor			x	
Daniel Haselsberger: Researcher and PhD Candidate	researcher	x	x	x	x
	mediator	x	x	x	x
	co-designer		x	x	
	construction supervisor			x	

The Bahuarwa Foundation is addressing this problem and offering the affected children affordable school classes in a temporary shelter. This initiative was supported through this research and by the construction of a permanent school building. As such, the school should act as a flagship for the developed construction methods rather than a prototype of a single residential building. A public building benefits a wider target group and avoids a difficult selection of one favored family to “receive” a new building. In addition, a school provides more room for a participatory design approach and the testing of new construction methods, which is more problematic in private residential buildings, as this could lead to a changed social status of the inhabitants and to envy of other community members. To avoid a one-sided relationship, where the research is of “absolute worthlessness” for the researched and of “absolute usefulness” for the researcher (Smith, 2008, p. 3), the creation of a win-win situation should allow me to gain important data for my research, which in turn should serve to have a positive impact on the living conditions of the target groups. The planning and construction of the school is both method and legitimization of the research. While the research is aimed at contributing to the rooting of the school in the local community, the construction of the school is intended to legitimize the research and lead to further insight. The impact-oriented approach should also lead to a higher willingness of the participants to share information, and increase the authenticity of the information, as the participants’ responses influence the design decisions for the school. While the long-term operation and maintenance of the school is funded by donors of the Bahuarwa Foundation, the construction of the school was financed by foundations from Liechtenstein and private donors¹¹ of the Arch Aid¹² association that my wife and I founded to implement this

¹¹ The H.E.M. Stiftung, the Guido Feger Stiftung, the LIFE Klima Stiftung Liechtenstein and numerous private donors made it possible to finance the construction costs of CHF 70,000 or INR 70 lakhs.

¹² Arch Aid is a non-profit organization founded in 2020 by Isha and Daniel Haselsberger with the aim to support underprivileged communities in India through built projects that are based on participatory design processes and the promotion of sustainable building methods.

and future projects. The close connection between research and the construction of a school raised the question of the extent to which the school is a gift (Del Real, 2009; Mauss, 2001; Pawlicki et al., 2023, pp. 60–61) or the result of a genuine collaboration. In the case of a gift, a hierarchy arises between the giver, who pays for the gift – or in this case organizes its financing – and is thus able to determine its design, and the recipients, who accept or reject it. Acceptance depends on how well the gift meets the needs and expectations of the recipients and therefore also on how well the giver knows the recipients and respects their needs. This points to the importance of cooperation in the sense of an intensive communication process.

But even if the recipients accept the gift and it meets their needs, this does not mean that they will be able to make good use of it in the long run, as they may lack the means to do so. Here, too, cooperation plays a central role, because joint development and implementation enable the cooperation partners to acquire the means – knowledge, tools, methods – to build and maintain the project themselves. This presupposes that the donor is open to the process and to possible resistance on the part of the cooperation partners and does not exploit a position of power as simultaneous researcher, financier, and architect to impose his (Eurocentric) ideas onto the research context.

This dissertation should meet the requirements for meaningful cooperation in three ways: (1) By collaborating with a reliable partner who demonstrates great initiative and commitment to the long-term operation of the school. In this case, the project partner's required initiative became evident in several activities prior to the start of our collaboration, such as the independent construction of a temporary shelter for lessons, the provision of own land for the school, and the securing of several years of funding for activities that benefit underprivileged villagers. These observations prior to the research, in particular the planning and construction process of the school, were good indications that a long-term dependency of the project partner on the researcher can be avoided. (2) By identifying an urgent need for a building, it was possible to ensure that my knowledge and intentions were useful to the target groups. Often, legal

adjustments at a political level or infrastructural interventions, rather than individual buildings, lead to a positive impact on the living conditions of underprivileged people. In this case, however, the construction of the school building should assist the project partner in obtaining state recognition for the education provided. (3) The research and construction process involved a willingness to compromise, ensuring equal cooperation among all parties. The aim of the research was to integrate regenerative building materials into the design of the school. This condition was communicated to the participants and accepted by them from the outset. It was agreed that the use of regenerative building materials was not exclusive, but rather a compromise between regenerative and more fossil-fuel based materials based on the aspirations and needs of the target groups. Negotiating a compromise should help to investigate the social acceptance of building materials and methods. Discussion, resistance, and conflict were expected and accepted as part of the research.

Another point to consider was the legitimization of the experimental nature of the research and the school building in relation to underprivileged groups. Projects of this sort are often criticized for their experimental nature, particularly in areas of the Global South where the power dynamic of funding architects can lead to experimentation that results in poor quality or insufficient means for maintenance and operation by its users (Del Real, 2009; Pawlicki et al., 2023, pp. 64–65). Although the research methodology is referred to as a “real-life experiment” (Groß et al., 2005), this primarily relates to researching the social acceptance and feasibility of the hybrid solution tested in political and economic frameworks, rather than the construction and maintenance itself. Through a collaboration of specialists in contemporary bamboo construction, a civil engineer, and professional installers and craftspeople, the building should be of high quality. The aim of this dissertation was not to develop a new construction method, but rather to combine existing methods in a new way. The findings of other successfully implemented projects (Kaminski, Lawrence, & Trujillo, 2016) were also utilized.

The last point to be mentioned here is the negative ecological impact, which is often lamented in Design Build projects (Pawlicki et al., 2023, pp. 65–68) and which results from the necessary travel from Switzerland to the research context in Bihar. During the research, planning and construction process, I visited the site four times to initiate, plan, implement and evaluate the school building and the associated research process. This meant four return flights from Zurich to Delhi and three return flights from Delhi to Darbhanga, which is the nearest place from Bahuarwa with an airport. The train was used twice to travel from Delhi to Darbhanga and back. Public transportation and tuk-tuks were used for trips in the surrounding of Bahuarwa. Even if this does not reduce emissions, it should be mentioned that the trips were combined with visits of my wife’s family in Delhi and would therefore have taken place for family reasons even without the research project. Conversely, the project would not have come about without my wife and the resulting connection to India. As the air travel served both research and private purposes, I did not undertake any further air travel for private purposes during the entire research period. By leading a sufficient lifestyle without a private car and living in just under 65 square meters of living space, my wife and I are trying to offset the emissions caused by air travel to some extent and create time and financial opportunities for our social engagement in India.

2.2 Research Paradigm

Transformation research played an important role for the approach and objective of this dissertation. The development of an understanding of an existing system, the identification of transformation paths and the support of transformation processes and actors are the central concerns of transformation research, which is not yet viewed as clearly defined discipline, but as an open vessel that brings together different research directions that aim to transform towards a sustainable society (Wittmayer & Hölscher, 2017, p. 11). This research is concerned with the investigation of building transformations, the identification of their influencing factors and the development of a sustainable alternative

to the prevailing emission-intensive building practices through the use of regenerative building materials.

Perceiving the desired transformation as a design mandate, transformation researchers are not only concerned with generating knowledge, but also with actively initiating and supporting change through concrete actions, which enables them to analyze transformation not from a passive, observational role, but as an active player (Schneidewind & Singer-Brodowski, 2014). Similarly, this research is not just about gaining scientific knowledge, but also about making a practical contribution that should have a positive impact on the living conditions of the target groups.

Actively working towards sustainable development, transformation researchers do not understand knowledge as value free and separated from the real world, but as normative and socially constructed (Herweg et al., 2016, p. 13). Instead of separating science and society, representatives of transformation research call for an increased exchange between the two to ensure that research is not only used as a driver of technological innovations in the service of the economy but also promotes social and cultural innovations (Schneidewind & Singer-Brodowski, 2013, pp. 131–132). Otherwise, according to Schneidewind and Singer-Brodowski (2013) it tends to exacerbate rather than solve current sustainability problems. Here, too, the underlying assumption of this dissertation is that the practical testing of scientific findings in a real-world context is a prerequisite for identifying the lever points that can enable a sustainable change in building practices.

Based on action research (Greenwood & Levin, 2007), Wittmayer and Hölscher (2017, pp. 11–12) distinguish between conceptual knowledge and practical knowledge. While the former serves to examine transformation processes in a descriptive-analytical manner and to stimulate scientific discourse through publications and lectures, practical knowledge focuses on the direct, action-oriented, and participatory support of social transformation processes. Based on a definition of the WBGU¹³ (2011, pp. 342–343),

¹³ Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen.

the authors differentiate between “transformation” and “transformative” research: whereas the former stands for a more descriptive-analytical approach and can thus be understood as research “on” transformation, the latter stands for an active and action-oriented approach and thus for research “as” transformation (Wittmayer & Hölscher, 2017, pp. 40–41). In terms of this dissertation, the first part can be understood as research on transformation, while the second part represents research as transformation.

With regard to suitable methods for transformation and transformative research, Wittmayer and Hölscher (2017, pp. 70–83) provide a comprehensive overview. The authors list well-known methods from social sciences as well as newer methods that have emerged in the course of transformative research. The methods are assessed based on the research approach, which the authors classify as more descriptive-analytical or more transformative, and based on the research results, which contain more practical knowledge or more conceptual knowledge. Well-known social science methods of interviews, observation and document analysis have proven to be helpful with regard to achieving conceptual knowledge using a descriptive-analytical approach. Participatory methods and frameworks, in turn, such as the real laboratory or participatory action research favor a transformative approach and lead to practical knowledge (Wittmayer & Hölscher, 2017, pp. 89–90). Here, too, the first part of the dissertation is more strongly oriented towards descriptive-analytical methods, while the second part makes use of participatory action research and can also be understood as a real-world laboratory.

Referring to the distinction between the forms of knowledge in “system”, “target” and “transformation knowledge” (Schneidewind & Singer-Brodowski, 2013), Wittmayer and Hölscher (2017, pp. 88–92) state that there are numerous methods for generating system and target knowledge, while the implementation and thus the actual transformation from the current state (system knowledge) to the desired vision of a more sustainable society (target knowledge), often fails to materialize based on a lack of transformation knowledge. The authors (Wittmayer & Hölscher, 2017, pp. 88–92) conclude that all three forms of knowledge should be

considered equally when choosing appropriate methods so that they complement each other. In this dissertation the different forms of knowledge and the associated methods are combined. The insight into existing construction methods and their adaptations (system knowledge) are mainly gained through interviews, participatory observations and building documentations. The hybrid construction method and the design of the school (target knowledge) are developed by negotiating appropriate materials and construction details for each building part with members of the Bahuarwa Foundation and craftspeople. The transformation knowledge is gained through the participatory construction of the school with bamboo experts from Gujarat, as well as residents and craftspeople from the region of Bahuarwa.

A normative understanding of science and the associated consideration of social relevance differ from the objective and neutral perspective of prevailing scientific paradigms. Familiar quality criteria such as peer reviews and citation indices are not sufficient, appropriate and expedient for the much broader research questions of transformation and transformative research respectively (Wittmayer & Hölscher, 2017, p. 67). Wittmayer and Hölscher (2017, pp. 67–69) name five criteria by which the quality of such research can at least be discussed: scientific impact, social impact, trustworthiness, transparency and reflexivity. The scientific and social impact depend on a descriptive-analytical or transformative orientation of the research. Although both approaches can have both scientific and social impacts, the former tends to have a stronger impact in the field of science, while the latter is more aimed at social impacts. Regardless of the research approach chosen, it is crucial that the researchers document and disclose their approach (transparency) and that they structure the individual steps in a comprehensible manner and come to logical conclusions (trustworthiness). In dealing with the numerous factors of persistent problems that are difficult to determine and in order to do justice to the normative attitude, a critical questioning (reflexivity) of the procedure, the results, as well as the effects of research on science and society is decisive (Wittmayer & Hölscher, 2017, pp. 67–69).

The findings of Wittmayer and Hölscher (2017) provide a relevant methodological framework for this research. To meet the quality criteria, the research approach is described in detail on the following pages (transparency). The structure of this dissertation should make it easy to follow the individual research steps and the gradual formation of insight and conclusions (trustworthiness). Finally, the approach and types of impact (social and scientific impact) of the research are critically reflected upon in the conclusion (reflexivity).

2.3 Methodology

Positioned in the field of transformative research, this doctoral dissertation is related to three different methodological frameworks: Real experiments, participatory action research, and research by design. Listed by Wittmayer and Hölscher (2017, pp. 81–83) as suitable participatory methodologies for the generation of transformation knowledge, “real laboratories” (Schneidewind, 2014) or “real experiments” (Groß et al., 2005) and “participatory action research” (Greenwood & Levin, 2007) offer valuable guidelines for the creation of an appropriate research design in terms of the inclusion of the local community and the consideration of a real life situation. Since design is a central component of the research process as well as the results, this transformative research also contains relevant aspects of “research by design”, wherein design is not just “an object of scientific study” but an “equal agent in the production of knowledge” (Hauberg, 2011, p. 48). The relation to these three frameworks is explained in the following section. The notions “real experiment” or “real laboratory” seem contradictory at first sight: Whereas the term “real” states that research takes place in the “real world” with its numerous uncontrollable factors, the terms “experiment” or “laboratory” are commonly related to scientific contexts where external factors are mainly controlled (Groß et al., 2005, p. 11). The aim of this apparent contradiction is to link science and society more closely and to generate socially relevant knowledge that supports sustainable processes in the sense of transformative research. Instead of primarily generating new knowledge, a real experiment demands a

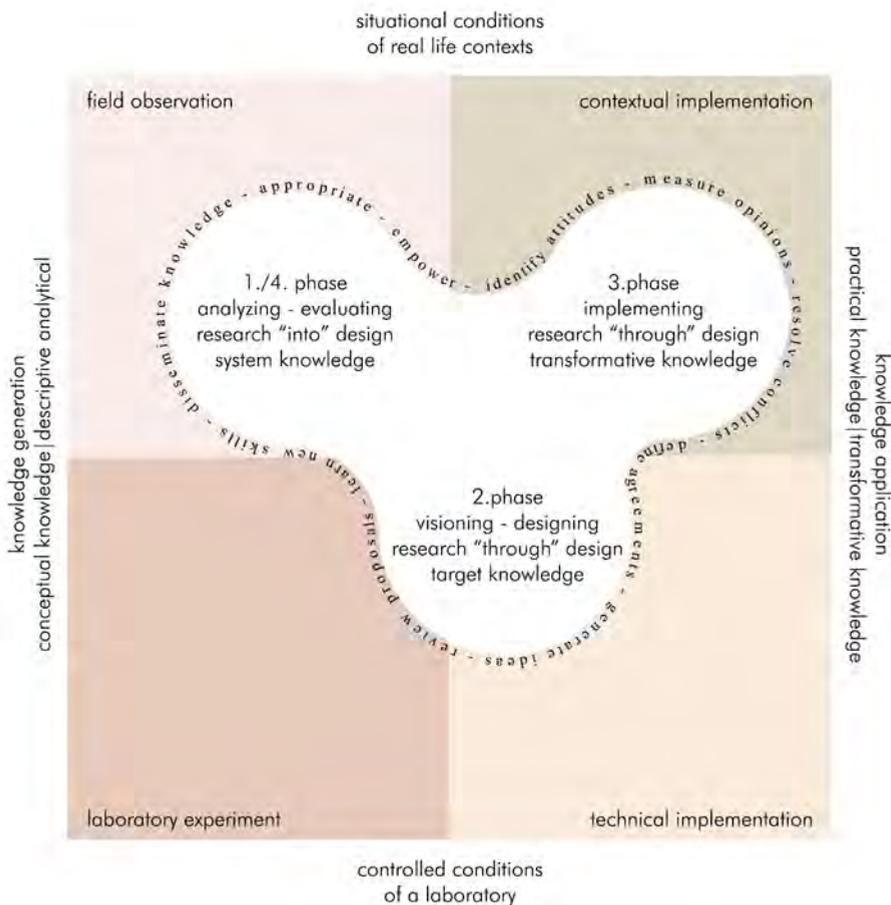
continuous oscillation between the generation and the application of knowledge, which Gross et. al. (2005, pp. 13–16) describe as a “recursive learning process” wherein knowledge is generated through processes of observing and understanding and then applied in concrete plans and actions that lead to new knowledge gaps and uncertainties. In addition to the interaction of knowledge application and generation, the authors underline the degree of controllability of external factors as a second dimension in a scheme that describes the position of real experiments in a “typology of experimenting” (Figure 6) (Groß et al., 2005, pp. 16–19). The real experiment or the real laboratory (Schneidewind, 2014), as it is often called in the context of transformative research, is relevant for this dissertation insofar as it provides important information on the dependencies between knowledge generation and application, but also with regard to the distinction of the situation-specific and controlled boundary conditions within the different phases of the research.

With regard to the inclusion of the local community in the design and construction process of the school, participatory action research, in particular Sanoff's (2000) “community participation methods in design and planning” play an important role. Participatory action research (Greenwood & Levin, 2007) is based on the concept of action research (Lewin, 1946), which assumes that one can only understand a system if one deals with it through action. In participatory action research, priority is given to a specific research group and its needs (Sanoff, 2000, p. 60). Referring to Sanoff's purposes of community participation in design (2000, p. 11), this research is aimed to “measure opinions” and “identify attitudes” towards vernacular and new building methods and materials, “resolve eventual conflicts” among participants, “generate ideas” for new design solutions, “review proposals” given by the researcher and “disseminate information” about the developed design principles among the participants through active collaboration.

Sanoff (2000, pp. 13–14) suggests community participation to happen in four stages: In an initial “goal setting” phase the purposes of the community participation are stated, information about the needs of the participants

Figure 6: Planned research design in the "typology of experimenting" (modified from source: Groß et al., 2005, p. 19).

shared and problems defined. The aim of this first phase is to ensure a common "language" among the participants. The following "programming" phase is characterized by a further sharing of the participants' expectations and objectives to rule out later misunderstandings. The "design" phase involves physical designs of the participants that serve as resources for the professionals to "[...] synthesize alternative and final plans" (Sanoff, 2000, p. 13). Sanoff (2000, p. 14) underlines the relevance of the often omitted final "implementation" phase, "[...] when the how-to, where-to, when-to, and who-will-do-it must be added to what people want and how it will look". Leaving out the implementation phase resembles the findings on transformation research (Schneidewind & Singer-Brodowski, 2013, p. 135; Wittmayer & Hölscher, 2017, pp. 89–90), where accumulated system and target knowledge stay unconnected due to an



often missing transformation knowledge. For this research the programming phase is integrated in the initial goal setting and the design phase, the remaining three phases, named as “analyzing”, “visioning”, and “implementing” and corresponding to the system, target, and transformation knowledge, are complemented by a final “evaluating” phase, which closes the loop and overlaps with the first phase (Figure 6).

Depending on the research phase, design takes on different roles, which Frayling (1993/94, p. 5) describes as research “into” design, “through” design and “for” design. Hence, design is either the object of investigation, the method for knowledge production, or the goal of the research. Similarly Borgdorff (2005, pp. 5–7), differentiates between research “on”, “for” and “in” the arts. Hauberg (2011, p. 50) compares the design process with the research process; in both, new products and new knowledge are sought, but in the case of the design process with the language of the designers; with drawings and models instead of written words. This is where a key feature of this research lies. The participatory planning and construction process should be a relevant communication medium and thus a data generator. The topics addressed in the initial ethnographic analysis should take on a concrete form during the construction process and thus become more comprehensible for the target groups, which should result in additional conversations and a deeper understanding of the analyzed building transformations. King’s (2016, p. 34) outlines of her active participation in the incremental building process of informal settlements in Delhi as a methodology of her dissertation show similarities with this research:

“In this context making (doing) is a useful strategy for engaging with and provoking ideas and responses from a community. [...] Thus, architecture is understood as a tool for engagement and dialogue, empowering communities to contribute towards the shaping of their city. Here the role of the architect goes beyond that of design to encompass a whole range of skills from finance, political lobbying, fundraising, community liaison and the traditional skills of design development and project delivery. This approach to architecture

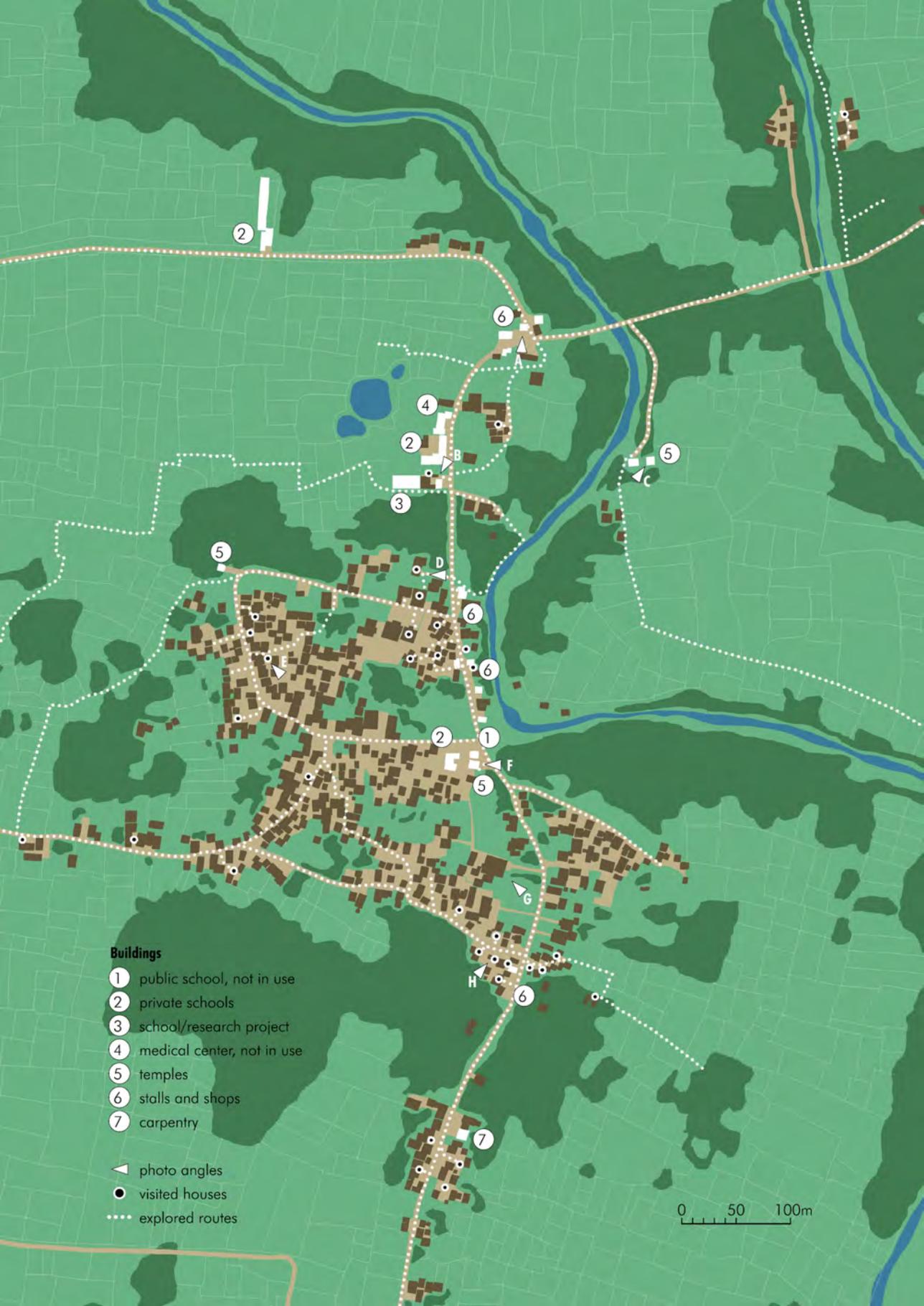
(and the methodology of this research) emphasizes the process as opposed to the final product.”

2.4 Methods

In the initial analyzing phase, wherein the changes in the use of building materials and -methods were being investigated, design acted as an object. This research “into” design (Frayling, 1993/94, p. 5) corresponds with the aforementioned descriptive-analytical approach of transformative research (Wittmayer & Hölscher, 2017) and should lead to a system knowledge (Schneidewind & Singer-Brodowski, 2013, p. 134) about the transformation processes wherein vernacular buildings made of earth, bamboo, and thatch are being replaced by houses made of fired bricks, concrete and steel. Hereby, knowledge was mainly generated through ethnographic methods, such as interviews, participatory observations and building analyses in the village of Bahuarwa. This included visits of more than thirty residential houses as well as ethnographic interviews (Flick, 2018, pp. 241–243) with the inhabitants of twelve households.

In the course of the research, it turned out that spontaneous conversations during walks through the village (Figure 7) were often more productive than preplanned interviews. While the request to conduct an interview is met with skepticism by many inhabitants, having a cup of tea together is welcome. Most residents are also skeptical about audio recordings and declarations of consent. They are willing to talk about their living situation, but they cannot understand why they should be audio recorded or why they should sign a document, as they are not familiar with a (Eurocentric) concept of research and even less with its methods and ethical requirements. However, these restrictions were accepted in favor of authentic statements and in respect of the demands of the interviewees. If it turned out that spontaneous conversations provided relevant content for the research, the residents were made aware of this and asked whether the content could be used for research and publication purposes. The same applies to interior photographs of houses or family members taken for research purposes.

Figure 7 (following double page): Map of Bahuarwa with an overview of visited households and impressions of buildings.



Buildings

- ① public school, not in use
- ② private schools
- ③ school/research project
- ④ medical center, not in use
- ⑤ temples
- ⑥ stalls and shops
- ⑦ carpentry

- ◄ photo angles
- visited houses
- ⋯ explored routes

0 50 100m



Bahuarwa Foundation's temporary school (B)



small shop (A)



temple (C)



house of a wealthier family (D)



incremental vertical expansion (E)



public school (F)



"Mannat," one of Bahuarwa's largest houses (G)



house of a Dalit family (H)

Without exception, the residents responded positively to these requests, since they recognized that the conversations and home visits contributed to the construction of the school. The information was recorded in short notes, followed by detailed explanations after the house visits.

Parallel to the participatory observations and ethnographic interviews, the residential buildings of the interviewed inhabitants were documented through photos, measurements, and sketches. This included the orientation, organization and size of the rooms, the positioning of openings, the transition from outside to inside, but most of all the applied materials and construction techniques. The majority of home visits and discussions were spontaneous. In case a specific selection was made, it occurred in close exchange with Priyadarshan Kumar from the Bahuarwa Foundation, who

Figure 8: Talk with a resident at her home. While my wife is translating, I am taking notes which I extend shortly after the interviews and talks.





Figure 9: Discussing different building materials and methods with villagers using pictures. The villagers are asked to choose their “favorite building” from the selection and to give a brief explanation of their choice.

knows most of Bahuarwa’s inhabitants and is in contact with them daily through his work. The houses and interview partners were selected based on the materials and construction techniques that are applied in their houses, which should cover a wide range of transformation stages from houses almost exclusively made of regenerative materials to those made of fired and more carbon-intensive materials. This should provide insight into the different stages of transformation and help to understand the advantages and disadvantages of different building materials and methods. Since most of the inhabitants are illiterate and do not speak English, interviews were held with the help of Mr. Kumar and my wife. Most of the ethnographic interviews (Flick, 2018, pp. 241–243) with the inhabitants took place at their homes (Figure 8). This allowed the inhabitants to relate their

experiences to their immediate surroundings, which helped to avoid misunderstandings and combined the heard with the observed. The ethnographic interviews had a narrative character (Flick, 2014; Rosenthal & Loch, 2002; Schütze, 1977); inhabitants were asked a few broad questions with follow-up questions, such as “What do you like about your house? What are the problems that you are facing in your house? What would you like to change about your house?” This allowed the inhabitants to express their experiences freely while making room for unexpected answers that might not be unveiled in more structured interview forms. In the following visioning process, design acted as a tool to co-create a hybrid building strategy with inhabitants, school operators and craftspeople, based on the gained system knowledge of the previous analysis with the inhabitants. This

Figure 10: Visit of local brick kiln. The manager of the brick kiln explains the firing process of the bricks.





Figure 11: Prototyping of different structural elements with bamboo at the workshop of CIBART in Ukai, Gujarat.

“research through design” (Hauberg, 2011, p. 51) resulted in a target knowledge (Schneidewind & Singer-Brodowski, 2013, p. 134), in this case, a design strategy. Therefore, different materials and their suitability for different building parts were discussed, images and visualizations presented to the community and Mr. Kumar to better understand the acceptance of possible alternatives (Figure 9). One to one testing of possible layouts based on the existing temporary school allowed a better understanding of required room proportions and sizes. These hands-on methods provided a common language among the participants. Potential contributions through local craftspeople were analyzed during visits of different production sites, such as the local brick kiln (Figure 10) and carpentry. Together with bamboo experts of the Center for Indian Bamboo Resource and Technology in Ukai, Gujarat, construction details for the bamboo structure were being developed and preparations made for the implementation of the school building (Figure 11).

In a third stage, the implementation of the developed design lead to a transformation knowledge (Schneidewind & Singer-Brodowski, 2013, p. 134) that linked system and target knowledge and allowed a transition from thinking to doing. Inhabitants of Bahuarwa were invited to take part in the construction process. In different construction stages concerning the foundation and plinth, the bamboo structure of the walls, ceiling and roof, the infill of the walls, the roofing, the interior fitting and the production of furniture, residents and craftspeople contributed to the implementation of the school building. The selection process of willing helpers occurred in close collaboration with the Bahuarwa Foundation.

Care was taken to ensure that all interested residents were involved equally. Whereas men were more involved in physically more demanding work for the foundation and structure, women were mostly responsible for the wall fillings with earth and straw. The implementation phase allowed a testing of the developed construction technique as well as a spatial appropriation of the school through the inhabitants. Different opportunities were given to let the participants leave their "traces" in the building to make it their own.

The construction process was documented daily. The planning, and particularly the construction process turned out to form a relevant data generator for the research. During previous talks and interviews, it sometimes proved difficult to formulate certain topics and questions in such a way that the respondents can relate to them. They are not used to answering questions about the condition of their house or about their building traditions. This challenge was remedied by the construction process, when the research took shape and became tangible for the participants. Suddenly, everyone was able to relate to and comment on the building that was gradually being constructed. This lead to valuable insight that was deepened and recorded in further discussions.

In addition to spontaneous conversations, twelve participants in the construction process and ten construction experts were interviewed, including three bamboo experts from CIBART, the manager of CIBART, the manager of the brick kiln in Bahuarwa, local masons, a civil engineer from

Darbhanga responsible for the planning of the foundation, two painters, and a carpenter from Bahuarwa. Besides the daily conversations and observations, active participation in the construction process and site management provided relevant insight into the applicability of the developed hybrid solution.

In the end, the building as well as the process were evaluated in a more descriptive-analytical way. Mr. Kumar from the Bahuarwa Foundation, the students and teachers, and involved craftspeople were asked about their perception of the building, to what extent the building materials and methods used correspond to their aspirations, to what extent they were able to benefit from the construction process and whether they can imagine living in houses that are built in a similar way. Table 2 provides an overview of the research design.

As can be seen from the descriptions of the methods used, most of the data was obtained outside of strictly structured methodological frameworks: During walks through the village, visits of local markets, religious ceremonies, unexpected invitations to a tea, breaks at the construction site, while playing with the students and staying at the Kumar family home in Bahuarwa for a total period of about four months. From a scientific point of view, this can be seen as a disadvantage but was ultimately a way of obtaining authentic data and respecting the local population's lack of reference to (Western-style) research methods.

The data collected includes fourteen transcripts of audio recorded interviews, notes from 22 more informally led conversations, daily logs of participatory observations over a total duration of about four months, photographs, sketches and drawings. The conversation partners include inhabitants, construction workers and schoolchildren, as well as experts related to the research topic such as Mr. Kumar from the Bahuarwa Foundation or the head of the local Panchayat¹⁴.

Table 2 (following double page): Overview of research design.

¹⁴ Panchayat translates as an assembly (yat) of five (panch) selected, usually older, male villagers who are elected by the village population. This decentralized form of village self-government is particularly common in India, Nepal, and Pakistan (Encyclopaedia Britannica).

research paradigm	transformative research	
methodologies	ethnography — real experiment — participatory action research — research	
chapter in book	chapter 4: from raw to fired	chapter 5: between raw and fired
phase	analyzing	visioning
purpose	understanding changes of building practices	developing a hybrid design
	identifying relevant design factors	developing a design for the
form of knowledge	system knowledge	target knowledge
	conceptual knowledge	conceptual/practical knowledge
relation to design	research <i>into</i> design	research <i>through</i> design
	design as object of investigation	design as method
methods	ethnographic interviews	ethnographic interviews
	participatory observation	participatory observation
	house visits, village walks	participatory planning
	documentation of buildings	prototyping with mock-ups
objectives	understanding of building transformations, identifying influencing factors	
	development of context-sensitive design measures to integrate regenerative building	
	assessment of the suitability of the applied transformative methodologies	
local benefits	improved educational infrastructure for 150 children from underprivileged backgrounds	
	temporary income source for underprivileged villagers through participatory construction	
	knowledge transfer from bamboo experts to villagers	

by design

and fired

	implementing	evaluating
strategy	building the school in a participatory process	identifying measures to upscale the design
school	transferring knowledge and creating employment	evaluating the applied methodologies
edge	transformation knowledge	combination
	practical knowledge	conceptual knowledge
	research <i>through</i> design	research <i>into</i> design
	design as method	design as result and object of investigation
	ethnographic interviews	ethnographic interviews
	participatory observation	participatory observation
	participatory construction	

ding materials in new construction methods

grounds, multipurpose hall for public uses on non-school days

nstruction

Most of the conversation partners are male, since most construction workers and construction experts are male. At least during the home visits and discussions with villagers, a balanced ratio of male and female participants was achieved. All conversations took place on site and were recorded with notes or audio. The people interviewed are mostly from Bahuarwa or the surrounding region. Not included in the list of interviews are the numerous informal and spontaneous conversations with schoolchildren, teachers, craftspeople, residents or NGO members, which were recorded by making entries in the observation protocol. The appendix contains an overview of the interviews conducted, the questions asked, and excerpts from the observation protocols.

All text-based data was analyzed and evaluated by means of a qualitative content analysis (Mayring, 2022) using MAXQDA software. Already during the collection of the data, three relevant aspects emerged, which were formulated deductively as categories prior to a more detailed inductive analysis of the text-based data and a subsequent formulation of codes. These three categories correspond to the three chapters (4.1 – 4.3) of the first part of this research and serve to better understand the building changes in Bahuarwa over the last decades: environmental challenges, socio-economic transformations and technological developments. After all components of the text-based data were subdivided according to these categories, a fine-grained, inductive coding was carried out, which is reflected in the subchapters of the first part.

The relevant design criteria for the construction of the school were derived from the codes of the first part of the research and described in the first chapter (5.1) of the second part. The design criteria were then examined regarding their compatibility with the integration of regenerative materials in the intended hybrid construction. The relevance and feasibility of the individual design criteria were compared in relation to different building components, base – wall – roof, and prioritization was made. The result of this central part of the dissertation is a hybrid strategy, which was then tested in practice and described in the second chapter (5.2) of the second part. After the implementation, the previously defined design criteria were evaluated again

in retrospect to formulate necessary measures to upscale the developed building method. Table 3 shows an overview of the categories, codes and chapters of the research.

2.5 Validity

Even though this research is a single case analysis that is bound to a specific location and a defined purpose, the learnings can be applied to contexts with similar climatic and socio-economic conditions. Nevertheless, it is not the primary goal to achieve generally applicable insight that risk being superficial. Instead, a specific context should be carefully analyzed in depth and a suitable construction method developed for it. More importantly, the applied research design should provide architects and architecture students that aim to implement comparable projects with a strategy. The research is not only aimed to come up with a building (method) that is rooted in the local community but also with an appropriate (research) approach that helps to develop this building (method). This dissertation combines established methods from social sciences with those from architecture and attempts to create synergies. While on one hand the integration of social science methods such as interviews and participatory observations can provide a strong basis for the design and thus avoid an arbitrarily developed idea of the architect being forced onto the target groups, on the other hand the participatory planning and construction process creates a common platform for discussions and observations among all involved stakeholders such as researchers, planners, craftspeople, target groups and operators. Through building, research takes shape and becomes tangible. The construction becomes a means of communication and a relevant data generator that examines and consolidates the previously obtained data through practical application, while at the same time producing further data and raising new questions.

Table 3 (following double page): Overview of categories, codes and chapters as structure of the dissertation.

chapter 4: ethnographic analysis: from raw to fired

categories/chapters	environmental challenges	socioeconomic transition
codes/topics of subchapters	fire: village fires during dry season	self-sufficiency
	water: rainy season and floods	migration and income
	earth: earthquakes	social structures
	insects: termites and bugs	housing program
derived design factors	durability and maintenance	aspiration
	thermal comfort	expandability

chapter 5: participatory design process: between raw and fired

chapters	planning process	building process
topics of subchapters	relevant design factors	base
	base: waterproof and maintenance friendly	structure
	wall: contemporary look outside, cooling inside	walls and openings
	roof: waterproof and lightweight	roof and ceiling
derived upscaling measures	make alternative building methods maintenance-friendly	avoid polarizing housing
	make alternative building methods durable	promote awareness
	underline benefits such as thermal comfort	develop measures

transformations	technological developments
individualization	self construction
	brick firing
	building industries
	building services and furnishing
	availability
	affordability

	evaluation of design factors
	durability and maintenance
	thermal comfort
	availability
	affordability
	aspiration
	expandability
	environmental impact

housing programs	promote training and knowledge distribution
awareness of residents regarding climate change	make infrastructure accessible
incentives to build multistorey buildings	ensure equal salaries

“[Architectural history] amounts to little more than a who's who of architects who commemorated power and wealth; an anthology of buildings of, by, and for the privileged [...] with never a word about the houses of lesser people.”

(Rudofsky, 1964, Preface)

3 Conceptual Framework

3.1 Introduction

In this chapter, the dissertation is embedded in an existing discourse on topics relevant to the research. Based on four subchapters, the references to (1) vernacular and informal architecture, (2) Gottfried Semper's and Karl Marx's understanding of metabolism, (3) subaltern urbanism and the current developments and (4) forecasts of India's construction sector will be explained.

The first part serves to position the dissertation in architectural history and theory, which gradually emerged from the middle of the 20th century, and that perceives building not only in terms of its material characteristics and technological advancements, but also as an engagement with the environment.

In the second part, two different interpretations of the concept of metabolism are presented, referencing Semper and Marx. Both interpretations of metabolism prove to be helpful for the investigation of Bahuarwa's building transformations: on one hand, in relation to the changing applications of building materials in the sense of Semper's *Stoffwechseltheorie* (*theory of material transformation*); on the other, in terms of the changing interaction between humans and nature.

If the first chapter is about the "ordinary house" in contrast to the architecture of the elites, the third chapter is about the "ordinary city" in the Global South in contrast to the "world class city" of the Global North. Although Bahuarwa does not exhibit what one might typically conceive of as "urban" character, the place is nevertheless deeply affected by broader processes of urbanization. The "ordinary village" of Bahuarwa essentially lies on the remote extents of an urbanized regional-scale space, thus lending validity to its designation as a specific form of urban periphery (Howe, 2022a, 2022b).

Finally, the last chapter is intended to summarize the historical development of construction methods in India and highlight current trends leading to the increasing displacement of vernacular construction methods. In doing so, it

underlines the necessity of this kind of research, occurring at the interstice of theory and practice.

3.2 Architecture without Architects

With the aim of making a social contribution to an underprivileged population group, this dissertation is grounded in an interest in architecture that comes about without architects, to reference the title of Bernhard Rudofsky's exhibition at MoMA in 1964. Rudofsky criticized the bias of architectural history, which "[...] amounts to little more than a who's who of architects who commemorated power and wealth; an anthology of buildings of, by, and for the privileged [...] with never a word about the houses of lesser people" (Rudofsky, 1964 Preface). With images of "non-pedigreed" architecture from all over of the world, he underlined the relation between these buildings and their environment.

With Rudofsky's exhibition, the relationship between architecture and the environment and thus between humans and nature gained great visibility. This was an issue that had already been discussed since the mid-1950s under the term "habitat" (Roesler, 2013, p. 223). Contrary to the ideas of the modernists such as Le Corbusier or Konrad Wachsmann, who saw the logic of building as being based on technological possibilities and inherent material properties, architects like Erwin Gutkind, Aldo van Eyck, Alison, and Peter Smithson emphasized the relevance of the specific environment for the design characteristics of a building (Roesler, 2013, pp. 215–249). Instead of a *tabula rasa*, they saw architecture embedded in a context that represented both potential and challenge, wherein they measured the quality of a building by its adaptation to its surroundings.

While the initial interest was primarily on the buildings' adaptation to natural conditions such as climate and topography, in the mid-1960s there was a shift towards the symbolic content of building: from building as a survival strategy in the battle with nature to a cultural technique that creates identity (Roesler, 2013, pp. 249–277). This led to the concept of vernacular architecture, an architecture that is adapted to the natural and social conditions of its location, reflects the ideas of its builders and inhabitants, and differs from "high" architecture as everyday architecture.

While the habitat discourse primarily drew attention to the relationship between architecture and the natural environment, architects like Paul Oliver, Labelle Prussin and Amos Rapoport expanded the discussion to include the social and cultural factors influencing vernacular building (Roesler, 2013, pp. 252–253). Rapoport (2002, pp. 18–45) in particular resisted the reduction of an understanding of building to single design factors. He perceived the climate, material properties and construction techniques as secondary factors, while he considered cultural and social aspects more important (Rapoport, 2002, pp. 46–49).

The formation of identity is a central concern of vernacular architecture. However, particularly in former colonies, the definition of one's own identity led to an ambivalent relationship with vernacular architecture, as it embodies both one's own identity and a past that one would like to leave behind (Roesler, 2013, pp. 254–256). The growing interest of architects in ordinary buildings (outside Europe) as opposed to extraordinary architecture led to an expansion of architectural theory and marked the beginning of an architectural ethnography whose findings came not from the building site, as had previously been the case, but from the field, which, along with the emerging construction laboratories, formed a new place of knowledge production for architects (Roesler, 2013, pp. 203–210).

In the course of increasing globalization and urbanization, however, the identity-forming boundaries of the vernacular are disappearing. Emerging building industries, rather than the specific characteristics of a natural environment, determine the choice of materials, increasingly displacing regenerative building materials and locally rooted traditions. The global spread of cement and steel leads to the ubiquitous use of Corbusier's Domino House, a neutral, prefabricated building that can be adapted to any situation and program. In contrast to the adaptation of vernacular architecture to its surroundings, the adaptability of this new architecture can be seen in its openness as a load bearing structure that allows for any layout and facade design. There is thus a shift from a building as a climatic structure, adapted to the conditions of its surroundings, to a building as a load-bearing

structure, adapted to the properties and load-bearing capacity of its materials (Roesler, 2013, pp. 326–347).

Serageldin (1990, p. 53) argued that architects – as was previously the case with vernacular architecture – only began to deal with the newly emerging informal ways of building at a late stage, due to the lack of aesthetics and quality of the buildings. She points out that in the early discussions about social housing, architects focused on design aspects and the provision of sanitary facilities in response to the growing informal building activities, without paying sufficient attention to affordability (Serageldin, 1990, p. 50). This was a consequence of the architects' training in the Global North, which failed to prepare them for the new challenges of growing metropolitan areas in the Global South. The architect John Turner (1972) was one of the first to address the characteristics of these “self-help housing” activities in 1972. He emphasized the peculiarities of an incremental building process, which is a relevant characteristic of informal construction methods, not least because the more expensive building materials rarely allow the complete building to be implemented at once (Turner, 1972, pp. 148–175).

The neglect of the natural environment, in particular the climate, as a design factor was supported by the spread of air conditioning systems. In *The architecture of the well-tempered environment* Reyner Banham (1973) drew attention to the relationships between built structures and building technologies. Using the example of timber, Banham stated two ways to exploit a material's environmental potential: “[...] either it may be used to construct a wind-break or rain-shed – the structural solution – or it may be used to build a fire – the power-operated solution” (Banham, 1973, p. 19). He observed that with the advent of air conditioning, the interaction between structural and technological measures is negated, as air conditioning systems can ensure a constant indoor climate independent of building measures. “Nevertheless, the possibility of absolute variety and infinite choice of building form is now with us – and as so often happens with infinite choices, has led to almost perfect homogenization of what is chosen,” noted Banham (1973, p. 190).

This research considers the complexity of the specific context with its different influencing factors on the design of vernacular-informal buildings, as emphasized by Rapoport (2002), although paying particular attention to the relation between climate and building in the face of the increasing challenges of climate change. A relation which, in the 21st century, must also be considered in reverse, as it is less about the climate determining construction than the construction industry altering climate. This reversal is closely related to Banham's observations of an increasing separation of building and technology through the use of air conditioning systems. The separation of indoor and outdoor climates through air conditioners and airtight building envelopes, ensuring a constant interior climate paradoxically contributes to a change in the exterior climate, so that the "human-made weather" (Banham, 1973, p. 172) of the interior ultimately also affects outdoor weather conditions.

The seeming paradox observed by Banham of an unlimited choice leading to a homogeneity of form also becomes apparent in the choice of materials. The materials identified by Semper as the basis of all human building activities – textiles, earth, wood, bricks – are increasingly being replaced by the products of a "quadrivium industrial complex," as Mark Jarzombek (2019) calls globally operating construction industries producing plastic, concrete, steel, and glass. The sales volumes of these goods are so large – concrete being the second most consumed commodity by weight globally after water – that they are no longer just the "innocent" building materials of vernacular cultures, but rather, are significant economic and political entities.

It is not surprising, then, that the research context, a remote, barely industrialized village in Bihar, India, is not spared from this transformation either. The context of the research is one of rapid changes in construction, which enables a juxtaposition of the above-mentioned debates between building and the environment, the creation of identity and the global construction industry. These topics therefore also form central components of this dissertation and can be found in the chapters (4.1 – 4.3) of the first part of the book.

3.3 Metamorphosis and Metabolism

The focus of this dissertation lies in the transitions and changes in building materials and techniques. On one hand, these dynamics can be seen as changes in the relationship between material and technology; on the other hand, and on a larger scale, as changes in the relationship between humans and their environment.

These two relationships can be described by two different concepts of metabolism: Gottfried Semper's metabolism, in the sense of a metamorphosis of materials and constructions (Roesler, 2023), and by Karl Marx's concept of metabolism as a relation between both humans and society, as well as humans and the environment (Burkett & Foster, 2010).

Contrary to the morally-motivated considerations of Pugin, Ruskin, or Viollet le Duc, who advocated an "honest" use of materials according to their chemical and physical properties, Semper understood the relationship between material and form, form and function, as a multidimensional structure that allows a material to take on different forms, including such that can be associated with other materials (Chestnova, 2018, pp. 113–117). For Semper, it is the creativity and self-will of people that lead to their relationships with materials through technology and use, not just the specific characteristics of materials (Chestnova, 2018, pp. 117–118). Neither material nor function alone are sufficient to explain form. Similar to Rapoport's (2002, pp. 46–49) demand that vernacular architecture should not be reduced to individual determinants, Semper calls for the consideration of a wide range of influencing factors to understand form. Semper's theory is interesting for this research, because it provides a suitable concept for the intended hybridization and recombination of building materials and techniques that are discussed in the second part of the book. The question of how to increase the social acceptance of regenerative building materials, which depends not least of all on the "metabolic capacity" of the materials, and can make regenerative building materials appear contemporary or even innovative, is of particular interest. Painting and plastering are relevant techniques for this transformation, as they can make a disliked bamboo wall look like the aspired masonry.

Sometimes bamboo appears as a load-bearing structure in the sense of Semper's wooden construction, at other times as wattle like a textile, and yet again in combination with earth and straw as a wattle-and-daub construction that looks like an earthen wall.

The concept of metabolism has a different but equally important meaning in this dissertation, referencing the term as defined by Karl Marx. Based on a biochemical understanding of metabolism, Marx uses the concept to describe relationships between humans and nature, as well as among humans between one another (Burkett & Foster, 2010, p. 227). Metabolism takes place through the transformation of the environment by human labor (human-nature relationship) and the exchange of goods (social metabolism). Marx argued that under capitalism, the drive for profit inevitably pushes beyond the limits of both human labor and the natural environment. Workers are compelled to produce beyond their physical and social capacities, while nature is exploited beyond its regenerative thresholds, generating growth but also deepening crises of degradation.

These considerations were subsequently taken further by Daly (1993, pp. 811–816, 2002, p. 6), in the formulation of an “ecological economy,” in which he points to the necessary limits of an economy as a subsystem of a limited ecology. Daly's concept of metabolism, essential for the maintenance of a living organism, also explains the functioning of the economy. Like organisms, economies require inputs from the environment and release them back as waste and emissions. The economy would only be ecological if its capacity for absorption and regeneration were not exceeded by this metabolism (Daly, 2002, p. 4). Daly's considerations on the metabolism of an ecological economy are particularly relevant because, in addition to “planetary boundaries” (Rockström et al., 2009), he also includes the factor of distributive justice of available goods among the world's population, which is again related to Marx's application of metabolism to social systems (Daly, 1993, pp. 814–816).

Semper's Stoffwechseltheorie and Marx' metabolism concept prove to be relevant to understanding the examined transformations in building materials: embedded in more

fundamental changes in the interaction of humans and the environment.

3.4 Subaltern Urbanism

The above explanations underline the need to consider changes in building materials and techniques in relation to natural conditions, social, economic, and technological transformations. It is therefore not enough to analyze individual buildings without considering their embeddedness in a specific socio-cultural context. The building transformations not only reflect technological changes, but they are also an expression of comprehensive urbanization processes. Even if the context of Bahuarwa shows hardly any urban qualities, the effects of an increasing urbanization are noticeable even in such a seemingly rural and remote place. Consequently, urbanization in this research is understood as a process rather than a form, as suggested by Brenner and Schmid (Brenner & Schmid, 2011, pp. 10–13).

As Serageldin (1990) pointed out, architects have long been uninterested in the informal building activities of the Global South, and have incorrectly prioritized “formal” design interventions due to their Western conditioning. Similarly, the transfer of tools, concepts, and ideals of a “world class city” of the Global North to “mega-cities” of the Global South was criticized by Robinson (2002) and Roy (2005), who recognized a contradiction in the fact that the majority of growth in urban regions takes place in the Global South, while the theories and tools for their analysis originate from the Global North. They call for a sublation of the separation between urban research in the North and research on developing countries in the South, and accordingly, a “post-colonialization” of urban research. Comparable to the more gradually increasing interest of architects in the ordinary house, in contrast to (star) architecture, the “ordinary city” (Robinson, 2006) and processes of subaltern urbanization also remained rather untreated in contrast to the development of the “world class city”.

Roy (2011) coined the term “subaltern urbanization” to characterize the informal processes of urban growth shaped by the expansion of socio-economically marginalized populations. While she focused on the urbanization processes

by “poorer” segments of the population in metropolises of the Global South, especially in the Indian megacity of Calcutta (A. Roy, 2003), Denis and Zérah (2017) use the term “subaltern” to describe urbanization processes of smaller cities in India. In using the concept of subaltern urbanism, the authors refer to the growth of settlement agglomerations, irrespective of state classifications.

They argue that India’s slow urbanization, as reflected in the Census of India, is largely a result of government-defined categorization criteria, particularly the share of workers employed in the primary sector (Denis & Zérah, 2017, p. 54). However, there are also political reasons that make a rural categorization by the state more attractive for some communities due to the receiving of government subsidies and political freedoms (Denis & Zérah, 2017, pp. 59–60). Denis and Zérah question the official criteria for the categorization of urban and rural places and call for the recognition of autonomy and thus an adapted view of those places that develop independently of the influence of the large metropolises despite their – in some cases – spatial proximity. To better understand urbanization processes of small cities in India, the authors call for empirical field studies tailored to the respective context instead of the application of generalized (Western) concepts and tools of the global city, which do not do justice to the peculiarities and autonomy of subaltern urbanization (Denis & Zérah, 2017, p. 60). Similarly, the rigid categorization of agrarian and urban must also be questioned, as Bathla’s (2024, p. 2000) observations illustrate, where unfinished landscapes of speculative urban expansion projects are repurposed by pastoralists, “crafting a transhumance urbanism beyond the sedentary ontology of land and property”.

The study site of this dissertation is neither in proximity to a metropolis nor does it meet the (government) criteria to be categorized as a city. According to government figures, Bihar is the poorest, youngest and least educated state in India (Census Organization of India, 2011). The limited industrialization, lack of job opportunities, and inadequate urban infrastructure lead to a significant, at least temporary, migration of the population to other – more urbanized – parts of India. With around 2,200 inhabitants, most of

whom work in agriculture and live in single-story buildings, Bahuarwa could be described as an “ordinary Indian village” with a rural character. Nevertheless, processes of urbanization transformation are also noticeable here. This can be observed in the expansion of roads, the establishment of fast internet connectivity, and changing construction methods. In a sense, Bahuarwa is at the frontier of budding urbanization, and thus offers a perspective on urbanization from the periphery.

Based on building transformations and their influencing factors, the aim of this research is to examine whether and how the specific local characteristics can be strengthened, without ignoring the reach of ever-increasing globalization. Despite a noticeable convergence of building methods and materials, this dissertation’s focus lies on the specific and ordinary of the respective context and everyday life.

3.5 Converging Building Cultures in India

Until the middle of the 19th century, India’s vernacular architecture developed in close relation to the climatic and topographic conditions. This “insular period,” (Alsayyad, 1995, pp. 14–15) isolated it from other factors, and ended with British colonialization in 1858, when local building typologies and imported ones started to merge. This resulted in hybrid forms, such as the bungalow, which is “[...] no more Indian than British [...]” (Alsayyad, 1995, p. 16). After India gained its independence in 1947, it was in need to (re)define its identity as a nation state. However, being the oppressed for almost a century, resulted in a dilemma, wherein the desire for an independent identity stood in conflict with the trust in the own potentials. Thus, the former oppressor transformed into a role model for the formation of an “own” identity and “[...] the Western model of public housing was used as an instrument of nation-building” (Alsayyad, 1995, p. 18).

The impact of this process became increasingly visible in the built environment from the 1990’s on, when India transformed into a market-based economy (Nugent, 2022). Industrialization and globalization included advancements in technology, transportation, and telecommunication; these have led to altered ways of living and building. New

technologies enabled different ways of manufacturing materials and assembling building components. Faster and more advanced transportation networks encouraged international trade and the introduction of new building materials. New ways of communication made Western building cultures widely visible. The Western world became a reference model for the urban areas of India, which in turn act as role models for the surrounding villages (Nugent, 2022). Among the newly introduced advancements, cement, steel, and fired bricks have had the biggest impact on the building cultures of India. These materials have managed to unify the versatile vernacular building techniques into one informal way of building that can neither be described as vernacular nor as industrialized. What has been adapted to the specific climatic and topographic conditions of its context, was replaced by an “international style” that reflected Corbusier’s vision of the domino house. A framework of reinforced concrete provided a neutral structure, able to be filled with meanings and programs independently of their cultural roots (Roesler, 2013, p. 302). In its unifying impact, the new informal way of building led to new encounters of urban and rural characteristics. In this hybrid condition, the lifestyle of people in informal parts of cities is still rural, whereas the buildings in the rural villages become increasingly urban (Bourdier & Alsayyad, 1989, p. 351; Roesler, 2013, p. 296).

Analyzing the *Transformations of Vernacular Architecture in India*, Jagatramka et al. (2021, p. 26) first list the availability of new materials at affordable prices as a reason for the disappearance of vernacular building traditions. However, building on Rapoport’s theories (2002), the authors emphasize a variety of reasons, including: climate change, political ambitions, social aspirations, changing labor markets, altering social structures, and the loss of vernacular building knowledge (Jagatramka et al., 2021, pp. 26–27). Increasing land prices in cities and the need to accommodate a growing number of inhabitants did not leave any space for vernacular elements such as the courtyard or the veranda (Nugent, 2022). In addition, “[...] it was faster and easier to throw up tall structures using steel and concrete, rather

than use earth blocks which are suited to lower-rise structures” (Nugent, 2022).

Focusing on the environmental impact of the ongoing material transitions, Praseeda et al. (2014) analyze the consequences on the buildings’ embodied energy. They found that, for example, replacing rubble masonry with fired brick masonry or stabilized earth block masonry increased the embodied energy of a residential building by 9.7 times and 2.8 times, respectively (Praseeda et al., 2014, p. 346). Shubham and Kolhatkar (2020, p. 39) came to comparable results when calculating the grey energy required for producing vernacular building materials (ranging from 0.11MJ to 18MJ per kilogram) compared to new materials (ranging from 2.6MJ to 36MJ). Consequently, the authors call for greater consideration of the ecological footprint of building materials and the combination of new and vernacular building materials (Shubham & Kolhatkar, 2020, pp. 39–40).

According to Roychowdhury et al. (2022, pp. 20–22), state-mandated categorizations of temporary and permanent building materials hinder such combinations, with vernacular buildings made of regenerative and locally available materials designated as *kutch*a and newer buildings made of fired bricks, concrete, and steel as *pukka* buildings. Government support programs tie beneficiaries to the use of *pukka* materials. This further exacerbates the existing dichotomy, promoting new materials, associated techniques, and professions while abandoning vernacular ones. The authors criticize this black-and-white thinking and stress the importance of hybrid solutions bridging vernacular and new materials and techniques. Hybrid solutions can, for example, combine the thermal qualities of regenerative building materials with the durability of new building materials, potentially at a lower cost and supporting regional economies. However, the lack of testing and certifications currently hinders upscaling individual experiments of progressive architects (Roychowdhury et al., 2022, p. 27).

This dissertation responds to the call to overcome existing dichotomies between vernacular and new building methods by developing a hybrid solution, with its planning and implementation a central part of the scientific exploration. The

aim is to gain insight into the social acceptance of building materials, to develop and test a hybrid solution of vernacular and new building materials and to identify obstacles and potentials for its upscaling.

3.6 Conclusion

The transformation of the built environment in Bahuarwa is the subject of research and the starting point of this dissertation. It includes questions such as: Which factors bring about these changes in a remote place like Bahuarwa? Is it still mainly the natural environment as investigated during the “habitat” discourse, (Roesler, 2013, pp. 215–249) is it more the cultural and social factors of Rapoport’s (2002, pp. 46–82) findings, or is it already Jarzombek’s (2019) “quadrivium industrial complex” of global construction industries? These questions are analyzed in the first part of the dissertation. Although the specific material changes to the buildings are the focus, they are analyzed in a broader context and understood as a consequence of more fundamental conditions. They are seen as an expression of social values, political conditions and economic frameworks. The *Stoffwechsel* of the building is used to understand the changing metabolism between humans and their environment.

More practically, the second part of this research represents an attempt to overcome dichotomies between so-called *kutchas* and *pukkas* houses in Bahuarwa, regenerative and more carbon-intensive building materials, vernacular and new building methods. It documents a participatory planning and construction of a school building. In this context, the conceptual framework points to the required open-mindedness of the architect and researcher from a different context. On one hand, with regard to the subject of research, buildings that were built without architects; on the other hand, with regard to the location of the research, which, in contrast to the researcher’s origin, is situated in the Global South. Instead of Eurocentric concepts of architecture and urbanism, the specific characteristics of the context and the needs of the target groups form the basis of the research.

“I began this research with the naive assumption that the people of Bahuarwa might not be aware enough of the potential of locally available and regenerative materials. However, it turned out that I was even less aware of their shortcomings.”

Field notes, Bahuarwa, February 2023

4 Ethnographic Analysis: From Raw to Fired

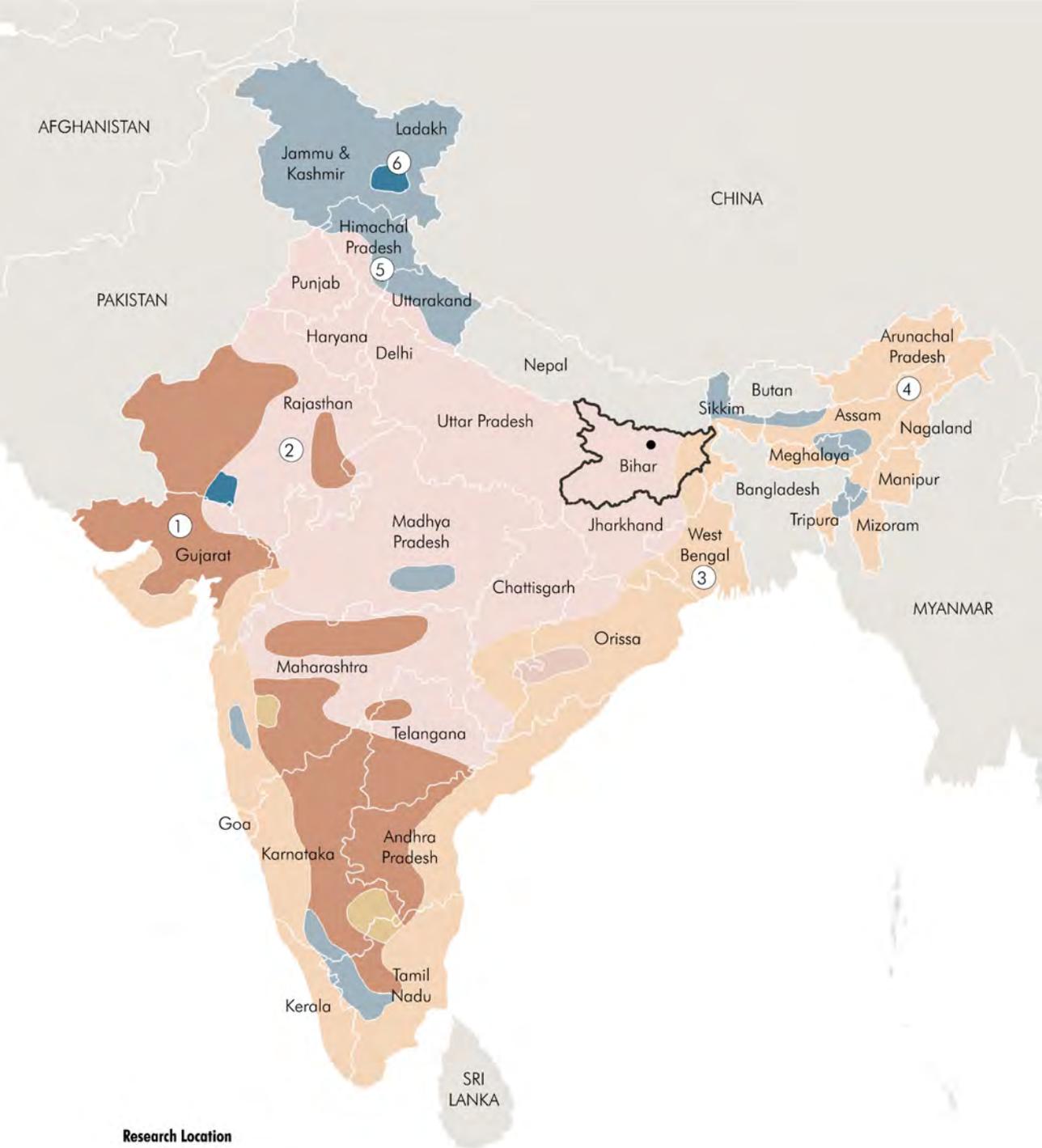
4.1 Environmental Challenges

4.1.1 Introduction

The first part of this study revolves around the significance of building as protection against the elements. The house, as a second skin, protects humans from the forces of nature and provides security. Most residents of Bahuarwa still live in close contact with the natural environment. Usually, there are no air conditioning systems, insulating or airtight building envelopes that ensure a separation between the external and internal climate, and thus a constant thermal comfort indoors. Side streets and alleys are often not (yet) paved and, during the rainy season, they become muddy and barely passable. The analysis in this section examines building transformations in response to natural events such as fires, floodings, and earthquakes. It shows how the materiality of individual building components has been gradually adapted, beginning around 1950, in response to specific natural disasters.

The state of Bihar is characterized by a subtropical climate; the location of Bahuarwa has “composite climate” (Bansal & Minke, 1988, pp. 17–18): a climate zone of versatile characteristics that cannot be allocated to the other five more precisely-defined zones of hot and dry, warm and humid, moderate, cold and cloudy, cold and sunny. All the areas where these defined criteria prevail for more than six months of the year are ascribed to one of these five zones; the others are defined as composite climate zone (Figure 12). According to the Meteorological department of India (2011) Bihar’s climate can be structured into four seasons: (1) a mild and dry winter from December to February, (2) a hot pre-monsoon season from March to May, followed by (3) a humid monsoon season from June to September and (4) a post-monsoon season with occasional rainfall from October to November.

Figure 12 (following double page): Map of Indian states, climatic zones and related building typologies (modified from source: Bansal & Minke, 1988, p. 18).



Research Location

● Bahuarwa, Bihar

Climate Zones

- hot and dry
- warm and humid
- moderate
- cold and cloudy
- cold and dry
- composite

1



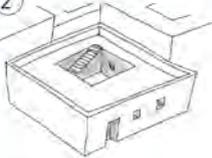
Climate zone: hot and dry

Location: Kutch, Gujarat

Materials: earth walls, thatch roof

Typology: round and compact shape for improved earthquake resistance and for minimum exposure to sun, thick walls with high thermal mass to balance temperature differences between day and night

2



Climate zone: hot and dry

Location: Rajasthan

Materials: stone or earth walls

Typology: reduced openings and minimum exposure to sun, narrow courtyards for lighting and ventilation, thick walls with high thermal mass to balance temperature differences between day and night

3



Climate zone: warm and humid

Location: West Bengal

Materials: earth walls, thatch roof

Typology: bungalow typology with veranda as a climatic buffer and a semi-open space for many daily life activities

4



Climate zone: warm and humid

Location: Assam

Materials: bamboo structure, bamboo mats, thatch roof

Typology: lifted from ground for flood protection, open construction for improved cross ventilation

5



Climate zone: cold and cloudy

Location: Himachal Pradesh

Materials: stone walls with timber ring beams, slate roof

Typology: timber ringbeams for improved earthquake resistance, compact shape to reduce heat loss and improve earthquake resistance further

6



Climate zone: cold and dry

Location: Ladakh

Materials: stone walls

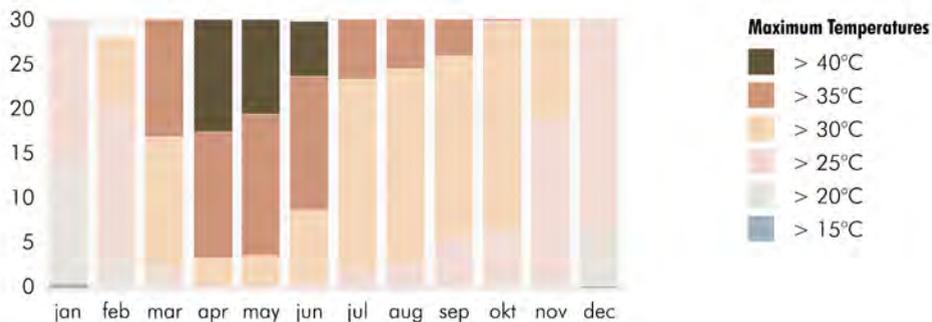
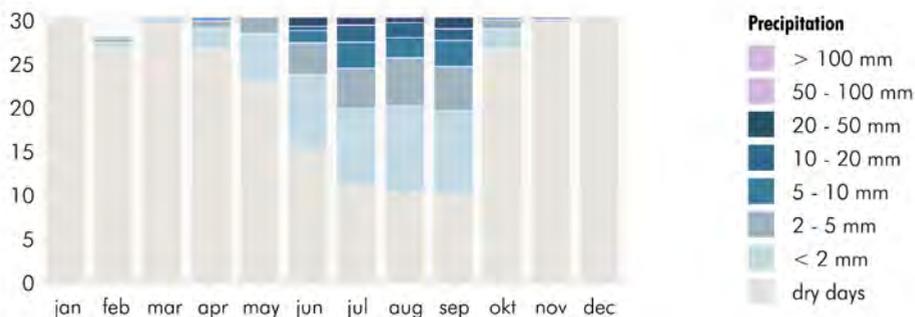
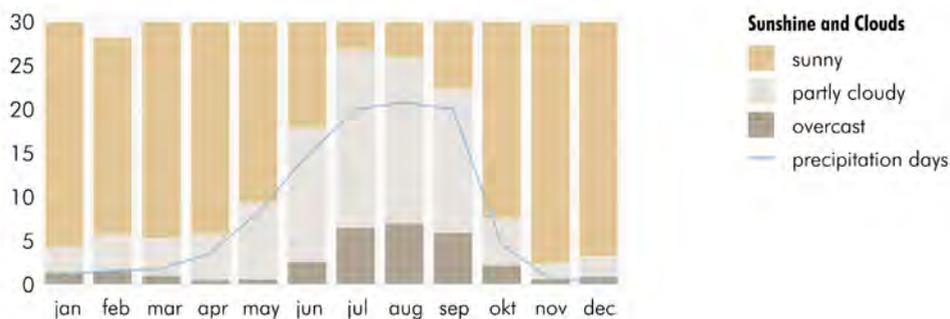
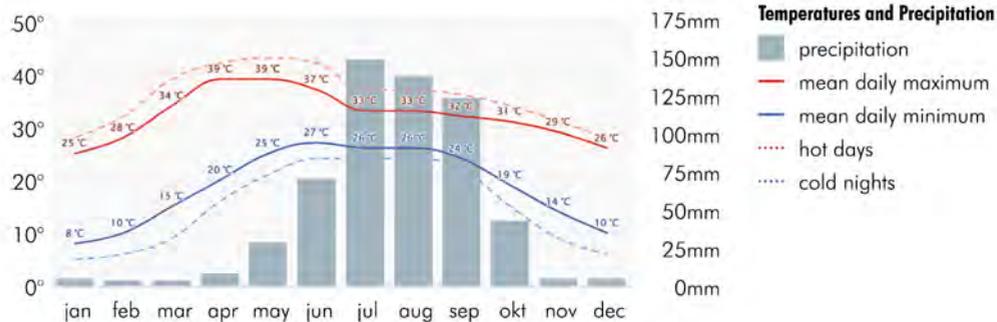
Typology: thatch stored on flat roof for additional insulation, compact shape to reduce heat loss

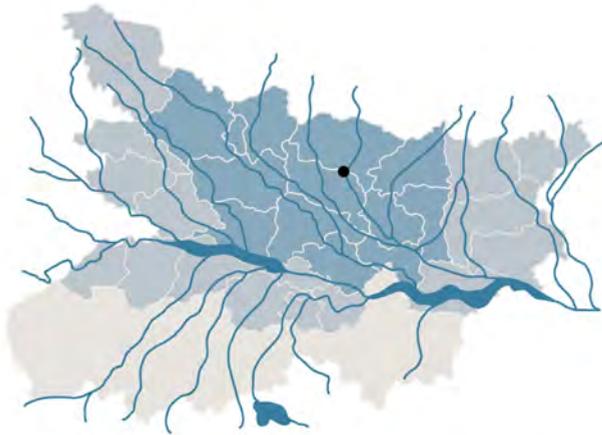
Depending on the region, the temperature in Bihar ranges from a mean minimum of 7.8°C to 11.9°C in January to a mean maximum of 34°C to 40.5°C in May (Figure 13). Winds usually blow from the south and southwest during the winter months, and from the east during the summer months. Annual precipitation increases towards the north and the northeast of the state, reaching from 700 to 2800mm (India Meteorological Department, 2011).

Based on its topography, the state can be divided into three different regions: the Sub-Himalayan Foothills, the Indo Gangetic Plain and the Southern Plateau Region. Most of the area belongs to the Indo Gangetic Plain, at around 150 meters above sea level. Flowing through the middle, from east to west, the Ganges River divides the Indo Gangetic Plain into the north and the south plain (Figure 17). The Sub-Himalayan Foothills can be found in the very north at the border to Nepal, whereas the Southern Plateau Region creates the transition to the plateau of the state of Jharkhand in the south (India Meteorological Department, 2011).

According to the Bihar State Disaster Management Authority, due to its mostly flat topography and the numerous rivers coming from the Himalayas and merging into the Ganges, around 73% of the area of Bihar are at risk of flooding, and 28 of the 38 districts fall under the most flood prone category. Most of the rainfall occurs during the monsoon season and lets the rivers increase up to fifty times of their usual size. Thus, 30-40% of India's flood damage occurs in Bihar. Located in the seismic zone of the Bihar-Nepal border, 15.2% of Bihar's area is classified under the highest risk zone, V, and almost two-thirds of the country falls under the zone IV. The strongest earthquake ever recorded in Bihar occurred in 1934 and more than 10,000 lives were lost. Due to its flat topography and distance from the sea, Bihar is not affected by landslides or cyclones; the state does, however, experience significant winds classified as a high-damage risk zone (Bihar State Disaster Management Authority; Ministry of Housing & Urban Affairs; see Figure 14 for hazard maps of Bihar).

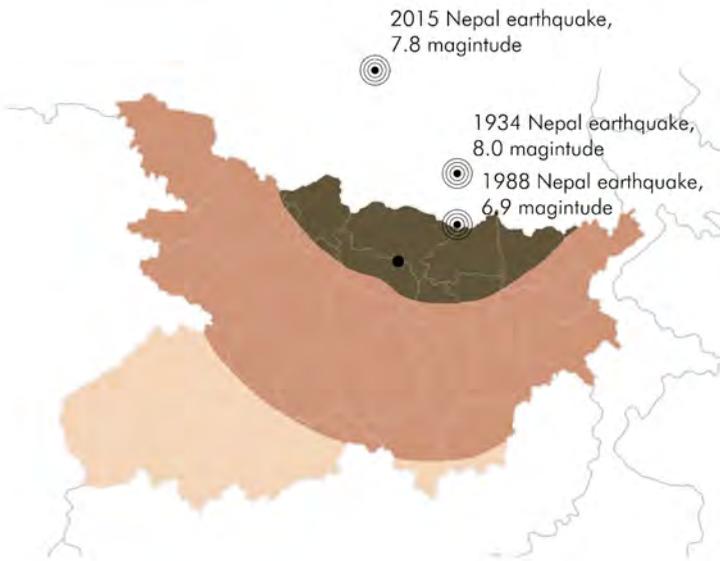
Figure 13: Climatic data of Bahuarwa (modified from source: Meteoblue, 2022).





Flood Hazard Map

- rivers
- flood prone districts
- highly flood prone districts



Earthquake Hazard Map

- zone V: very high
- zone IV: high
- zone II: moderate



Wind Hazard Map

- high risk zone
- moderate risk zone

Research Location

- Bahuarwa, Bihar



Figure 14: Hazard maps of Bihar (modified from source: Ministry of Housing & Urban Affairs).

The village of Bahuarwa belongs to the subdivision of Manigacchi which in turn is part of the district of Darbhanga in the center of the northern Indo Gangetic Plain. The village is in an area of highest seismic risk and most prone to flooding. It is therefore not surprising that earthquakes and floods play a key role in the following analysis. However, periods of drought and associated fires are the starting point of this first part. The fires are connected to the annual dry season that intensifies in the months of March and May before the onset of the rainy season. The chapters related to the natural elements fire, water, and earth are complemented by a fourth chapter that provides insight to the residents' confrontation with unwanted intruders and cohabitants from the world of animals and insects.

4.1.2 Roof on Fire

When visiting the village of Bahuarwa today, it is evident that the rainy season and subsequent flooding pose major challenges for the residents. Two small rivers are located immediately to the east of the village, and Kamla River, a large tributary to the Ganges, is less than six kilometers east of the village. During prolonged and intense rainfall, these rivers overflow their banks and inundate the surrounding area. It may be surprising, therefore, that it is not water-related events, but rather, drought and fires that are particularly vivid in the memories of elder villagers.

Until the turn of the millennium, fires regularly destroyed neighborhoods, even the entire village. Until well into the second half of the 20th century, houses in Bahuarwa were mainly built from earth, bamboo, timber, and thatch. In more affluent households, the walls were massive earth constructions, with a thickness of thirty to sixty centimeters. These were stacked layer by layer, without formwork, using a mixture of thatch and earth, which was subsequently tamped and carved to form straight walls. This technique, also known as cob construction, was not common in poorer households, where the walls consisted of a simple bamboo framework filled with leaves and thatch. However, in both cases, the roof was supported by a bamboo structure and covered with thatch. These small single-story houses, which contained only a few rooms, were closely packed together

to form open courtyards, which marked the center of each household as the heart of everyday life rhythms and focal point of social interactions. In many cases cooking was and still is – especially in poorer households – done over an open fire in these courtyards (Figure 15).

Once the monsoon comes to an end in September, the surrounding fields of Bahuarwa remain submerged for several weeks. The muddy streets and alleys are softened and have large puddles. The thatch roofs are still damp. During October, there are still occasional small showers, and on rare occasion, this can last into November. From December to February, however, there is hardly any rainfall. The fields are dry, and the ground become increasingly dusty. As the temperature rises again in March, the dryness intensifies until the end of May when the first occasional signs of the monsoon arrive.

Figure 15: Courtyard (*angan*) with open fire-place (*chulah*) and thatched roofs.



It was during the months of March and April, particularly before the 1990s, that village fires frequently occurred in Bahuarwa. These fires, triggered by the flames of the open courtyard fireplaces, rapidly spread across the adjacent and overlapping dry thatch roofs of the houses. Since the nearby rivers hardly carry any water during these months, the residents had to rely on groundwater for firefighting through wells and hand pumps. By the time they could do so, the fires were already so large that severe damage often could no longer be prevented. For this reason, when a fire broke out, the residents usually did not even attempt to extinguish it; instead, they fled the village with their family members, animals, and whatever belongings they could carry.

The most devastating village fires of the second half of the 20th century happened in 1965 and 1972. They prompted many residents to adopt the emerging technique of brick firing to replace the thatched roofs with non-flammable brick tiles. In the Bahuarwa Region, brick kilns were not yet widespread at that time. Therefore, wealthier households began to fire bricks with the help of members of the Kumhar caste¹⁵, who were skilled in pottery and brickmaking. A local carpenter was commissioned to build a mold into which the locally-abundant clay was pressed. The molded bricks were then left to air dry for a few days before being fired in a small, temporary clamp that was set up near the construction site.

Only wealthier households could afford to cover their roofs with brick tiles. Others had to continue living in houses with thatch roofs. By changing the roofing material to brick tiles, fires could no longer spread as they used to. However, as households from the same socio-economic background often lived in the same neighborhood, poorer households continued to suffer from the destruction caused by recurring fires. For those neighborhoods, the situation regarding fire hazards only improved with the advent of more affordable fiber-cement corrugated sheets (Figure 16).

¹⁵ In India, "Kumhar" literally means "potter," derived from the Sanskrit *Kumbhakara*. The Kumhar community traditionally produces clay pots, sculptures, and folk figures. Most Kumhars identify as Shudra in the caste system (see footnote on p. 12). Their artisan skills earn them social respect, even though their occupation, associated with dirt and manual labor, carries stigma (Kumar, 2023).



The material transformation of the roof was initially a response to the fire hazard posed by the highly flammable thatch. Later transformations were more of a reaction to protection from precipitation. Plastic tarps, fiber-cement corrugated sheets, industrially manufactured roof tiles, corrugated metal sheets, and reinforced concrete slabs expanded the range of possibilities and allowed residents to make more or less expensive and durable adaptations to their roofs.

Conversation with a male member of the Shudra caste, aged 60–70, at his home (Field notes, Bahuarwa, November 23, 2023).

The man grew up in Bahuarwa. He still remembers the years 1965 and 1972 vividly. He was a boy at that time when two devastating village fires occurred in Bahuarwa. Fires were a regular occurrence, he recalls, but these two destroyed the

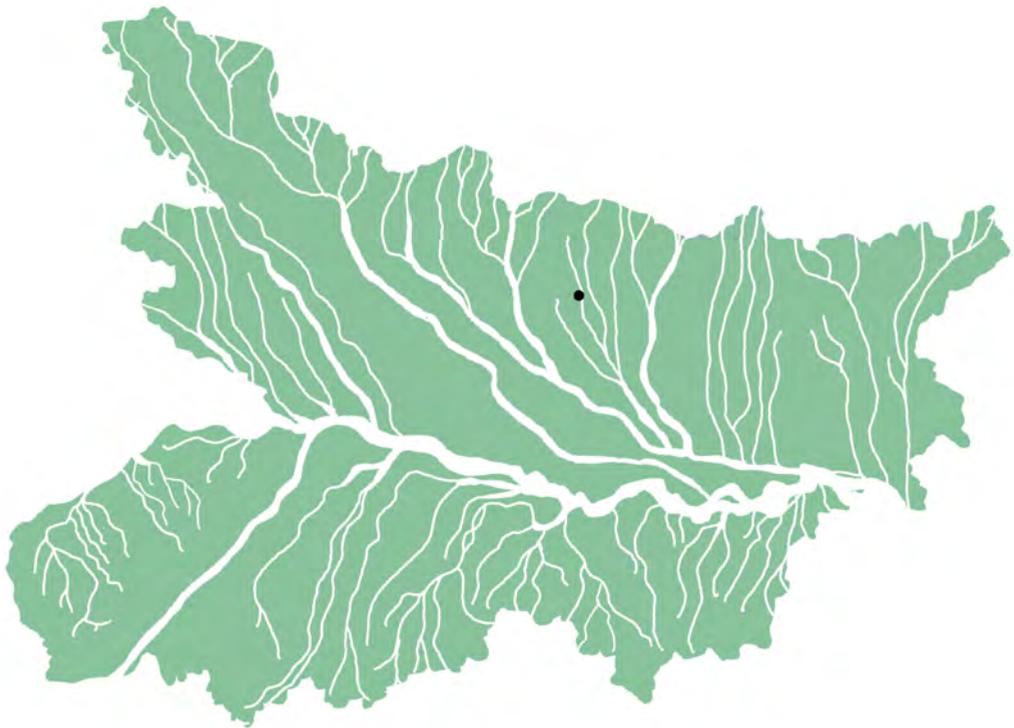
Figure 16: Corrugated fiber-cement sheets as a fireproof and low-maintenance alternative to thatched roofs.

entire village as they broke out towards the end of the dry season. At that time, he lived in the center of Bahuarwa, which was rarely spared from fires due to its dense housing. In March 1965, a man tried to smoke out a beehive to access its honey. A spark from the fire jumped onto a thatch roof and quickly ignited a fire. The residents could not react in time as the fire spread to the surrounding buildings. Soon, he could see the smoke cloud from his courtyard. People were screaming and running through the narrow alleys. Together with his siblings, parents, and grandparents, he gathered all their belongings and fled the village with their goats and cows. In no time, the village was engulfed in flames. Shortly after, reconstruction efforts began, to make sure that by the start of the monsoon in June, they had a roof over their heads again. The effort of rebuilding, especially the roofs, was substantial and led to losses in the harvest, posing another challenge for the residents. The second major fire that caused comparable damage occurred in March 1972, when a child was playing with matches. Since then, there have only been smaller village fires as the residents increasingly replaced their thatch roofs with non-flammable materials.

4.1.3 House under Water

During the monsoon season, from June to September, it rains an average of about twenty days per month (Figure 13). The intense and prolonged rainfall takes a toll on all buildings, but especially on those made of regenerative materials such as earth, bamboo, and thatch. The thatch roofs gradually become leaky, the earth walls erode, and the bamboo structure starts to rot. The earth floors become waterlogged, and the foundation weakens.

In response to the devastating village fires, the residents of Bahuarwa began to cover the roofs of their houses with self-fired bricks instead of thatch, as was previously customary. This material transformation of the roof covering improved both fire resistance and water tightness. Thatch roofs require annual repairs and need to be replaced every five years, otherwise they become leaky. These high maintenance efforts were eliminated by using roof tiles. However, not all households could afford them, so thatch roofs remained a



maintenance-intensive but cost-effective alternative for poorer households.

In the 1980s, when fiber-cement corrugated sheets became available in the Bahuarwa region, they provided a cheaper yet equally watertight and fire-resistant alternative to fired roof tiles. While the use of roof tiles, like thatch, mostly led to hipped roofs, the use of fiber cement corrugated sheets resulted in a change in roof shape from a hipped roof to a gabled roof.

Another major change in roof typology occurred with the emergence of cement and steel, leading to the creation of the first house in Bahuarwa with a flat concrete roof in the late 1980s. These new materials allowed the construction of larger houses with flat roofs, which enabled additional uses and vertical expansions. Furthermore, the flat reinforced-concrete roofs provided an even more robust - albeit

Figure 17: Rivers of Bihar indicating the location of Bahuarwa (modified from source: Bihar PSC Exam Notes, 2024).

more expensive - alternative to fired roof tiles and fiber cement corrugated sheets. Those households who continued to live in a house with a thatch roof could usually not afford any other type of roof. They increased water tightness and reduced maintenance effort by adding plastic sheets on the thatch, which became commonly available in Bahuarwa from 2000 onwards.

The severe impact of the annual monsoon rains on the buildings also led to material transformations of other building components. Although the walls are not exposed to the rain as much as the roof, they still suffered damage. The thick earth walls, constructed with cob techniques, thus eroded, and required annual repairs to maintain their structural integrity. Often even more problematic than the rainfall itself is the increasing occurrence of flooding, which mainly depends on the amount of precipitation in northern Bihar and the adjacent Himalayan Mountain range in Nepal, where most of the tributaries north of the Ganges River originate. When these rivers overflow, the surrounding areas become submerged. Since the topography of Bahuarwa is completely flat, residents attempt to protect their homes by building them on high plinths. These plinths, as well as the walls above them, were primarily constructed from earth until fired bricks became more commonly available. By protruding the plinth from the walls, residents attempt to create a buffer against erosion (Figure 18). However, during floods, the thick earth walls are regularly weakened, leading to cracks and partial collapse.

Conversation with a Dalit woman, aged 40–50, mother of eight, in “Ram Toli,” a neighborhood largely inhabited by Dalit families (Field notes, Bahuarwa, January 30, 2023). The roof starts to leak, everything is so wet and humid; our floors, our mattresses, our kitchen, everything! The kids and us are not able to sleep peacefully during that entire time because of so many mosquitoes that love these dark and humid conditions. We all try to find that one corner of the house that is still dry and we all somehow sleep there. [...]

Mostly I just sit there and cry. I fight a lot with my husband during this time. I even beat my kids out of frustration during the monsoons. It is such an uncomfortable time for all of us. Both my husband and I are clueless and frustrated every time on how we will go through this time. We don't know where the kids will sleep, where we will sleep.

Figure 18: Projecting earth base to create protection against erosion by flooding.

According to quantitative statistical data (National Remote Sensing Centre, 2020) as well as qualitative interview information from the inhabitants of Bahuarwa, flooding is a phenomenon that has steadily increased over the last fifty to sixty years. This is partly due to inadequately planned infrastructure for irrigation and flood control (Mishra, 1997, pp. 2206–2207), but also due to the increasing extraction



of river sand for construction materials such as concrete, mortar, and plaster. Consequently, the riverbanks erode and the risk of flooding increases (Bhadbhade et al., 2020, p. 11). This is compounded by the effects of climate change, which is leading to more frequent extreme precipitation.

Because of the increasing floods, wealthier households - the ones who had recently started firing their own roof tiles with members of the Kumhar caste - also commissioned them to produce fired bricks for the walls and foundations of their houses. The use of cement was not yet widespread in the region of Bahuarwa at that time, so the residents used a clay mortar to lay the self-fired bricks. Many opted for the application of clay or lime plaster to protect the masonry from the rain. The somewhat irregular, self-fired bricks and the use of water-soluble clay mortar still required high maintenance efforts. Unless frequently renewed, the clay plaster was washed away, leading to erosion of the mortar and consequently to unstable brick bonds. The introduction of cement and the emergence of brick kilns addressed this issue. With the availability of mass-produced bricks and cement, foundations and walls could be built that were more durable than their regenerative or self-fired predecessors, even when left without plaster.

The new materials, bricks, cement, and steel initially only represented an option for wealthier households. Poorer families continued to build their houses using earth, bamboo, and thatch. Nevertheless, many of them also made occasional use of the new materials. One easily recognizable change is the covering of the thatch roof with plastic sheets. The interior remains drier due to this cost-effective measure, and the thatch roof lasts longer. However, plastic sheets only extend the durability of the roof to a limited extent. Regularly, strong winds during the monsoon season, as well as mice and rats, destroy the plastic sheets; maintenance of the roof remains a time-consuming task.

Other strategies become apparent upon closer inspection. Some residents take another measure when anchoring the bamboo supports in the earth base. To prolong the life of the buried part of the bamboo, residents used to wrap jute sacks around it to prevent direct contact between the

bamboo and the soil. Nowadays, however, they use plastic sacks originally intended for the transportation and storage of cement. These sacks provide adequate protection, further reducing the need to repeatedly replace bamboo supports. For about five years now, specially-prefabricated Y-shaped concrete supports for simpler constructions have been

Figure 19: The house colored in pink has pre-fabricated, Y-shaped concrete pillars in the corners as a more durable replacement for bamboo.



available in Bahuarwa for an affordable price of 500 to 600 INR¹⁶ per piece. Poorer households often make use of these supports to replace the main structural parts made of timber or bamboo (Figure 19). This transformation has resulted in the secondary and tertiary structures of the walls no longer being connected through intricate bamboo joints, but with the help of nylon cords that are used to bind the walls to the concrete supports. Many of the residents emphasize that this structural adaptation increases the durability of their homes, as concrete does neither decay when in contact with the ground nor does it erode during rainfall.

Conversation with a couple, 50–60 years old, at their house in a neighborhood in Ujan (Field notes, Ujan, December 1, 2023).

The couple lives with their families northeast of Bahuarwa. Their houses are located next to a river about 400 meters outside of the village and belong to the neighboring municipality of Ujan. The husband is one of five brothers whose houses are lined up on adjacent plots. The houses are all in different stages of transformation from a house made of bamboo, earth, and thatch to one made of fired bricks, cement, and concrete. Currently, only the house of their family is still made of regenerative building materials, while the other four are either under construction or already made of fired bricks and reinforced concrete. The husband, the youngest of the five brothers, also plans to rebuild his house with bricks, cement, and concrete soon.

The planned reconstruction was inspired by an event in 2019. During the monsoon season, it rained continuously for many days, causing the adjacent river to overflow and inundate the surrounding land. “Suddenly, there was water on all four sides. We stood in the middle and called upon the gods for help,” he recalls. The water reached up to his waist, and his house was submerged. Even the protective earth base, with its height of 40 centimeters, did not offer sufficient protection from the floods.

¹⁶ 500 – 600 INR = 5 – 6 CHF, considering an exchange rate of 0.01 (XE, 2024).

At that time, only one of his brothers had already completed a house with fired bricks and concrete. This house had a base of about one meter in height and a flat roof that could be accessed via an external staircase. Although the floods were so high that they even slightly exceeded the base of this house, the flat roof still provided protection against the floods. So, the families of all five brothers took refuge on the flat roof of this new house, where they erected a temporary shelter using bamboo posts and plastic sheets.

For about a month, they endured crowded conditions on the roof, while their houses eroded and partially collapsed under the floods. The families stored their belongings and food on the roof. Only if necessary did they venture into the water with long sticks to search for vegetables in their submerged fields.

He has already rebuilt his earth and bamboo house several times in his life, but after this experience, the time has come for a new house, even if they have to take out a large loan for it. A house that withstands rain and floods, providing protection even in such situations. For how would the family have fared without the protective house of their brother?

4.1.4 Falling Walls

It has been nearly a hundred years since the great Nepal-Bihar earthquake on January 15th, 1934, with its epicenter approximately 9.5 kilometers south of Mount Everest in eastern Nepal, near the border to Bihar. With a magnitude of 8.0, it is the largest and most devastating earthquake ever recorded in India. The number of fatalities was estimated to be between 10,700 and 12,000, with approximately 7,250 in Bihar (Brett, 1935, p. 7). The area between Motihari and Purnea in Bihar was particularly affected by the tremors and ground fissures, which led to the collapse of numerous buildings. Furthermore, substantial damage was caused by the spraying of sand and water from underground cracks, transforming fertile areas into temporary deserts (Nasu, 1935, pp. 419–421).

According to expert assessments, the Darbhanga district, where Bahuarwa is located, was the second most affected zone by the earthquake (Nasu, 1935, p. 428). Analyzing the impact of the earthquake, Nasu (1935, pp. 422–423)

summarized the recorded damage to homes: “Generally speaking, the damage was worst in houses of the kutcha-pucca type, while earth huts collapsed in many places, although the substantially built and light pucca buildings escaped with only slight damage. Bamboo huts were nowhere damaged.”

Although it is difficult to comprehend from today's perspective to what extent this earthquake led to changes in construction practices, the majority of houses in Bahuarwa built at that time used the cob construction technique, which cannot be found in any of the present-day buildings in the village. There are still neighborhoods of poorer population groups today, where buildings are largely made of bamboo and earth; the construction methods, however, have changed.

At the time of the earthquake in 1934, walls were typically made of a mixture of thatch, water, and earth, stacked layer by layer without any formwork, and then shaped and compacted in thirty-to-sixty-centimeter-thick walls. These massive walls served as space-defining, weather-protective, and structural elements. Earth was available almost everywhere, easily accessible, and free of cost. As this construction method was labor-intensive, walls were also built from a wattle of bamboo and grasses, depending on available time and resources. Bamboo was generally used for the supporting structure of the roof, which was then covered with thatch.

Nowadays, however, among those buildings that still predominantly consist of earth and bamboo, both the roof structure and the walls are made of bamboo. The infilling and space-defining function of the walls is achieved by splitting and unwinding bamboo. Earth, apart from the solid base, can only be found as a thin layer of plaster on the bamboo structure. The once over forty centimeters thick earth walls have now become a thin skin of a few millimeters, outlining the underlying bamboo structure like a skeleton (Figure 20).

This fundamental change in the use of earth and bamboo can be better understood through more recent events. Due to a lack of alternatives – and probably also due to the infrequent occurrence of severe earthquakes – solid earth

walls in the cob construction technique remained a prevalent method to build walls in Bahuarwa well into the second half of the 20th century. It was not until the widespread availability of fired bricks from regional brick kilns that earth walls gradually began to be replaced by masonry.

In 1987, Bihar experienced severe floods. The Koshi River, located a little more than thirty kilometers east of Bahuarwa and one of Ganges' major tributaries in northern Bihar, submerged most of its adjacent regions. Thirty out of the thirty-eight districts of Bihar were affected by the floods, including Darbhanga, in which Bahuarwa is located (Figure 14). The earth foundations of many buildings got undermined by the floods. The situation was further exacerbated by a strong earthquake in the following year. The 1988 Nepal earthquake, with a magnitude of 6.9, occurred on August 21st in eastern Nepal, close to the epicenter of the earthquake in 1934 (Figure 14), and caused significant

Figure 20: Earth skin and bamboo skeleton of a house at the eastern outskirts of Bahuarwa. The house shows the multi-layered bamboo structure made of vertical bamboo poles, horizontal and diagonal bamboo slits, and vertical unrolled bamboo. The slits are mirrored on the inside to hold the unrolled bamboo in position.



damage, especially in northern Bihar. In many cases, the residents had not yet had the chance to repair the damage caused by the previous year's floods. As a result, the earthquake caused the collapse of many already weakened structures.

Elder residents of Bahuarwa vividly remember the impact of the consecutive disasters. The heavy earth walls, weakened by the floods of the previous year, collapsed during the earthquake. Earth containers, which still serve as natural refrigerators for storing rice and grain, toppled over due to the vibrations. Numerous residents in Bahuarwa were injured, and some even lost their lives. For many people who had been living in buildings with thick earth walls, the 1988 earthquake was the tipping point to abandon this construction method. Despite the free availability of earth and thatch, the time and effort required for construction and continuous repairs were too high to continue using cob work. Moreover, many were frightened by the natural hazards. Unlike in 1934, alternative construction methods using fired bricks and cement were already more widespread in Bahuarwa by 1988. Only a few residents continued to use cob work after this earthquake. Those who could afford it embarked on building new houses with fired bricks and cement or opted for quickly constructible, more temporary bamboo structures to save money for a "proper" house.

Conversation with two Dalit women, aged 40–50, in the "Ram Toli" neighborhood (Field notes, Bahuarwa, December 8, 2023).

It was really a stormy earthquake! All the groundwater mixed with whitish sand was being pumped up above ground. In my house this thick mud wall still existed in that time, and it collapsed. Since then, we do not dare to build these thick walls anymore [...].

[Imagine], if such an earthquake happens again and we are outside working on a field, and our small kids are in the house... that is why we are afraid to build such walls.

Even now when there is a big storm, I stand and hold the columns for a long time and pray that the house does not fly away with the storm.

However, it was not only earth buildings that could not withstand the horizontal forces of earthquakes. The newly emerging brick buildings in Bahuarwa also proved to be non-earthquake resistant. According to Duggal and Sato (1989, p. 100) of the nearly 150,000 houses damaged by the 1988 earthquake in Bihar, approximately 57% were constructed of earth and bamboo, while 43% were brick buildings. Although earth buildings were more prevalent at the time, the high proportion of damaged brick structures underscores their vulnerability to seismic events. In the heavily affected Darbhanga district, the proportion of damaged brick buildings was even higher, accounting for 51.4% compared to 48.6% of earth buildings (Duggal & Sato, 1989, p. 100). This heightened susceptibility is attributable to the inherent properties of brick construction: its substantial weight, high rigidity, and low tensile and shear strength render it poorly suited to withstand the horizontal forces generated during an earthquake (Duggal & Sato, 1989, p. 95). Other reasons for the damage to brick buildings included the use of self-made, often irregularly shaped bricks, the use of clay instead of high-quality cement mortar, inadequate connections between walls and between walls and roofs, large openings near the corners of the buildings, as well as the absence or insufficient use of reinforced concrete bracing and lintels (Duggal & Sato, 1989, pp. 95–97). This problem has been tackled by combining brick buildings with reinforced concrete elements. In the globally spread construction method known as – reinforced cement concrete (RCC) – load-bearing columns, lintels, ring beams and ceiling slabs are reinforced by steel bars, which contribute to increased earthquake resistance. If this measure is insufficient, the distances between reinforced concrete columns are reduced, and additional ring beams are provided.

Conversation with a female member of the Shudra caste, aged 40–50, and the eldest inhabitant of Bahuarwa, aged 100–110, at their house (Field notes, Bahuarwa, October 10, 2023).

In 2023, there is only one person left in Bahuarwa who experienced the earthquake herself. The woman, now around 105 years old, was about fifteen years old at the time. She

remembers the chaos as people fled from their homes, seeking refuge in open spaces and fields where no roofs could collapse on their heads. The ground was shaking, and the massive walls of the earthen buildings cracked and collapsed. Hand water pumps moved by themselves for several days, spraying water and sand. People ran around, desperately seeking help. Many were injured or even died under the weight of collapsing earth walls and toppling heavy earth containers used for storing rice and grains.

The younger woman, who is old enough to have experienced the earthquake of 1988 shares her memories with Bahuarwa's eldest resident. The two women describe how they could even hear cracks forming in the ground. As with the 1934 earthquake, thick earth walls collapsed, burying young children and elderly people who were not able to escape quickly enough. People in their own families were also victims of the earthquake. Since that event, most residents who previously lived in buildings made of heavy cob walls have switched to using lightweight bamboo constructions that are more resistant to earthquakes and provide less danger to the inhabitants in case of a collapse. Moreover, the new buildings can be erected more quickly. The woman continues to explain that people no longer place large, heavy earth "refrigerators" used for storing rice and grains in their bedrooms, where they could fall on sleeping people during an earthquake. This marked the end of the thick earth walls, the two women point out. In Bahuarwa, these can no longer be found, and in the surrounding regions, too, there are hardly any cob houses left.

4.1.5 Unwelcome Roommates

The environmental challenges mentioned thus far occur either on an annual basis, along with the rainy and dry seasons, or irregularly after events such as floods and earthquakes. The challenge described below, however, accompanies the residents continuously: the infestation of food and bio-based building materials by insects and fungi.

Specifically, termites and beetles attack the buildings (Kaminski, Lawrence, & Trujillo, 2016, pp. 23–25). Since termites and beetles feed on organic material, they seek out bamboo, wood, thatch, or hummus. In addition to

damaging buildings, which can go as far as destroying the load-bearing capacity of the bamboo structure, termites also eat the residents' belongings, such as documents, books, or even paper money. The shady interior, the dampness of the earth floors, the supporting structure made of bamboo, the thatch on the roof, and in the walls make vernacular buildings in Bahuarwa an ideal home for termites. They dig tunnels through the earth floors and walls to reach their prey, remaining unnoticed by the inhabitants. Since bamboo structures are integrated into earth foundations and covered by an often-leaking and only slightly-overhanging roof, it is often in contact with moisture. This also increases its susceptibility to fungal attacks, especially on the ends of the bamboo posts and in damp spots, further accelerating the decay of the buildings (Figure 21).

Figure 21: Supports made of bamboo or wood, integrated into earth floors, shady and humid rooms, as well as insufficient ventilation provide suitable conditions for termites and fungi to gradually decompose the organic building components. The smoke from open fires, however, protects the surrounding bamboo and thatched roofs from insects, but at the same time poses a health risk to the residents.





Figure 22 (left): Surface and rings to determine age and suitability of bamboo. Young bamboo with shiny surface and yellowish rings.



Figure 23 (right): Older bamboo suitable for construction with matte surface and whitish rings.

Besides the organic building parts, insects and vermin are also attracted to food. In the subtropical climate of Bahuarwa, where hardly any household possesses a refrigerator beyond the cool of the earth, most food items cannot be stored for long. Above all, fruits, vegetables, dairy products, and meat must be processed and eaten immediately. If something sits too long, it will attract pests. This also applies to leftover or spilled food on earth floors. Since earth absorbs moisture and is therefore not as easy to clean as a hard-tile floor, it quickly becomes infested with insects, which then attract other animals such as birds, rats – or even snakes.

So long as local and regenerative building materials were the only available resources, residents developed strategies to manage unwanted cohabitants. Smoke produced by cooking on open fires provided a protective shield for roofs made of thatch and bamboo. The smoke, rising several times a day with cooking rhythms, repelled insects, providing sustainable protection for the bamboo and thatch. This is why one can find bamboo roof structures in Bahuarwa

that have been blackened by the fires below, but have endured for several decades (Figure 21).

Although locally-grown bamboo reaches its full height after just one year, residents often leave it standing for another three to four years, because young bamboo is more susceptible to termite and beetle infestation. Elderly residents who previously lived in bamboo and earth houses, and in some cases still do, recognize bamboo that is suitable for construction by its matte surface, dark green color, and white rings (Figure 23). If the surface is glossy, light green, and the rings are still yellowish in color, the bamboo is too young (Figure 22). After cutting it, residents soak the bamboo in a pond of water for about two weeks; by doing so, a part of the starch, which attracts beetles and termites, gets

Figure 24: A woman from Bahuarwa mixes clayey earth with cow dung to create a plaster for walls and floors that repels insects.



washed out. After this natural treatment method residents use it for construction. The residents have also developed a technique to protect their earth walls and floors from pests. They mix clay-rich soil, cow dung, and water to create a soft, easily applicable mass for plastering walls and floors. An equally high proportion of cow dung in relation to the clay is crucial to ensure a repellent effect on pests (Figure 24). This protective layer, used most intensively with earth floors, must be renewed on a weekly basis.

These strategies, on one hand, are time-consuming; on the other, they provide only limited protection. Despite the bamboo being the right age and soaked in water afterwards, it is still frequently infested by insects, especially if not built directly above an open fire and exposed to rain or ground moisture. The earth floors and walls require regular treatment with cow dung to be adequately protected from insects. In other cases, protective measures are even more difficult to implement. Mice and rats burrow through the earth floors and walls to reach food supplies inside the houses. Snakes, attracted by the mice and rats, follow, and, as we learn from residents, sometimes lead to deadly encounters with the inhabitants. Mice and rats not only find food supplies appealing but also gnaw on the plastic sheets meant to protect the underlying thatch roofs from rain. In other cases, there are issues with monkeys jumping over house roofs in large groups, causing damage to roofs made of fragile self-fired brick tiles.

Although infestations by insects and animals do not present an immediate challenge directly related to structural transformations, as is the case with floods and earthquakes, they still represent a constant burden that reinforces the residents' desire for structural and material adaptations. Unlike organic materials such as bamboo, wood, and thatch, fired bricks, concrete, and steel cannot be eaten by any insects and animals. The increasing availability of highly-processed and standardized products also leads to a material transformation of other building components and furnishings.

Doors, windows, and furniture traditionally¹⁷ made of local wood, such as Jamun, are either covered with a thick layer of paint or replaced with metal or plastic products, due to their higher resistance to pests and humidity.

Conversation with two members of the Shudra caste – a woman aged 40–50 and a man aged 60–70 – at the woman’s house (Field notes, Bahuarwa, October 6, 2023). Not only termites and mice dig tunnels through the earth foundations and walls of vernacular houses. The inhabitants of Bahuarwa remember a different incident when a family was robbed by neighbors. The thieves dug a tunnel to the house of a family whose daughter was to be married in a few days. As is customary for Indian weddings, the family had prepared numerous gifts to give to the husband and his family as a condition of the wedding. The thieves knew where the gifts were stored and were able to steal them unnoticed through the tunnel.

4.1.6 Conclusion

The improvement of protection against natural elements is a relevant reason for the transformations of buildings in Bahuarwa. A review since the earthquake in 1934 establishes connections between environmental challenges and transformations of construction methods and building materials. Although these changes depend on residents’ needs as well as on available options, environmental challenges seemed

¹⁷ Referring to Anttonen (2005) and Stock (1990) the term traditional is commonly juxtaposed with the modern, in the sense of the past versus the new. According to this understanding, the separation between the traditional and the modern takes place through processes of enlightenment, industrialization and urbanization. Due to its widespread use, this understanding is also used in this dissertation, even though it does not correspond to the original meaning of the term. Based on the Latin *tradere*, meaning to carry forward, hand down, pass on, tradition stands for the transmission of knowledge from previous generations to the next. Tradition is therefore not a historical snapshot, but a dynamic updating process. In contrast, the term modern, from the Latin *modernus* for new, present, today, stands for something temporary that changes over time or is replaced by something else. Accordingly, the modern could be understood as the temporary result of the ongoing process of an updating tradition, whereby the traditional is necessarily the modern, too (Anttonen, 2005; Stock, 1990).

highly influential in determining the use of appropriate building materials and methods (Figure 25).

In all transformations related to environmental challenges in Bahuarwa, residents expressed the desire for a permanent dwelling that does not require constant maintenance. This results in the regenerative building materials being increasingly replaced by more carbon-intensive materials, which involve high temperatures for their production and sometimes long transport distances. In this, two fundamental aspects of sustainable construction come into conflict: durability and re-naturability. While buildings made of regenerative materials such as earth, bamboo, wood, and thatch seamlessly return to the natural environment at the end of their use, re-naturability, recycling, or reuse of fired bricks, cement, and reinforced concrete is not possible or requires significant efforts in terms of energy demands and carbon emissions. Conversely, buildings made of regenerative, unfired materials depend on constant maintenance to ensure a durable protection of the residents, while more fossil-fuel based materials are less affected by the surroundings.

What makes the use of locally available, regenerative materials environmentally friendly is at the same time what reduces the durability of the building and entails additional maintenance costs. The daily experiences of the residents in Bahuarwa show that the re-naturability of materials, which is valued in the discourse around sustainability, in the case of vernacular buildings in Bahuarwa already starts when the raw materials are extracted. Since these materials are only treated using knives, axes, hammers, and other simple tools, and do not undergo any treatment that leads to an irreversible change in their material properties, they remain part of nature and inevitably return to it. This renaturation process manifests itself depending on the material: earth erodes, organic materials such as bamboo, thatch and wood rot or are eaten by insects.

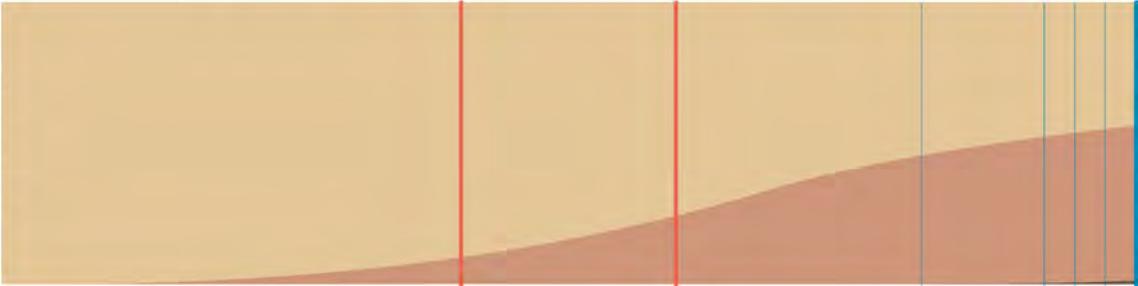
For the second part of this research, the question therefore arises as to what extent the contradiction between durability and re-naturability can be overcome – or at least be brought into a balance that meets the needs of the local population.

Figure 25 (following double page): Environmental challenges in relation to the change of building materials and methods. The graph represents an illustrative estimate based on the verbal information of the residents.

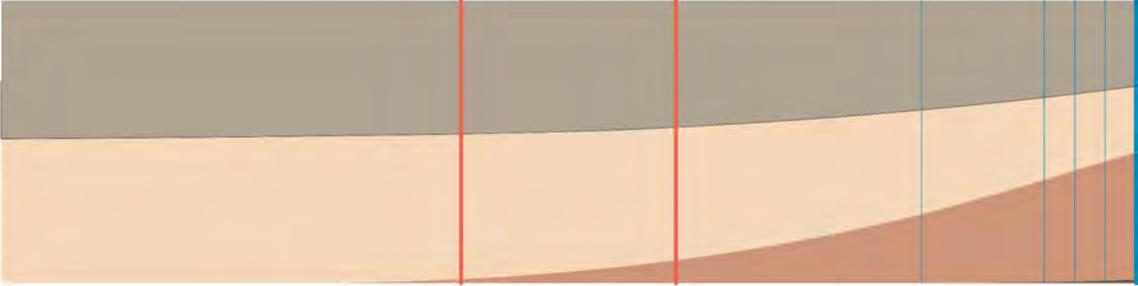
Exemplary Buildings



Roof Materials



Wall and Foundation Materials



1950

1960

1970

1980

Natural Hazards since 1950

- | earthquakes
- | fires / dry seasons
- | minor and major floodings

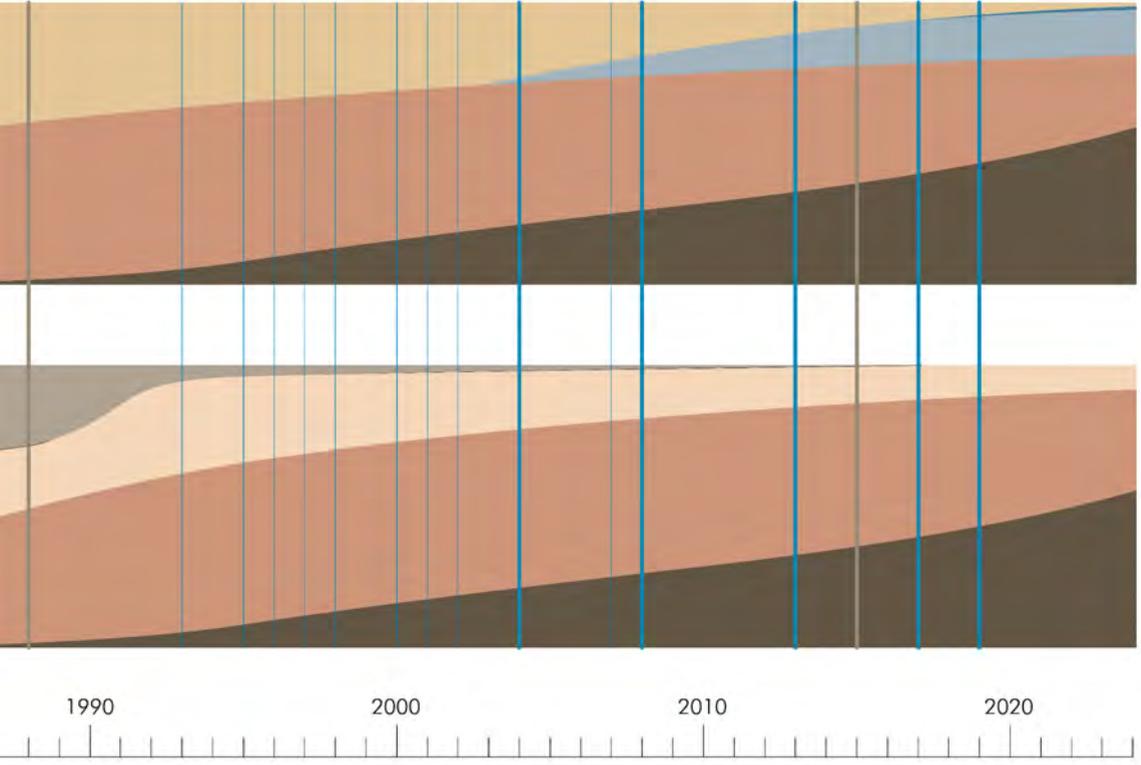
Building Materials

- thatch
- bamboo structures
- cob walls
- fired roof tiles and bricks
- reinforced concrete
- corrugated sheets (fiber cement or metal)
- plastic sheets on thatch

1965 village fire remembered by elder inhabitants

1972 last major village fire

1997 Bihar flood with more than 1,200 deaths



1990 2000 2010 2020

1976 Bihar flood with more than 1,500 deaths

1988 Nepal earthquake, magnitude 6.9

2004 Bihar flood with more than 800 deaths

2008 Bihar flood with more than 200 deaths

2013 Bihar flood with more than 200 deaths

2015 Nepal earthquake, magnitude 7.8

2017 Bihar flood with more than 500 deaths

2019 Bihar flood with more than 100 deaths

4.2 Socio-Economic Transformations

4.2.1 Introduction

After presenting an investigation of the relations between material transitions of building components and environmental challenges, this second chapter focuses on the interactions between changing lifestyles, building materials, and housing typologies. Although most households in Bahuarwa still consist of extended families, there is an increasing need for privacy among the occupants, as reflected in the transforming typologies of their houses. Until a few decades ago, interior spaces were limited to the space needed for simple sleeping arrangements, often shared by multiple family members, and the storage of few belongings. This space is expanding, which leads to changes in housing typologies, with the vernacular open courtyard often being sacrificed for the increased need for interior space. The relation of these changes to urbanization processes, manifested in – albeit relatively light – industrialization and infrastructural innovations, will be examined in this chapter.

The name *Bihar* is derived from *Vihara*, which means monastery, and testifies to the historical relevance of the state as a religious center. It is the birthplace for Jainism as well as Buddhism. During British colonization, Bihar was part of the Bengal Presidency until 1912, when Bihar and Odisha became a separate province. In 1935, Odisha was divided into its own province; in 2000, southern Bihar was ceded, forming the new state of Jharkhand. Since then, the state of Bihar has existed in its present form with Patna as its capital (Ministry of Tourism and Culture, 2003).

The state of Bihar has a population of around 104 million people, spread in 38 districts and on a total area of 94'163 km² (Government of Bihar). According to the national census, Bihar is the second-least urbanized state in India after Himachal Pradesh, despite its high population density, with only 11.29% of the population living in urban areas in 2011, compared to a national average of 31.2% (Census Organization of India, 2011). Around 58% of the population is under the age of 25, which makes Bihar the youngest state of India. At the same time, the illiteracy rate (38.2%) is

higher than in any other state, which therefore also makes it the least educated (Census Organization of India, 2011). According to Guruswamy & Mohanty (2004, pp. 2–6), Bihar’s seeming reversal of globalization trends can be traced back to neglecting policies of India’s central government, which supports the states unevenly, leaving Bihar as the last priority of any urban development policy. Poor education and health facilities, as well as few construction-oriented activities, combined with unhygienic conditions create little incentive to move to urban areas within Bihar (Guruswamy & Mohanty, 2004, p. 6). Due to limited working opportunities in the industrial and the service sector, landless laborers as well as educated youth search for jobs in other states. This leads to the further decrease of investment by the government, as the more affluent part of the population spends money and pays taxes elsewhere (Guruswamy & Kaul, 2003, p. 5). These conditions result in a vicious cycle, making Bihar India’s poorest state, too.

Closely related to the state’s socioeconomic condition is its high number of more than 16.5 million inhabitants belonging to a “scheduled caste” (Census Organization of India, 2011). The members of scheduled castes do not belong to any of the four main castes – Brahmins (priests and scholars), Kshatriyas (political rulers and soldiers), Vaishyas (traders and merchants) and Shudras (farmers) – and form the lowest social class (Deshpande, 2010). Especially in rural parts, the caste system is still influential and determines the educational and working opportunities of its members. In Bihar, for instance, the illiteracy rate among members of scheduled castes is more than 50%, compared to 38.2% of the state’s total population (Census Organization of India, 2011).

The village of Bahuarwa consists mainly of informally constructed buildings inhabited by extended families. It is surrounded by agricultural fields and small forests. According to the Census (2011), Bahuarwa contains an area of 128 hectares and a population of approximately 2,209 people. 1,027 are women and 1,182 are men. More than half of Bahuarwa’s inhabitants are illiterate: 66% of women and 46% of men. Almost 13% of the inhabitants belong to a scheduled caste. The number of young inhabitants is

relatively high, with around 12.5% of the inhabitants aged between 0 and 6 years (Ministry of Home Affairs, 2011).

4.2.2 The Courtyard House

Descriptions from elder villagers, old plans, and remaining vernacular housing typologies allow for the reconstruction of typical family life in Bahuarwa around the mid-20th century. Households consisted of large, multi-generational families. Since women often had children at a young age of less than twenty years, families could include up to four generations. Another factor that determined family size and composition was the number of sons in a family, as they would traditionally continue living with their parents after marriage, while daughters moved to their husbands' families. While this custom is still common in many Indian families, the housing typologies have often changed considerably.

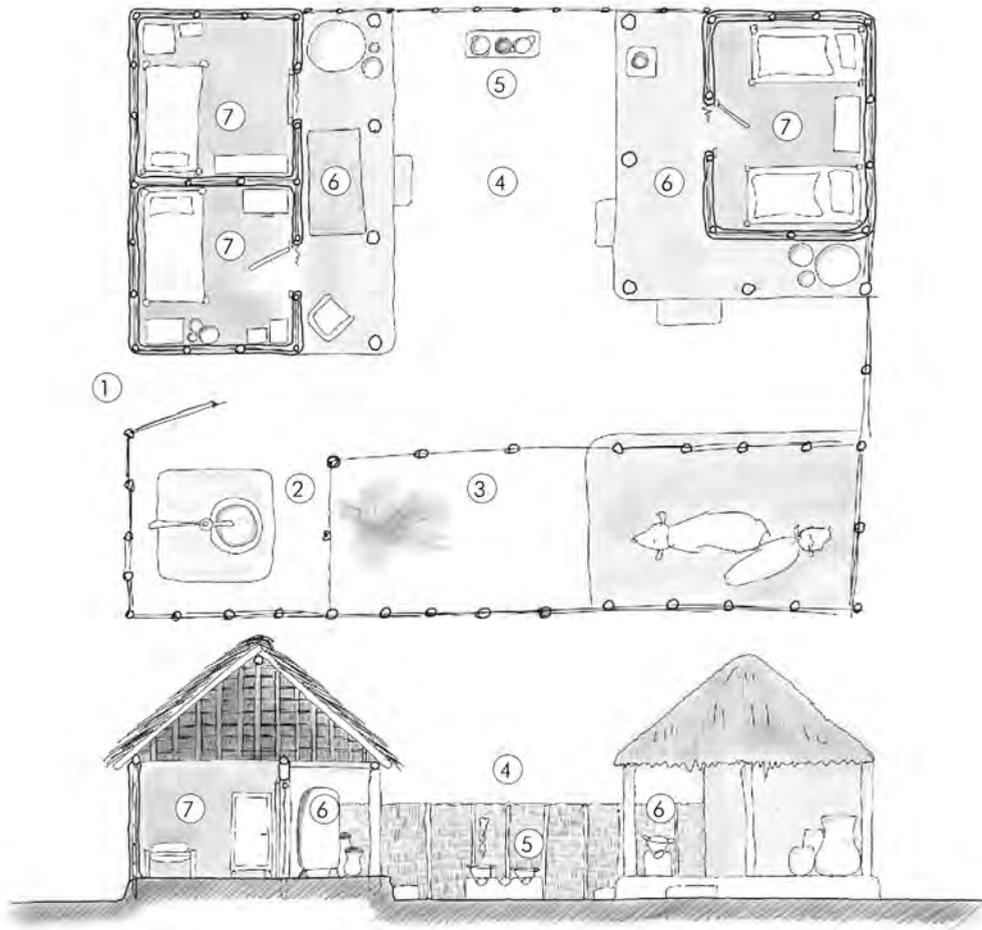
Figure 26: Shared courtyard surrounded by houses with porches in front of them. The different building materials and methods testify to the incremental construction process and the changing availability of materials.





Figure 27: Typical open fireplace (*chulah*) made of earth.

Today, socioeconomically underprivileged households provide insight into the common housing typologies of the past. These homes still consist of several small buildings grouped around a shared open courtyard, which marks the spatial center of the family (Figure 26). The individual buildings are single-story in height, and often contain only one room. A veranda in front of the houses creates a transition zone from the open courtyard to the enclosed private rooms. Like its adjacent rooms, the veranda is slightly elevated compared to the courtyard. Openings are directed to the courtyard, where most of the daily-life activities takes place. They provide access to the rooms from the veranda and allow a minimum of lighting as well as fresh air supply. If space is limited, the house serves both the inhabitants and their livestock. Since most activities take place outdoors the requirements for interior spaces are reduced to sleeping purposes and storage of few possessions. Cooking takes place on the veranda or in the courtyard. The fireplaces are made of earth (Figure 27). They are regularly rebuilt or shifted to be protected from the monsoon rainfalls or to receive more sun during the dry winter months. The bathroom is usually separated from the other rooms. To take a shower, to wash



clothes or dishes, a bucket is filled with water from a hand-pump, which is often shared with neighbors.

There is a gradual transition from the public street to the semi-public open courtyard, which is accessible for family-members, guests, and friends, to the more private, elevated, and covered veranda to the private enclosed rooms (Figure 28). Most of the activities take place in the courtyard and the shaded verandas, depending on the time of the day and the inclination of the sun (Figure 29). In the hot months, even the beds are sometimes transferred from the enclosed rooms to the veranda or courtyard to enjoy the winds and the cooler temperatures of the night. Except for the beds and some storage facilities, there is not much furniture in the houses. People usually sit on the floor to eat their meals.

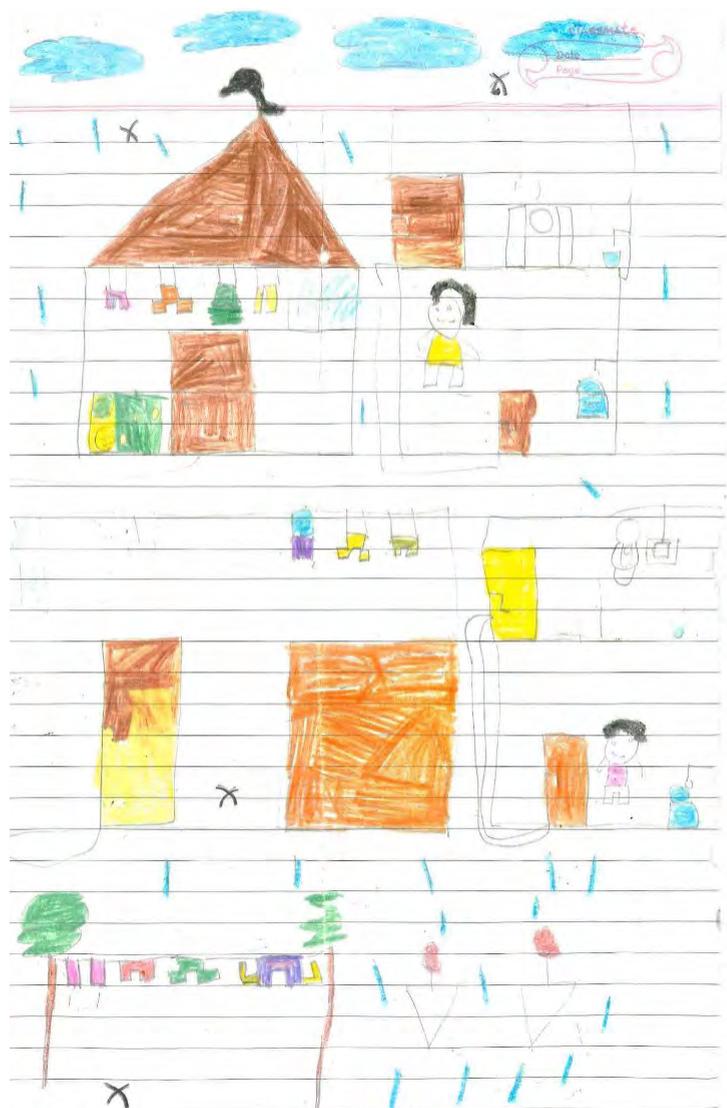
Figure 28: Spatial organization of a typical (kutcha) house made of bamboo, earth and thatch: Entry (1), hand-pump (2), stable (3), courtyard (4), fireplace (5), veranda (6), bedroom (7).

Figure 29: Drawing of a local child's home with a pitched roof, showing the importance of outdoor spaces for daily activities.

Cooking, washing, and many other activities are conducted in a squatting position.

Residents grow their own food, mostly rice, vegetables, and some fruits. Most own a few goats and chickens, while wealthier families also have cows and buffaloes. The sub-tropical climate, fertile soil, and numerous rivers allow for a continuous cultivation of rice, vegetables, fruits, and grains throughout the year. Just like the food supply, the construction of homes is traditionally carried out by its residents. When the family grows, additional rooms are added.

The typologies of the residential houses remained largely unchanged until the late 20th century. Even the emerging



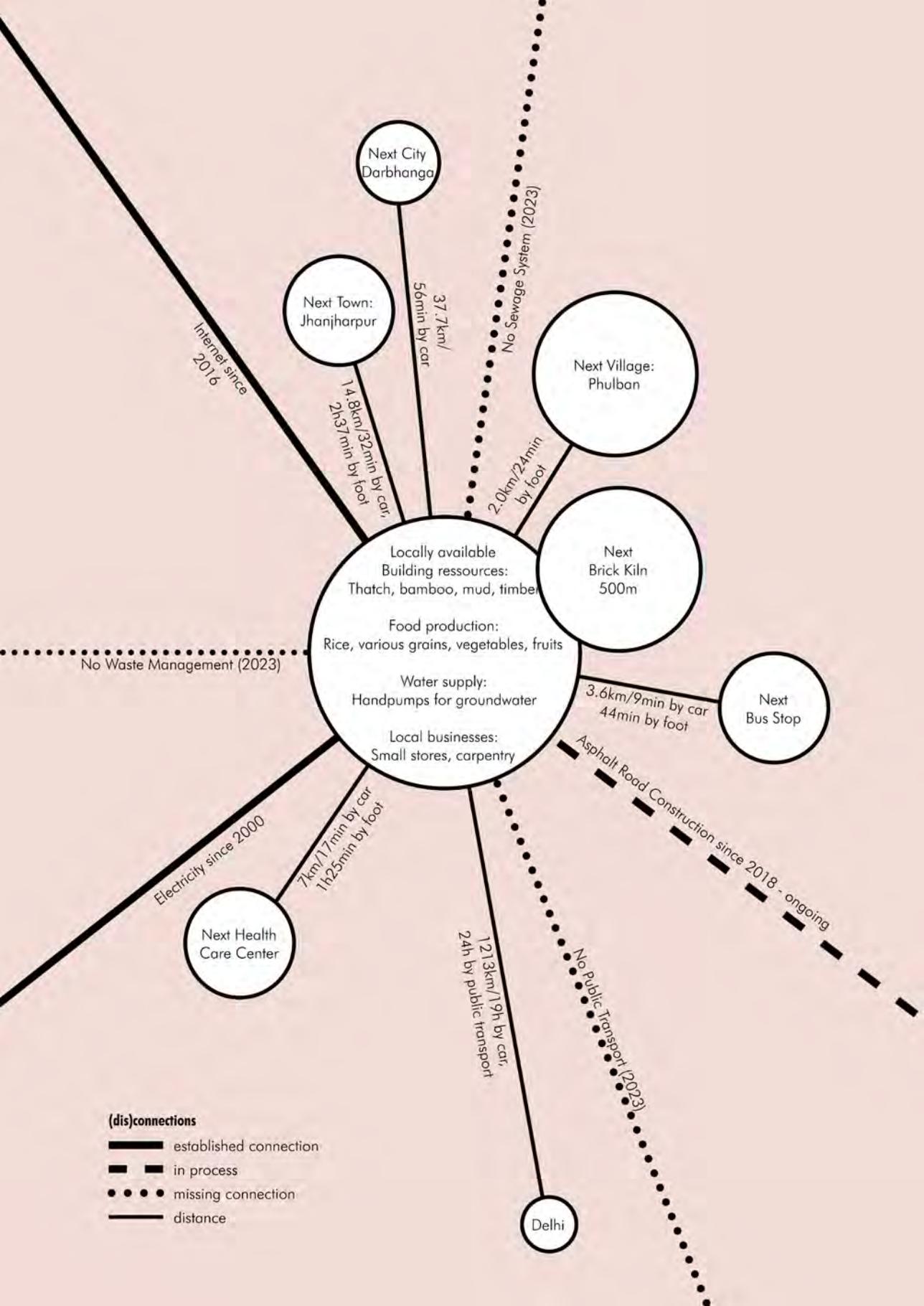
changes resulting from the use of new building materials had initially little impact on the floorplan typology of individual small buildings gathered around a common courtyard. The introduction of fired roof tiles and bricks did not lead to major changes in building volumes and shapes either. It was only with the use of cement, concrete, and steel that the size, shape, and the intermediate spaces of the buildings began to transform.

4.2.3 Local – Global – Individual

Elder residents of Bahuarwa recall how what was initially slowly-progressing change accelerated when the neighboring village of Ujan was connected to the railway line around 1945. Although the district capital of Darbhanga was already connected to the rapidly expanding railway network built under British rule, the 35-kilometer stretch between Bahuarwa and Darbhanga remained an obstacle. However, the connection of Ujan to the railway line enabled links to one of India's largest metropolitan areas – Kolkata – and the wider region, particularly eastern India. The mild industrialization of the region around Bahuarwa and the resulting lack of income sources outside of agriculture led many young men to use the railway to seek employment in more industrialized areas outside of their village and state.

With the increasing expansion of the railway network, more distant parts of India and additional employment opportunities became accessible. Nowadays, the workplaces of the male residents range from large cities such as Delhi, Mumbai, and Kolkata to Goa and Chandigarh, but also include smaller towns in India and Nepal. It is primarily the male members of the family who migrate to work outside the Bahuarwa region, while the rest of the family remains in the village. The village community therefore consists mainly of children, women, and the elderly, while the majority of young men work outside Bahuarwa and, depending on the work and the place of work, only return to their families once or twice a year. Instead, they regularly send money home. In some cases, especially when the husband's parents and grandparents are no longer alive or the family has little land,

Figure 30: Bahuarwa's (dis)connections to infrastructure, resources and urban areas in early 2025.



Locally available Building resources:
Thatch, bamboo, mud, timber

Food production:
Rice, various grains, vegetables, fruits

Water supply:
Handpumps for groundwater

Local businesses:
Small stores, carpentry

Next City
Darbhanga

37.7km/
56min by car

Next Town:
Jhanjharpur

1.48km/32min by car,
2137min by foot

Next Village:
Phulban

2.0km/24min
by foot

Next Brick Kiln
500m

Next
Bus Stop

3.6km/9min by car
44min by foot

Next Health
Care Center

7km/17min by car
1125min by foot

Delhi

1213km/9h by car,
24h by public transport

Internet since
2016

No Waste Management (2023)

No Sewage System (2023)

Asphalt Road Construction since 2018 - ongoing

No Public Transport (2023)

(dis)connections

-  established connection
-  in process
-  missing connection
-  distance



wives and children also follow husbands, hoping for better living conditions in the new place. Migration has a twofold effect on the transformations of people's houses. On one hand, life in more urbanized places provides new aspirations and building methods; on the other hand, the new sources of income in more urbanized places lead to opportunities to implement these aspirations, at least in part. In contrast to India's rural regions, there are hardly any buildings made from regenerative materials in urban areas. According to the IEA (2021, p. 84), the proportion of vernacular buildings in India in 2018 was 20% in rural regions and only 3% in urban regions (Figure 5). The new sources of income and construction methods in urban areas make people perceive urbanity as progress, which reinforces their aversion to vernacular construction methods, which are equated with poverty and a backward village life.

Figure 31 (left): Veranda of an unplastered brick building with an earth floor, encountered in Bahuarwa in 2022.

Figure 32 (right): Refinement of the same building in 2023 with plaster, color and tiles. The change in furniture and everyday objects is also apparent: the wooden couch gives way to a plastic chair, woven baskets to a plastic bin.

Figure 33: Today, even vernacular buildings are painted in colors – often in blue – to hide the materiality and the associated status.

Conversation with a female member of the Shudra caste, aged 40–50, at her house (Field notes, Bahuarwa, November 8, 2023).

The construction of the railway line and the station in the neighboring Ujan allowed the residents of Bahuarwa to work in other places, to discover a world outside Bahuarwa, the woman recalls. Back then, it was a sensation when someone returned from work in Calcutta. These people were treated like VIPs! They worked so far away from home, in a big city! These people have seen something of the world and brought new ideas and knowledge to the village.

Most buildings in Bahuarwa represent a shell construction that meets the primary requirement for a durable, waterproof, low-maintenance, and insect-proof dwelling (Figure



31). Having reached this stage, the next goal is to refine and customize this shell with individualized finishes. The walls are plastered inside and out with cement, often colored, and painted decoratively, floor tiles are laid, and bars are replaced with windows (Figure 32). Buildings with flat roofs are completed with decorative railings or additional floors. Bold and vivid colors are used in this process as the inhabitants try to distance themselves from the earthy tones associated with traditional ways of building and poverty (Figure 33). If not the entire building, at least the facade facing the street is plastered and painted (Figure 34). This phase of individualizing the building involves transforming the anonymous, globally recognizable raw structure made of reinforced concrete and bricks into a building that reflects the preferences of its occupants and distinguishes itself from the rest of the village. The transitions of materials not only affect the durability, maintenance, and aesthetics of the buildings, but also relate to changing social practices.

Figure 34: Colorful facade towards the street, while the rest remains raw.





Figure 35: Multi-story building including more private and interior spaces.

While the one- and two-room structures made of bamboo, earth, and thatch are arranged around a common courtyard where most of the daily activities take place, these activities shift more to the interior of the larger concrete and brick buildings, which ultimately incorporate all the originally individual structures and the courtyard into themselves and reorganize them on multiple levels (Figure 35).

The process of individualization manifests itself in two ways: on one hand, between the village and the family, through changes in the external appearance of the building with plaster, paint, and decorative elements; and on the other, within the family, through changes in the layout of the rooms that increase private and enclosed spaces of individual family members (Figure 36).

Conversation with a man, aged 40–50, and two of his three sons, aged 20–30, at their house (Field notes, Mahthaur, December 12, 2023).

Once we were invited home by the three masons (mistris) who were plastering the exterior walls and building the floors of the schools. The father and his two sons took us on their motorcycles to Mahthaur, a place about six kilometers south of Bahuarwa. They transformed their previous house made of earth and bamboo into a house made of fired bricks and concrete a few years ago. They were able to do the work themselves as masons, so they only had to buy the materials. In some places, a few bamboo supports still remained from the old structure, but otherwise, earth, bamboo, and thatch were replaced with concrete, bricks, and fiber cement corrugated sheets. The three men have painted and decorated the pillars, floors, and walls of their house. Currently, the building is single-story, but a staircase to the flat roof has already been built, and the father tells us about the expansion plans for the house that will be implemented in the near future. Like almost all buildings with reinforced concrete flat roofs, the protruding reinforcement bars already hint at the

Figure 36: Drawing of a local child's dream house with a flat roof, terrace and colorful facades.





Figure 37: The house of three local masons (*mistris*) illustrates the aspiration to achieve a new expression with new building materials.

intended expansion of the house. The families of the father and of his two sons live in the house. In addition to their own bedrooms, the three families also have their own kitchens and washrooms. The lifestyles and family structures have changed, one of the sons says. Nowadays, a shared kitchen is no longer sufficient for a large family. The need for privacy and retreat is bigger now. That is why the expansion of the house is necessary soon. Although the new house still has a courtyard, it is mostly covered. On the ceiling, there is a disco ball and lamps that shine in different colors. The base is painted red, the walls glow in yellow, and the pillars are adorned with colorful triangular patterns (Figure 37).

In the process of building individualization, the internet, accessible through personal smartphones, plays a central role. Even before the development of paved roads within the village of Bahuarwa began and while there is still no sewage and waste management system, the region was connected to the internet in 2016 (Figure 30), such that even residents with limited mobility options – especially women and children – can at least become digitally mobile. While most socio-economically underprivileged households have no sanitary facilities, apart from a hand pump, many of the adult residents have a cell phone with internet access. It is therefore not surprising that some of the residents pull out their cell phones when asked about their dream house and show a photo they have taken themselves in another place or a picture from the Internet. One Bahuarwa resident even modeled his home after a house owned by Bollywood star Shah Rukh Khan. “Mannat,” the name of the original in Mumbai, is also used by the villagers for its small imitation

Figure 38: One of the largest residential houses in Bahuarwa, inspired by Shah Rukh Khan's villa in Mumbai.



in Bahuarwa (Figure 38). However, it is only recognizable as such from certain angles. As inspiration is often gained through digital media and visits to other cities, the focus is less on adopting spatial concepts than individual facades, design elements and color combinations.

Conversation with a Dalit man, aged 60–70, and his daughter-in-law, aged 20–30, at their house in the “Kathbe Toli” neighborhood (Field notes, Bahuarwa, December 9, 2023). Kathbe Toli, a neighborhood of the Dalit community located on the southern edge of the village center, is where two brothers live with their families. They are both grandfathers and live with their wives, two daughters-in-law, and six grandchildren on a small plot of land. Their sons live and work in other states of India for most of the year. Until 2023, the extended family of the two brothers lived together on the property in four small buildings mainly made of bamboo, earth, and thatch, each consisting of two rooms of approximately three by three meters in size.

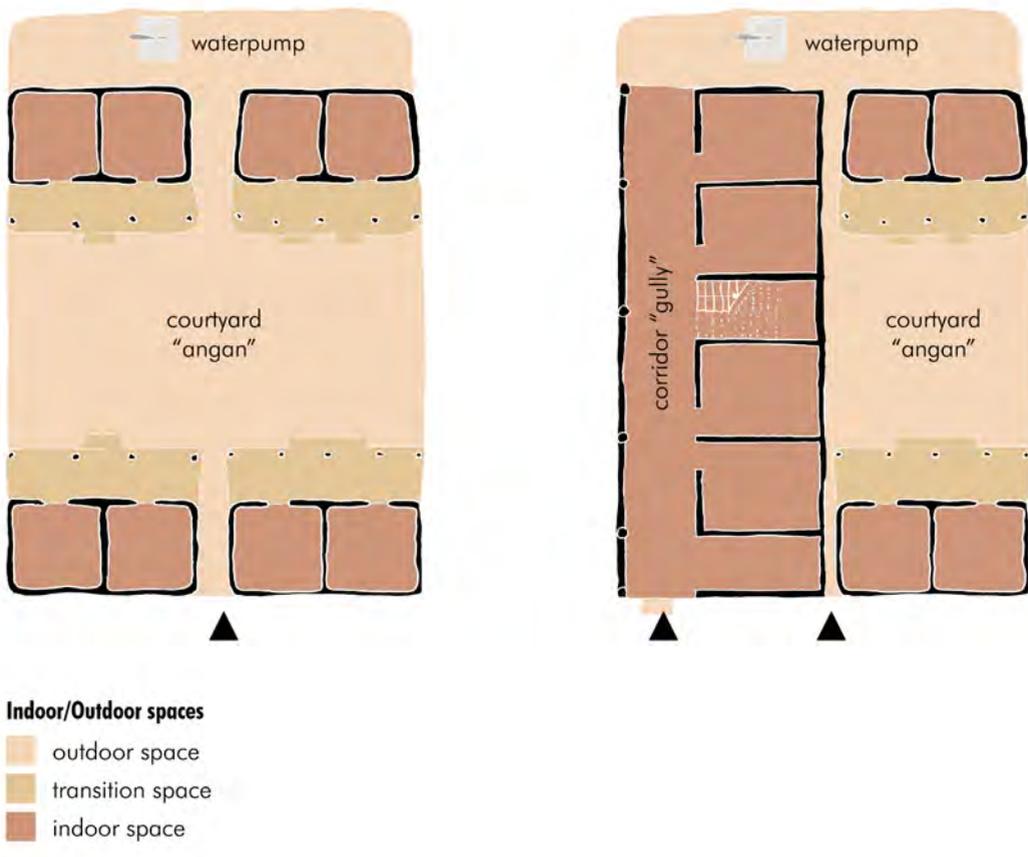
The younger generation has been dissatisfied with the living situation for some time. She cannot explain exactly why but a house made of bricks and concrete is simply better, the daughter in law argues. In contrast, the man, one of the brothers, is convinced of the construction of their home. He underlines that the houses remain pleasantly cool in summer, benefiting both residents and livestock. However, he understands if the younger generation does not share his view. He would not object to a new construction of the house if they could afford it, even though he was content with the current situation. We now have different lifestyles, he explains, some eat meat, others are vegetarians, so we want separate kitchens. In a shared courtyard with a shared cooking area, that is a challenge.

In 2023, the family of the man’s brother finally decides to rebuild their part of the house. The family has been saving for a new house made of bricks and reinforced concrete for some time and can now pursue this with the help of a government subsidy. Since the man’s family does not have enough money for a new construction yet, the property gets divided. The central courtyard is split in half. His family’s two buildings remain intact while the other two are demolished.

The new construction not only differs in materials but also in layout from the existing structure. The entire available area is built upon. The individual rooms are no longer accessed through a central, open courtyard, but instead through a covered corridor. The open “Angan” (courtyard) becomes the covered “Gully” (corridor). The shared entrance is replaced by two separate entrances. While the courtyard of the existing half of the house is below street level, a few steps need to be climbed to reach the front porch of the new construction (Figure 39).

By the end of the year, the foundation and walls have been erected, but the roof is still missing. Money still needs to be saved for it. In the meantime, the family sleeps under the open sky or seeks shelter with neighbors. Although it will take some time before the house is habitable, the family is looking forward to the larger indoor spaces. The outdoor space

Figure 39: Transformation of a house in the Kathbe Toli in Bahuarwa: from a shared courtyard for the families of two brothers to separate dwellings. The open courtyard (angan) becomes a covered corridor (gully).



will also not be lost as they will use the roof area. We will have enough space on the roof to celebrate events, highlights the daughter-in-law with excitement.

4.2.4 Unfired – Untouchable

In the year 2023, the village of Bahuarwa consists mainly of fired brick buildings, sometimes combined with reinforced concrete structures. The houses are mostly one to two stories high, rarely more than three. The roofs are made of brick tiles, corrugated fiber cement sheets, or concrete slabs, the latter waiting for a vertical extension of the building. Most of the buildings have a raw expression, showing the fired bricks and concrete frames. Only a few are plastered, painted, and decorated (Figure 40).

However, in some neighborhoods, one can still find buildings made of bamboo, earth, and thatch. Only a few of these are made entirely of regenerative materials. Most of the houses are at least partially covered with plastic sheeting. In some cases, the earth plaster on the walls has fallen off or washed away. The walls are sometimes leaning because the base underneath has eroded.

In these cases, it becomes clear that living in a house made of regenerative materials is not a matter of choice, but of necessity. The use of regenerative building materials is not a sign of environmentally conscious inhabitants, but a sign of poverty. A closer analysis of the building and social structure shows that the socio-economic structure as well as parts of the hierarchy of the Hindu caste system can be read along the building materials used.

Conversation with a Dalit woman, aged 20–30, in the “Ram Toli” neighborhood (Field notes, Bahuarwa, October 4, 2023).

On a walk through Bahuarwa, we are invited to visit the house of a Dalit family. Apart from the metal sheets on the roof, the house is mainly made of earth and bamboo. The mother immediately tells us about her problems with the house. She is ashamed of it. It seems ridiculous to her when we tell her that her house is beautiful despite all its disadvantages. She gives us a questioning look: What’s beautiful about it? In this moment, we realize how romanticized our

perception is and that we have no idea how hard and miserable her life is in this house.

All the houses, which are primarily made of bamboo, earth, and thatch, are inhabited by people belonging to Dalit or tribal communities (Figure 44). These minorities are excluded from the Hindu caste system and represent the bottom of the socioeconomic pyramid. In this case, the use of regenerative building materials, caste, and socio-economic condition coincide. Looking at the buildings made of fired bricks, concrete, and steel, the building materials still reveal the socio-economic status of the inhabitants, but not necessarily of their caste.

Besides the materials, the location of the building in the village also reflects the status of its inhabitants. The densely

Figure 40: Few colored houses indicating higher social status of inhabitants.



clustered one and two-room houses of the Dalit are usually located near a neighborhood of upper caste members, such as Brahmins or Kshatriyas. Since Dalit members do not possess land, they usually live on upper caste land, which requires them to serve their landlords. The proximity allows for control by the landlords as well as quick delivery of services by the Dalit. The Dalit tend the landowners' fields and livestock and may keep some of the harvest for personal use or to sell at a market.

Although the proximity to upper caste neighborhoods applies to most of the buildings made of regenerative materials, some defy this pattern and are located on the periphery of the village. A few of these buildings form their own small neighborhood at the southern end of Bahuarwa and are home to a tribal community. Although they are no better off socioeconomically than the Dalit, they lead more independent lives: instead of farming in someone else's fields, they hunt, fish, grow vegetables, and in some cases have a few goats and chickens of their own. Located at a distance from the rest of the village, the tribal community lives by its own rules.

Apart from the houses of the tribal community, there are a few more clusters of earth and bamboo houses that are, or were, temporarily located on the outskirts of the village near the river. These houses belong to Dalit members who have tried to escape the concept of ownership and dependency by settling on unclaimed land. However, as this land is often flooded, most of them have returned to their landlord's land. The financial situation characterized by dependency on the landlord and the lack of land ownership make it doubly difficult for the inhabitants to construct a building with materials other than earth, bamboo, and thatch. Firstly, other building materials are too expensive; secondly, constructing a permanent building with a temporary right to use the property is a risky undertaking that depends on the tolerance of the landlord.

4.2.5 Polarizing Housing Programs

The choice of building materials, along with their availability, is also influenced by government housing programs, which classify existing building materials in a polarizing

manner. Buildings are divided into two categories: kutcha and pukka – in other words, temporary and permanent – or more literally, raw and cooked houses. As the adjectives commonly used for cooking suggest, the classification is based on the processing and hardness of the building materials. While a kutcha house is built from “raw” materials such as earth, bamboo, wood, reeds, or thatch, the term pukka refers to a house made of “fired” materials such as bricks, concrete, or steel (Figure 41).

In 1985 the Ministry of Rural Development launched the Indira Awas Yojana social housing program, which was adapted and continued under the name Pradhan Mantri Awas Yojana (PMAY) in 2015, promising “[pukka] housing for all” by 2022. The program consists of two parts, PMAY – Urban (Ministry of Housing and Urban Affairs, 2015), for urban areas and PMAY – Gramin (Ministry of Rural Development, 2016), for rural contexts. Assistance is provided to those below the poverty line, such as landless and homeless families and families living in one or two room kutcha houses. It is emphasized in the regulations that only families living in houses without any concrete elements are eligible to receive funds. In states with flat topography, the government assistance is INR 1.2 lakhs¹⁸ and in those with hilly topography, it is INR 1.3 lakhs (Acharya, 2025).

Even though the government has fallen far short of its target of “housing for all” by 2022 and has therefore extended the program until the end of 2024, studies (Balamurugan 2023; Swaminathan and Nagbhushan 2023) show the positive effects on the living conditions of the beneficiaries. In many cases, inhabitants benefit from new houses made of reinforced concrete and fired bricks, toilet facilities, kitchens and electrification. These amenities provide them with improved safety and hygiene, a higher social status and a feeling of ownership (Balamurugan, 2023, p. 99). Especially for poorer households, buying a plot of land and

Figure 41: From kutcha to pukka: collage of different buildings in the Bahuarwa region to illustrate the incremental changes in the buildings and thus the construction methods and materials.



building a permanent house is often the most promising way to achieve a little more prosperity (Swaminathan & Nagbhusan, 2023, pp. 82–84). The increased demand for a house made of steel, cement and fired bricks, driven by the government housing programs, also leads to an increase in construction activities, resulting in new jobs and sources of income (Hazarika & Nayak, 2019, p. 62).

The impact of PMAY – Gramin is also visible in Bahuarwa. Since the first research stay in April 2022, it is estimated that approximately a third of the bamboo and earth houses found at the time have been completely or partially demolished and rebuilt with bricks and reinforced concrete. Similar findings emerged from discussions with building contractors in the region.

Conversation with three male masons, aged 20–30 and 50–60, at the building site of the school (Field notes, Bahuarwa, December 11, 2023).

In the past five years, we have been building around 50 houses using reinforced concrete and bricks. Before that, it



was no more than five to eight per year. This increase is mainly due to PMAY – Gramin. The money motivates households to build a pukka house. And to build a pukka house, they usually call a contractor. If the house is built from earth, then the residents can do it themselves, but when it comes to a pukka house or just the installation of an asbestos roof, then they need a contractor.

Usually, the residents inform us about the design and layout of their house. But if they don't have their own ideas, we design the building for them. At the beginning, they may only build the foundations and wait until they have saved up enough money through work in cities to continue building. This is how a pukka house is gradually built.

Conversations with Bahuarwa residents also reveal that there are those who have been waiting in vain for government support for years, even though they meet the criteria to receive subsidies. Some of those who received support emphasize that they only received part of the promised amount. These statements are confirmed by reports from other parts of India (Khabar, 2019; Mavi & Sengupta, 2023) and testify to the political corruption inherent in these housing programs. Critics see them as mere electioneering strategies (Biwas, 2024), whose fulfillment is tied to political attitudes (Mavi & Sengupta, 2023) and the payment of bribes (Khabar, 2019). Those who are most in need of support are often not sufficiently informed about their options. In addition, the application procedures require documents that not everyone has (Mavi & Sengupta, 2023). Despite the socioeconomic situation and Caste Census being the basis for the beneficiary selection process, in some cases ineligible people have been favored while eligible people have been forgotten. In other cases, more affluent households have paid bribes and availed themselves of the benefits on behalf of poorer families (Khabar, 2019). Aside from the lack of transparency and the allegations of corruption underlying the housing schemes, which go beyond the scope of this dissertation, their polarization of the construction methods and materials is of particular interest.

Figure 42: Neighborhood “Ram Toli” in Bahuarwa whose inhabitants would be eligible to receive government funds but are still waiting for them.

Conversation with a Dalit woman, aged 40–50, mother of eight children, in the “Ram Toli” neighborhood (Field notes, Bahuarwa, October 6, 2023).

We asked for it several times, but they [government officers] told us that according to their survey all the Dalits in Bahuarwa have already benefitted from the scheme and have built a pukka house, a female inhabitant of a Dalit neighborhood explains. All the Ram neighborhood (Figure 42) in Bahuarwa has already built a pukka house from the scheme, they say. [...] The lady continues, it is just an assumption, but it could be that when we were in Delhi, someone else used our names to receive the funds, but we cannot do anything about it now. [...]





Although the beneficiaries are officially not bound to a defined choice of building materials, the state makes it clear which houses and thus building materials are considered kutchra and which are considered pukka. This polarization “[...] has blocked the opportunity to reinvent these materials for fusion and hybridization with new conventional techniques to maximize energy and environmental gains” (Roychowdhury et al., 2022, p. 9). The classification of progressive and backward houses involves a classification of appropriate and inappropriate building materials.

The quality of a building is measured by the building materials used, and materials are assessed based on their processing and hardness, and according to the industries that produce them. Rather than using locally available building materials according to their strengths and weaknesses, and

Figure 43: Housing programs such as the PMAY-Gramin promote the replacement of vernacular building methods using regenerative materials with fired bricks and reinforced concrete.

combining them in clever designs, the use of organic and unfired materials is avoided from the outset. As a result, the polarization of regenerative and non-renewable materials is further intensified, accelerating the shift away from building materials such as earth, bamboo, wood or straw to bricks, cement, concrete and steel (Figure 43).

4.2.6 Conclusion

While in the first chapter material transitions were discussed in relation to the interaction between people and their natural environment, the focus of the second chapter was on the changing interplay between lifestyles, building materials, and housing typologies. In this context, the environmental challenges influencing the material transitions analyzed were expanded to include socio-economic, political and cultural factors.

Employment opportunities outside the primary sector and outside Bihar are leading to changes in family constellations and to new sources of income. These enable an incremental expansion of the houses. An increasing demand for covered living space and the desire to individualize the appearance of the house, combined with new building materials and techniques, lead to larger, multistory building volumes and the usage of colors and decorative elements on the facades. These needs are, in turn, fueled by the gradual increase in mobility and access to the internet, which make urban building and living styles tangible or at least visible.

A walk through Bahuarwa makes clear how building materials and the socioeconomic status of the inhabitants are linked. Only members of the Dalit and tribal communities still live in buildings made of bamboo, earth and thatch.

As for the changing materiality of the buildings, the desire for a durable house goes hand in hand with an expression of higher social status. These factors are inextricably linked, as cramped living conditions, dusty earth floors or leaky thatched roofs contribute to the low social status of the residents. The question for the desired hybrid solution is therefore how, and to what extent, regenerative building materials can be integrated into new construction methods without negatively affecting the social status of the residents, while at the same time making the houses more affordable.

Figure 44 (following double page): Castes and social classes in Bahuarwa in relation to building methods and materials.

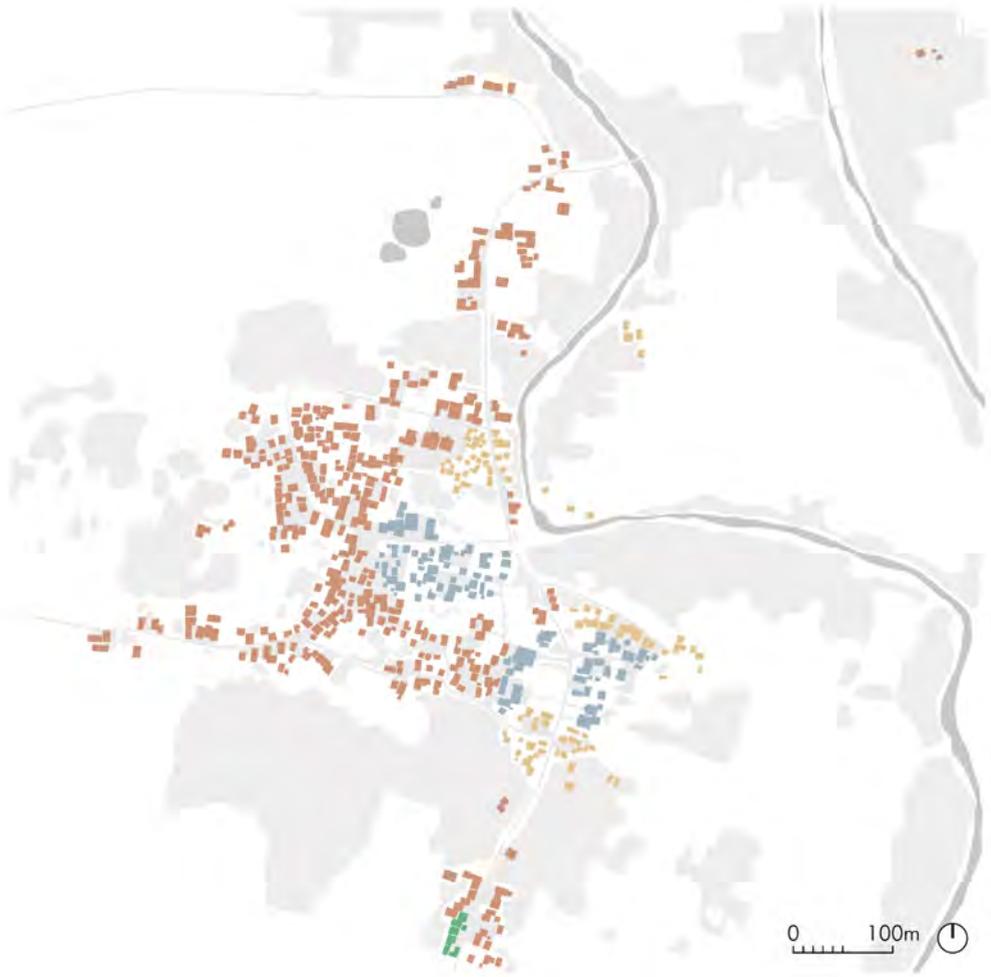


Incremental transformation of buildings and replacement of materials

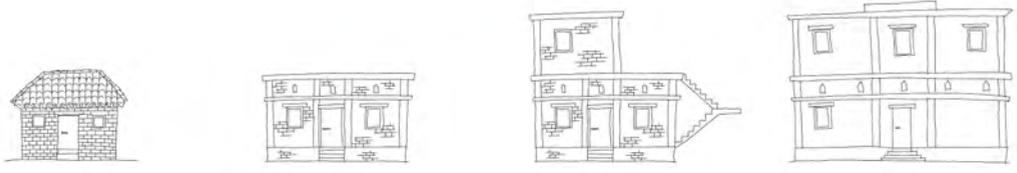
primarily biobased materials: earth, bamboo, timber, thatch



Castes and social classes of households



primarily fired bricks and reinforced concrete



4.3 Technological Developments

4.3.1 Introduction

While the last chapter revolved around changes in people's ways of living, this chapter is about changes in their ways of building. Until a few decades ago, houses in Bahuarwa were mostly built by the residents themselves, whereas today several professions are usually involved in the construction of a residential building. While the immediate natural environment served as the source of building materials until the end of the 20th century, processed products from regional and international industries and markets are increasingly used today. This chapter provides insight on how these changes affect construction methods, professions, production chains, and building processes.

4.3.2 Raw Materials – Self-Construction

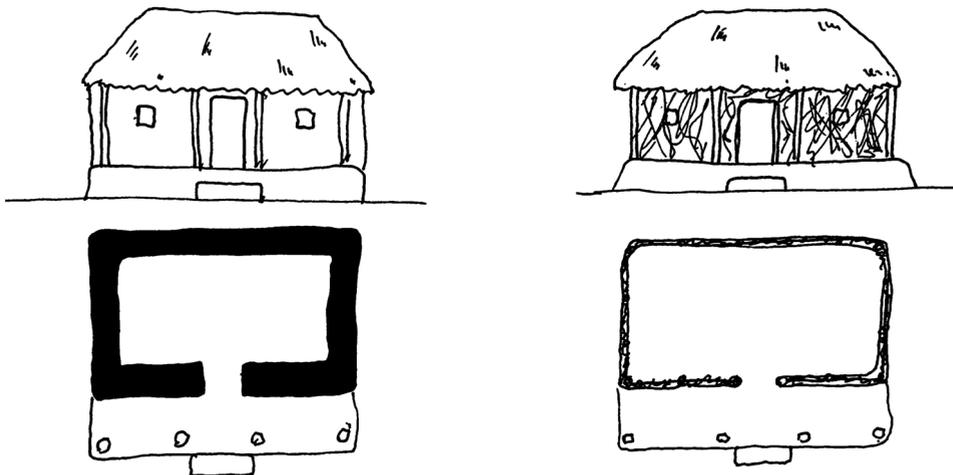
Until the late 20th century, a significant part of the buildings in Bahuarwa were made of materials from the immediate natural environment: earth, bamboo, wood, and thatch. The local earth contains a high proportion of clay and fine sand, giving it strong binding properties. The debris transported by rivers originating in the Himalayan mountains erodes into fine sand until it reaches the plains of Bihar, which is why there is no natural occurrence of pebbles or stones in most parts of the state. Bamboo grows in small forests in and around Bahuarwa. The fast-growing grass provides an abundant natural resource. Tree species such as mango, Jamun, sheesham, johar, or jackfruit grow in the local forests. Their wood is used for building components, furniture, windows, and doors. Thatch is also abundant, especially from rice but also from local cereal crops of the surrounding fields.

According to the descriptions of elder residents, until the second half of the 20th century most buildings in Bahuarwa consisted of two types, mainly differing in the construction of the walls (Figure 45). One type was made of solid earth walls with a thickness of 30 to 60 centimeters, while the other was constructed of a delicate framework of bamboo, leaves, and thatch. The roofs of both types were built of bamboo structures and covered with thatch. The base in

Figure 45: Until far into the second half of the 20th century buildings in Bahuarwa were either made of thick cob walls (left) or a lightweight bamboo structure filled with leaves and grass and sometimes plastered with mud (right). Regarding the roof structure both types were similar and consisted of a bamboo structure covered with thatch.

both cases consisted of piled-up earth. While an adapted version of the second wall type still exists in the village today, the solid earth walls of the first type have been abandoned for several years. They were constructed using the cob technique, in which earth, thatch, and water are mixed and applied in layers. Unlike rammed earth, this construction does not require any formwork. Instead, the wall is intentionally built thicker than necessary and then cut to the required thickness with spades. The walls are then usually plastered with a mixture of cow or buffalo dung and clay, in similar proportions. This mixture serves mainly as protection against pests.

In contrast to the solid cob walls, the walls made of bamboo, leaves, and thatch offer a delicate and quickly constructible alternative (Figure 46). In this construction, bamboo supports are inserted about 50 centimeters deep into the earth base, which raises the walls about 20 to 50 centimeters from the ground, depending on the location of the house and the abilities of the residents. The freestanding columns of the veranda, in the corners and in the middle of the building, are sometimes made of wood, as they form



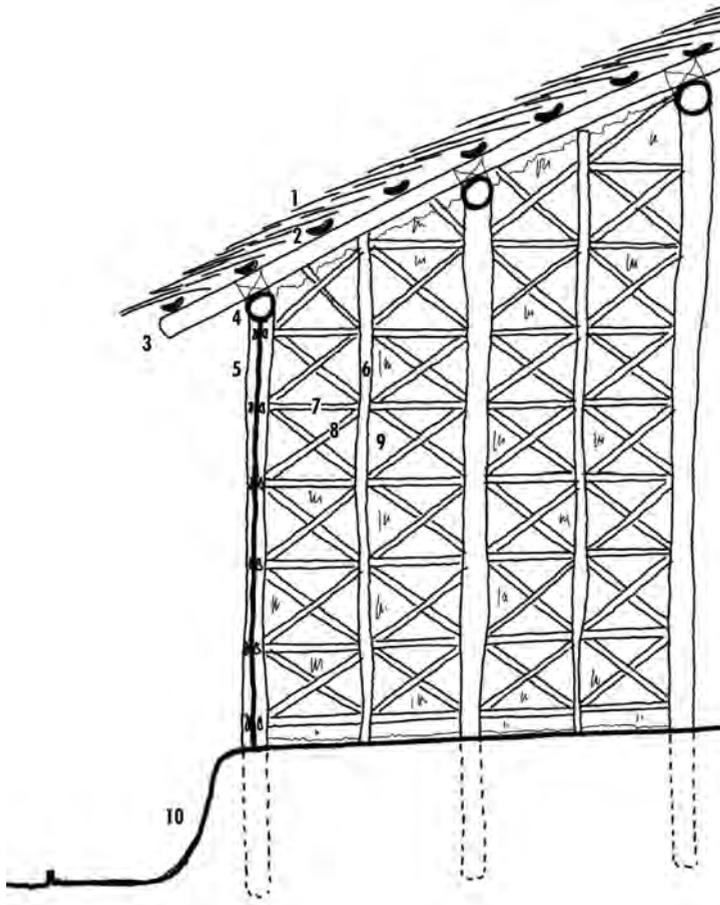


Figure 46: Detail section of a vernacular building with a thatched roof (1) on bamboo battens (2) supported by bamboo rafters (3) and purlins (4). The walls consist of a primary structure of bamboo columns (5), a secondary structure of half-cut bamboo (6) and a tertiary structure of horizontal bamboo slits (7). In more elaborate cases the horizontal layer is complemented with a layer of diagonal slits (8). The horizontal and diagonal slits provide a base for a wall filling with grass, leaves or unrolled bamboo (9). The structure is raised from the ground through an earth base (10).

the primary structural elements and wood is a more stable, albeit more expensive, option than bamboo. The secondary supports are positioned at intervals of about half a meter and sometimes consist of half cut bamboo poles. The bamboo supports are vertically punctured at regular intervals of about 30 to 40 centimeters, which allows a connection with horizontal bamboo strips. In more elaborate cases, a layer with diagonal strips is added. The strips provide a base to fill the walls with branches, and leaves. Today, the filling is often done with split and unrolled bamboo, which provides a more robust wall than leaves and branches (Figure 47). Depending on the residents' needs and capabilities, these constructions are either left exposed or covered with a thin layer of clay plaster. The clay plaster is mixed with fine thatch chippings, which serve as reinforcement to reduce cracking in the clay.

Figure 47: Today, bamboo buildings in Bahuarwa consist of a multi-layered hierarchy of vertical columns, horizontal and diagonal battens, and vertically unwound bamboo. Either left exposed or plastered with earth and cow dung.

The vertical supports are notched at the top, where a horizontal bamboo pole is placed to connect the supports and form the roof ridge. Inside the buildings, there are often two main central supports carrying a horizontally placed bamboo pole or a piece of timber as the ridge beam. Bamboo



rafters are placed at regular intervals of about 30 centimeters on the walls, leading to the ridge beam. The rafters are usually smaller in diameter than the vertical supports and ridge beams. On top of the rafters, the tertiary structure of the roof, consisting of bamboo strips, is laid, covered by the thatched roof, which is laid out from the eaves to the ridge. Aside from the entrance, the buildings have few openings. The entire house is constructed by the residents themselves. Depending on the number of helpers, a small two-room building can be constructed in two to three weeks with minimal costs.

The materials are mostly gathered and transported to the site by the residents themselves from the immediate surroundings. Earth and thatch are readily available on most plots and as side-products from the harvest, bamboo can be purchased from a landowner with bamboo groves for relatively low prices, only wood is rather expensive, unless

Figure 48: Bamboo as a temporary structure to support the construction of a more permanent structure made of reinforced concrete.





Figure 49: The *mistri*: A male building contractor skilled in working with fired bricks, reinforced concrete and cement plaster.

residents possess their own trees. Despite the addition of new materials such as plastic sheets, corrugated fiber-cement and metal sheets for roof covering, occasional replacement of bamboo supports with prefabricated concrete supports, and wooden doors, the materials and connections used in the few remaining houses made of earth, bamboo, wood, and thatch have changed little to the present day. They are, however, becoming increasingly rare as they are being replaced by buildings made of bricks, concrete, and steel. The use of earth, bamboo and thatch is concentrated in the few remaining residential buildings, whose inhabitants usually only see these materials as a temporary solution until they have saved up enough money for a building made of bricks and reinforced concrete.

While there are hardly any new uses for earth and thatch in their untreated conditions, bamboo is now often used in the Bahuarwa region for temporary structures, such as marquees or market stalls, as well as for scaffolding and formwork supports (Figure 48). The lightness and high load-

bearing capacity of the material make it easy to transport and quick to erect temporary structures. However, bamboo is used less for long-term use. As a result, the knowledge and craftsmanship involved in working with bamboo is gradually disappearing. Most younger residents in

Figure 50: Experts in working with regenerative building materials such as bamboo and earth lack formal recognition or titles.



Bahuarwa state that their parents or grandparents are still familiar with the use of bamboo and other regenerative materials, while they themselves no longer have the necessary skills to use them for construction purposes. Especially those who grew up in houses made of bricks and concrete retain hardly any connection to bamboo, earth, and thatch. In addition, young men are increasingly working in urban regions, where they earn more money, encounter new building materials and techniques, but lose touch with materials such as earth and bamboo (as described in the previous chapter).

Like the buildings, professional activities involving regenerative building materials also have a low social standing. There is no special occupational category for working with building materials such as earth, bamboo, or thatch in Bahuarwa. While people who know how to work with fired bricks, concrete and steel are referred to as *mistris*, and are treated with respect, people who specialize in working with bamboo, earth or thatch are referred to as laborers and are therefore no different from those who work under the *mistris*. Due to the low prestige of working with regenerative materials, especially earth, it is increasingly relegated to women (Figure 50), while the handling of non-renewable materials is reserved for men (Figure 49).

Conversation with the manager of CIBART in Gujarat, at his house (Field notes, Vyara, February 8, 2023).

Most people still associate bamboo with building methods of the poor, which belong to the past and have nothing to do with contemporary construction. They are unaware of bamboo's potential. Unfortunately, this ignorance is accompanied by a lack of respect for bamboo craftspeople. They are not just laborers, but artisans! This was one of the first measures I took when I started working for CIBART: I changed this term in all our documents.



The manager of CIBART has roots in a tribal community, which is why he underlines the importance of using regenerative building materials, not only to advance vernacular building methods, but to generate employment for members of tribal communities. CIBART employs women and men and respects both equally as artisans. As the working conditions of CIBART aligned with our approach, we decided to work together.

According to the bamboo experts of CIBART there is a growing demand for bamboo in the tourism sector and the production of interior furnishings and everyday objects. These are mainly indoor applications where the bamboo is protected from the weather. In some cases, there is also a demand for huts, bungalows, or pavilions, rarely for larger buildings (Figure 51). In most cases, customers are restaurant, hotel, or vacation homeowners who want a traditional village or eco look of their buildings. Thus, the use of

Figure 51: Prototype of a bamboo pavilion at the workshop of CIBART in Ukai, Gujarat.

bamboo is often limited to cladding surfaces, creating partitions and furnishings.

The bamboo experts interviewed have never worked on conventional residential or public buildings. Similar findings were made during a visit to a large national handicraft market in Delhi, where artisans from all Indian states exhibited their products. The exhibiting companies use bamboo almost exclusively to make everyday items such as bottles, lamps, toothbrushes, and furniture. As the manager of the CIBART in Gujarat puts it: “Bamboo has gone from being the wood of the poor to the pride of the rich.”

Although the interviewed bamboo experts of CIBART enjoy working with bamboo and are convinced of the versatile qualities of bamboo, they themselves live in houses made of brick and concrete. When they built their houses, they knew too little about how long a bamboo house could last. That was a time of experimentation, they emphasize, if they were to build their houses again today, they would rely more on bamboo.

4.3.3 Fired Materials – Brick Production

From the mid-20th century onward, the residents of Bahuarwa started to use fired bricks to construct their houses. Initially, their intention was mainly to replace the thatch coverings of the roof with a fire-resistant alternative, but later residents also used them to replace the erodible earth walls with more durable masonry. The process of firing raw clay led to a division of labor, which involved the profession and caste of pottery and brickmaking.

Members of the Kumhar caste built clamps on-site and had a local carpenter make molds. They extracted clay from local pits, transported it to the production site, and mixed it with water to create a moldable consistency. They then pressed the material into the molds, which they removed shortly after, letting the formed bricks dry in the sun. Before forming the next brick, they sprinkled sand inside the mold to prevent the sticky clay from adhering. After some days of drying in the sun, they stacked the air-dried bricks in the clamp and fired them during several days.

The fired roof tiles consisted of a half-pipe shape. The tiles were arranged in alternating positions to ensure a waterproof roof (Figure 52). The roofs were mainly hipped and pitched roofs with similar inclinations as previously common for the thatch coverings. Like the thatch, the roof tiles were laid from the eaves to the ridge, ensuring rainwater drainage through a continuous overlap of the layers. After some time, the firing process was also used to create bricks for the walls and plinths of the houses, which were previously made of bamboo and earth. While the bricks became waterproof through the firing process, the clay mortar was still washed out during intense rainfalls. Therefore, residents often tried to protect the masonry with a clay or lime plaster. The water-soluble clay plaster had two sides: on one hand, the water-soluble clay mortar required high maintenance

Figure 52: Traditional roof tiles complementing each other in alternating positions. The bigger tiles on the ridge are newer.





Figure 53: Brick kiln in Bahuarwa. The high chimneys are a characteristic feature in the landscape of the entire Gangetic Plains.

efforts, while on the other, it allowed for the reuse of the bricks. The necessary labor and time involved in the firing process, which could no longer be done independently, made masonry and roof tiles a more durable but also more expensive alternative, inaccessible for poorer households. During the British rule, large infrastructure projects such as the construction of railways and irrigation canals were initiated, which required an increase in quantity and quality of brick production (John, 2018, pp. 28–29). The traditional brick production in small clamps, built specifically for the respective construction site, was gradually replaced by permanent production sites and rationalized forms of

production. While members of the Kumhar caste had previously handled all the production steps for a brick, the mass production in the new brick “industries” was divided into individual steps (John, 2018, pp. 10–11). In the remote region of Bahuarwa, however, it was only towards the end of the 20th century that the small-scale firing of bricks, relying on temporarily erected clamps, was subsequently replaced by standardized, mass production in brick kilns. These production facilities, along with the closely linked construction sector, led to new jobs, and became important employers in rural parts of India, particularly in the Gangetic plains. India is estimated to be the second-largest brick producer in the world after China, accounting for about 10% of global production. Over 100,000 brick factories employ more than 15 million people (Lalchandani & Maithel, 2013,

Figure 54: Children living in the brick kiln in Bahuarwa, where they take care of their younger siblings or help their parents with the production of bricks instead of going to school.





Figure 55: Nandu's brick kiln in Bahuarwa from above: entry (1), manager's office and accommodation (2), workers' accommodation (3), coal preparation for brick firing (4), clay preparation, soaking in water, mixing with sand (5), moulding and air drying of raw bricks (6), firing of air-dried bricks in kiln (7), storage of fired bricks ready for sale (8).

p. 7). According to Lalchandani and Maithel (2013, p. 7) the largest share of production, or about 65%, is spread across the Indian states of Assam, Bihar, Haryana, Punjab, Uttar Pradesh, and West Bengal. A recently published study (Tibrewal et al., 2023, p. 1248) shows that the poorly documented activities of Indian brick production, which is more informally organized than the cement and steel industries, are severely underestimated in official calculations regarding emissions and energy use. According to the researchers, regionally-organized brick production requires an energy input of about 990 petajoules (PJ) for the annual production of an estimated 233 billion bricks, placing informal brick production between the energy inputs of the Indian cement industry (550 PJ) and the steel industry (1 400 PJ). According to the study, the energy requirement is met by 35 million tons of coal and 25 million tons of biomass (Tibrewal et al., 2023, pp. 1251–1253).

Brick kilns, with their tall chimneys, are a striking feature of the Bihar landscape (Figure 53). In the flat topography of Bihar, they can be seen from afar. At night, too, they stand out from their surroundings: numerous floodlights

illuminate the production area, contrasting with the sparsely-lit streets and villages. The brick kiln in Bahuarwa was built only a few years ago. According to the manager, about 100 people work at the kiln during the production season, which is the dry season from November to April. In the off season, there are only a few employees who take care of selling and transporting the bricks.

Although the brick kiln is in the outskirts of Bahuarwa, most of the workers come from further afield. According to the inhabitants of Bahuarwa, this is because the training and profession of a brickmaker is linked to a caste that does not exist in the village. However, investigations of brick kilns have also shown that a targeted system for exploiting the workers may be behind this (ASIVSJ, 2017). Payment according to the number of bricks produced and the great distance from home tempt workers to work in family units. Instead of going to school, the children stay at the brick kiln,

Figure 56: Man moulding bricks in “Nandu’s” brick kiln in Bahuarwa. The owner’s name is visible on every brick.



look after their younger siblings, and help their parents with the brick production at a young age (Figure 54). Although only men are officially employed in the brick kilns and although the handling of bricks on the construction site is reserved for the male mistris, women and children play a significant role in the production of this building material. As invisible laborers, they make up well over a third of the workforce (ASIVSJ, 2017, pp. 2–5).

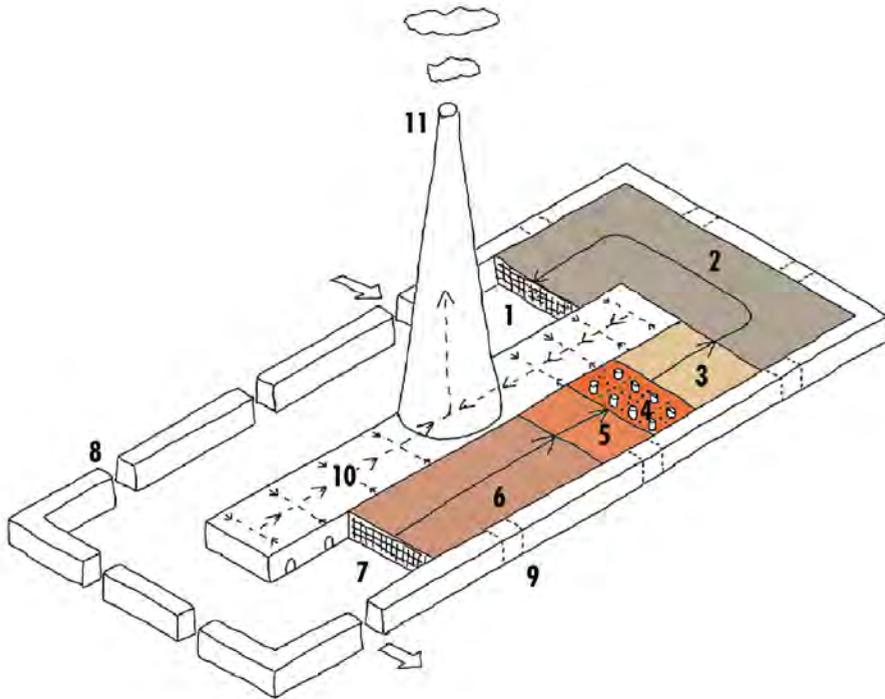
Figure 55 provides an overview of the brick kiln in Bahuarwa. Clay and sand form the raw materials for brick production. The clay comes from the immediate vicinity of Bahuarwa, the sand from riverbeds of the nearby rivers. The clay is extracted using excavators. Sometimes it can be found just below the surface, sometimes it must be dug one or two meters first to find the right composition. The clay is transported to the brick kiln on tractors. There it is heaved into a pit with an excavator and soaked in water for a night. The next day, the softened mass is mixed with sand from nearby riverbeds and then distributed on tractors in the production area, where it is shaped into individual bricks. As with the previous production of “home-made” bricks, a simple wooden mold is used (Figure 56). The clay is pressed into the mold, excess material is neatly removed, the mold is carefully inverted, the brick is removed, dry sand is thrown into the mold to prevent the clay from sticking and the mold is filled with clay again. In this labor-intensive process, one brick after another is formed. Each of them showing the name of the brick kiln owner, which is engraved in every mold.

The bricks are then loosely stacked and left to dry in the sun for several days before they are fired at a temperature of 800 to 1100°C in the kiln. They are carried into the kiln on wheelbarrows. The kiln runs around the central chimney as a channel about nine meters wide and three meters high (Figure 57). The rectangular circuit is about 30 meters wide and 120 meters long. The bricks are stacked at one end of the circuit in such a way as to form channels that allow the heat to distribute evenly and the firing materials to burn as completely as possible (Figure 58). The top layer of bricks is covered with an insulation layer of ash and brick dust to prevent heat from escaping.

The main fuel used is coal, which is fed into the kiln at regular intervals of 15-20 minutes through small openings on top of the stacked bricks. The fire moves along the circuit and burns continuously throughout the production season from November to April. The firing zone is about 12 meters long and moves about six to seven meters around the central chimney in 24 hours. Once the fire has moved on and the bricks have cooled, they are removed from the kiln and stacked for sale and transport. Approximately five million bricks are produced in Nandu's brick kiln in Bahuarwa during a production season.

The brick kiln in Bahuarwa uses the zig-zag method¹⁹, which requires less energy, produces fewer emissions, and results in a better brick quality than the older and more traditional

Figure 57: Functional diagram of a brick kiln with a fixed chimney: loading of air-dried bricks (1), "green" bricks (2), pre-heating zone (3), firing zone (4), soaking zone (5), cooling zone (6), unloading of fired bricks ready for sale (7), open wicket to load and unload bricks (8), closed wicket during firing process (9), ventilation shafts (10), central chimney to create air-draft (11).



¹⁹ The zig-zag method takes its name from the path of the air flow, which, due its zig-zag shape in new brick kilns, is about three times longer than in fixed chimney bull's trench kilns (FCBTK), where the air flows parallel to the circuit (Lalchandani & Maithel, 2013).



Figure 58: Sundried bricks stacked in systematic ways to ensure good air flow and even firing.

clamps and fixed chimney bull's trench kilns (FCBTK) (Lalchandani & Maithel, 2013, pp. 12–13). Surprisingly, poorly industrialized Bihar has the highest share (about 25%) of this newer production method, representing about 40% of the total number of zig-zag brick kilns in India (Tibrewal et al., 2023, p. 1251). The improved production capacity with reduced emissions is due, as the name suggests, to a change in the course of the air ducts from linear to zig-zag, which allows for a more even distribution of heat and better combustion of the fuels (Lalchandani & Maithel, 2013, p. 11).

According to the workers and the manager, one person can mold up to 1000 bricks in a day. For 1000 bricks the workers receive a wage of 600 INR²⁰. While this is higher than

²⁰ 600 INR = 6 CHF, considering an exchange rate of 0.01 (XE, 2024).

the usual wage of around 400 – 450 INR²¹ for unskilled workers in the construction sector, it often requires working as a family unit, working overtime, and away from home. There are several alarming findings from analyses of working conditions in brick kilns, ranging from inadequate housing and sanitation to child labor, long working hours, denial of wages, and debt bondage (ASIVSJ, 2017, pp. 2–5).

4.3.4 Cement and Steel – Incremental Building

Hand in hand with the construction of new brick kilns, the use of cement and reinforced concrete spread in the region of Bahuarwa. These new materials are no longer sourced from the immediate surroundings of the village and are more processed than their locally available regenerative predecessors. The higher load-bearing capacity of the materials allows for the construction of walkable flat roofs and multistory houses. Due to the increased weather resistance of the materials, it has become possible to construct the base, walls, ceiling, and roof from the same materials and over a longer period (Figure 59).

The new materials come along with new supply chains. Most of the sand used for building purposes in the region of Bahuarwa comes from riverbeds in Bihar. Sand from the Son River in the southern part of Bihar is particularly suitable for construction because of its low clay content (Narendra, 2023). According to our civil engineer, sand is also imported from the more distant Ennore in the state of Tamil Nadu for larger construction projects. Unlike regional river sand, the properties of Ennore sand and therefore its quality can be more precisely determined.

Due to their importance in the construction sector, sand and gravel are the second most consumed natural resources in the world in terms of volume after water. However, their extraction is largely unregulated (UNEP, 2019). Population growth, increasing urbanization, infrastructure development and changing consumption patterns are driving the construction sector and thus the demand for sand in India.

Figure 59: Incremental building process in the region of Bahuarwa: buildings are vertically extended as the needs and financial situation of the residents change.

²¹ 400 – 450 INR = 4.00 – 4.50 CHF, considering an exchange rate of 0.01 (XE, 2024).



Consequently, the former free commodity has become a taxable resource, for which the Indian government has introduced a set of guidelines in 2016 (Sustainable Sand Mining Management Guidelines, 2016). However, as legal extraction is unable to meet the rapidly growing demand in the construction sector, sand mafias are digging illegally for India's "new gold" (Bliss, 2017, p. 10).

Uncontrolled sand mining has serious consequences for nature and people in Bihar. Among the many consequences (Bhadbhade et al., 2020; Bliss, 2017; Narendra, 2023) is the impact on flooding, which in turn is linked to changes in construction practices. Sand mining in riverbeds leads to accelerated erosion of riverbanks, which results in an increased risk of flooding for adjacent fields and villages. This, in turn, poses a major threat to vernacular buildings with earthen bases, which drives their inhabitants to switch to brick, concrete and steel construction methods, further increasing the demand for sand.

Coarse aggregates for the use of concrete in Bahuarwa are usually sourced from the southern state of Jharkhand, in this case from the town of Pakur. With its rich mineral deposits, the state of Jharkhand is an important supplier of minerals and ores for India's construction sector. The steel used to reinforce concrete is also often sourced and processed in the states of Jharkhand or Odisha, further south.

Most of India's cement production, however, takes place in the southern states due to the large natural lime deposits there (Dasgupta & Das, 2021, p. 1377).

As with brick production, India is second only to China in steel and cement production. In contrast to sand mining and brick production, which are often informally organized and decentralized, India's steel and cement industries are mostly controlled by large corporations (Dasgupta & Das, 2021, pp. 1376–1377; Irfan et al., 2023). While brick production is spread over more than 100,000 brick kilns, the cement industry is concentrated in around 560 production sites (Dasgupta & Das, 2021, p. 1376). Like the processing of bricks, the production of cement (1450°C) and steel (1300°C) requires high temperatures, which contribute significantly to the high energy requirements and carbon emissions.

In addition, the extraction of raw materials such as limestone, ore and coal is energy-intensive, as it involves blasting and excavation. While residents had previously gathered earth, bamboo, and thatch in the immediate surrounding of Bahuarwa and built their homes themselves – poorer population segments still do this today – many now buy fired bricks from regional brick kilns and bags of cement and sand in stores of nearby towns and have their buildings constructed by local contractors and semi-professional construction workers. The higher degree of processing, the longer transport distances, and the increased division of labor lead to higher prices of these materials, further changing the construction process. While wealthier households can afford to build their entire house at once, in most cases the construction process happens in stages. Depending on the needs and financial means of the inhabitants it can extend over several years.

Despite no longer being self-built, new buildings are not professionally planned and built either. Only in exceptional cases is a civil engineer consulted in the planning of a residential house in Bahuarwa. The profession of an architect is unfamiliar to most residents. The planning is usually done by the residents themselves, with support from self-claimed building experts, the *mistris*. They are the local construction contractors who have usually learned their skills through work in cities.

After some unofficial apprenticeship years, they consider themselves capable of building houses from bricks, concrete, and steel. They then appoint themselves as *mistris* without the need for an examination. Upon receiving a contract, they gather a few willing labors. For their hiring, there is neither a contract nor insurance. Payment is made at irregular intervals, sometimes with significant delays. Once the work is completed, the *mistris* are on their own again, and the labors must look for other jobs. Dedicated labors use the experience they have gained to eventually take on independent jobs and achieve the status of *mistris* themselves.

Conversation with a male mason, aged 40–50 and his two sons, aged 20–30, at the building site of the school (Field notes, Bahuarwa, December 11, 2023).

At the age of fifteen, the mason left his village of Mahthaur, about seven kilometers south of Bahuarwa, and moved to Delhi to earn money. Together with a friend, he found work in construction. He learned about building materials and techniques that were not yet common in his village. After eleven years, he decided to return to Mahthaur to apply his knowledge there. He had now gained enough experience and to appoint himself mistri. He does not own any construction vehicles or heavy machinery. When he gets a job, he calls some willing helpers, packs his few tools into a suitcase and rides to the construction site on his motorcycle.

In the meantime, two of his sons have also attained the status of mistris. Having worked for several years under their father as well as for a construction company in the nearby city Darbhanga, they know the mixing ratios of concrete and mortar, how to lay bricks, reinforcement bars, concrete and plaster. That makes them mistris.

Unlike the techniques developed and passed down over generations for dealing with local and regenerative building materials, both the knowledge and technical abilities for proper handling of new building materials in the region of Bahuarwa are still limited. A large part of the work is done manually and is thus physically demanding. The equipment is usually limited to simple tools such as trowels, hammers, hand saws and buckets. Machines are rarely used. Building materials are delivered on tractors with trailers, in exceptional cases also by trucks. Excavation is usually done with shovels. Excavators are rarely used. Mortar and concrete are mixed by hand with trowels; for larger quantities, a small concrete mixer is temporarily hired, as only a few mistris possess their own concrete mixer. Cranes are nowhere to be found. Material transport on the construction site is done almost exclusively in a manual way.

The use of new building materials not only comes along with an increasing division of labor in the sourcing, processing, transportation, and application of building materials, but also results in gender segregation. Earth work in

particular is considered backward in Bahuarwa today, and is therefore relegated to women and girls, while the use of bricks, concrete and steel is reserved for men. A woman is therefore not considered a mistri, but merely a labor. The term mistri, or master, refers to the use of new materials to build a “proper” (pukka) house. No matter how well someone knows how to use bamboo and earth as building materials, this does not give them the status of a mistri.

4.3.5 Building Services and Furnishing

Just like the construction of houses, the furnishings and their manufacture have also changed. Until a few decades ago, furnishings were limited to but a few items. In the households of poorer families, this is still the case today. Apart from a fireplace, a bed, a small house temple, a shelf and a few pots and containers for storing rice and grain, there were not many other furnishings in the houses. As many activities were traditionally carried out in a crouching position on the floor, tables and chairs are rather new features.

Apart from the entrance, the small houses had hardly any openings, so that often only one door and neither windows nor shutters were required. The sanitary facilities were limited to a hand water pump. For many poorer households this is still the case today. Floors and walls received no further treatment apart from an insect-repellent plaster made of clay and cow dung. Wood and bamboo were used as fuel for the open fireplaces and oil or gas lamps as light sources. Until the electrification of Bahuarwa in 2000, the inhabitants had no electrical appliances. To cool buildings and food, they used the thermal properties of regenerative materials such as clay or straw.

Today, clay stoves are increasingly being replaced by gas stoves; instead of cooking on the floor, they do so in a standing position on a counter (Figure 60). In addition to the traditional bedstead with a wooden frame made of ropes and fabric straps, the inhabitants increasingly use mattresses. Wooden shelves and cupboards are often replaced with metal ones due to lower prices and termite resistance. The same applies to doors and windows, which are being used more widely in houses made of brick and concrete. Plastic tables and chairs are becoming more

common, too, even though people mainly eat sitting on the floor. Clay and bamboo pots and containers are still used to store cereals and rice thanks to their insulating and moisture-regulating properties.

Where the inhabitants can afford to do so, tiles are laid on the earth floors and reinforced concrete slabs and the brick walls are plastered and painted. In wealthier households, hand water pumps are supplemented with switchable motors. Most households do not have any sanitary facilities except for a hand water pump. Only few have a toilet with a septic tank since there is no sewage system. In addition to wood, gas is used for cooking. Nevertheless, open fires are still widespread. In the colder winter months, family members often gather in the evenings around an open fire in the courtyard. Since the electrification of Bahuarwa in 2000, the inhabitants use light bulbs and tube lights. Otherwise, electricity is mainly used to power ceiling fans, which are now widely used to counteract overheating in buildings

Figure 60: In this recently renovated house, the food is cooked on a gas stove on a counter instead of an open fire-place (chulah) on the floor, as is still common in many households in Bahuarwa. In addition, instead of a hand water pump, there is a sink and even a washing machine.



Figure 61: Ceiling fans are a characteristic feature and necessary equipment in houses made of fired bricks and reinforced concrete, which counteract the heat-storing properties of these materials. To provide the necessary space for the installation of ceiling fans rooms are built much higher which contributes to an increase of the material demand and costs.



made of fired bricks and reinforced concrete (Figure 61). The presence of larger appliances such as refrigerators, washing machines, televisions, computers or air conditioning systems remains an exception.

Conversation with a male carpenter, aged 50–60, at the building site (Field notes, Bahuarwa, December 13, 2023). Poorer residents are increasingly opting to use cheaper aluminum products instead of timber. For example, an aluminum door in the region of Bahuarwa currently costs around INR 4'500²², while a wooden door costs more than three

²² 4,500 INR = 45 CHF, considering an exchange rate of 0.01 (XE, 2024).

times as much and can even cost over INR 35'000²³, depending on the type of wood. Around half of the doors and windows that the carpenter installs are made of aluminum. Wooden doors and windows have become a luxury product. Wealthier customers in particular demand wooden products made from fine and expensive Johar and Sheesham wood. Around half of his customers come from the higher socio-economic classes, a quarter from the middle class and another quarter from poorer backgrounds. In the past, he often constructed roof structures, but today he concentrates on the manufacture of furniture, doors, and windows, as the roofs of new buildings are mostly made of reinforced concrete.

4.3.6 Conclusion

After analyzing the influence of the natural environment and social transformations on building materials and construction methods in Bahuarwa, this chapter focused on the technological changes and transforming building processes. Changes in the choice and availability of building materials, the use of new construction methods and the associated changes in production chains, division of labor and transportation distances were analyzed (Figure 62).

Until well into the 20th century, the building materials used in Bahuarwa came from the immediate surroundings and were only very lightly processed. Earth, bamboo, wood, and thatch were the most relevant building materials. The inhabitants built their houses themselves. This changed with the advent of brickmaking. Towards the end of the 20th century, there was a parallel and mutually dependent spread of brick kilns and cement. With the gradual availability of steel and cement, the first flat roofs made of reinforced concrete were built in Bahuarwa from 1980s on. The globally widespread method of building with reinforced cement concrete (RCC) has gradually become established in Bahuarwa as well.

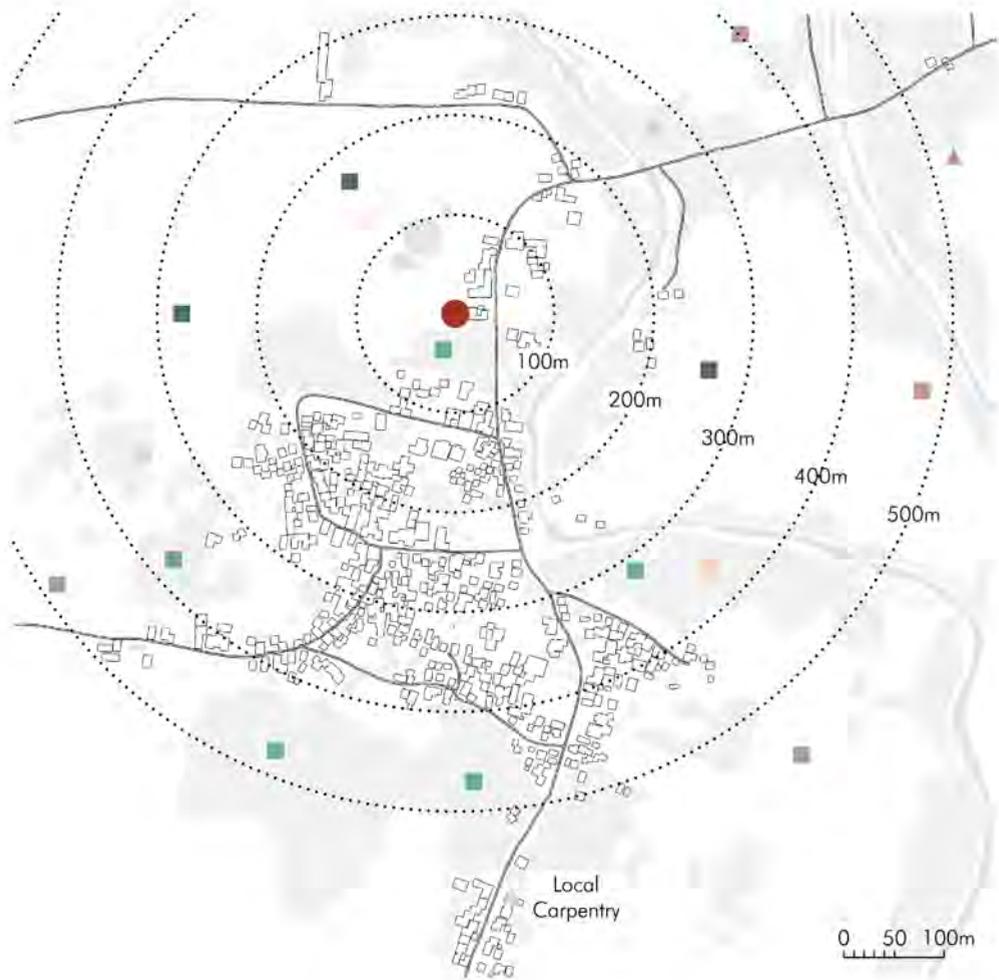
While bricks are produced decentrally in regional brick kilns, steel and cement are produced by internationally-active Indian companies. The new houses are no longer built by the residents, but by local, self-appointed building

²³ 35,000 INR = 350 CHF, considering an exchange rate of 0.01 (XE, 2024).

contractors who have acquired their knowledge through their work in cities. The construction process is carried out in incremental ways, depending on the size and structure of the family as well as its financial means. Whereas in the past the whole family contributed to building a house, women are excluded from working with fired bricks and reinforced concrete. They are mainly employed to work with earth, which equally illustrates the position of women and the status of earth as a building material.

The more widespread the use of reinforced concrete and bricks becomes, the more the knowledge of working with earth, bamboo or thatch is lost. While there is hardly any use for thatch and earth for construction purposes, bamboo is mainly used for temporary structures such as marquees, scaffolding or formwork supports. There is no contemporary use for treated bamboo in Bahuarwa. In general, treated bamboo in India is mainly used for furniture and everyday objects. Applications for structural purposes are mostly limited to the hospitality industry and tourist facilities. This raises the question of the extent to which knowledge, craftsmanship and infrastructure are still available for the integration of regenerative materials in the construction of the school, which will be described in the second part of the book.

Figure 62: Comparison of transport distances and production chains for a house made of regenerative and locally available materials and one made of fired bricks and reinforced concrete.



Locally sourced and manufactured building materials

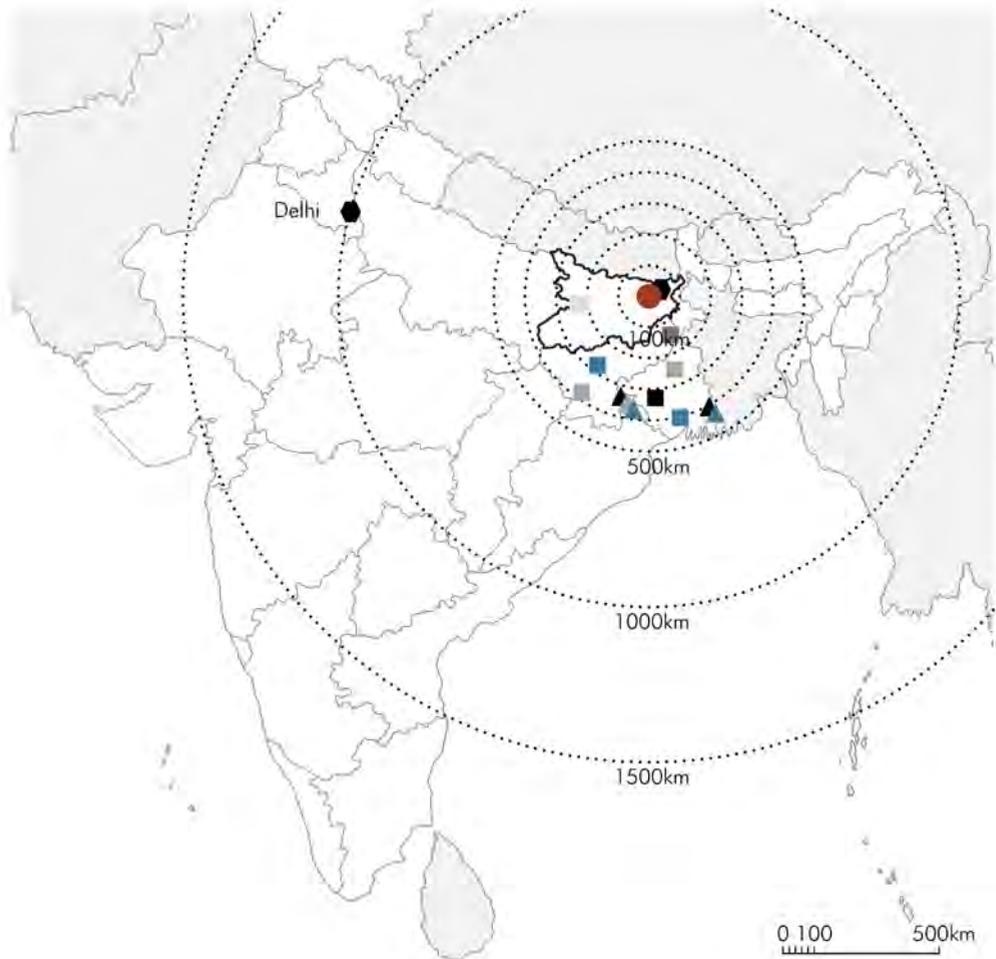
“Kutcha” house

- Material: bamboo, earth, thatch, timber
- Sourcing: local, walking distance
- Processing: local, in village, at building site
- Building time: few weeks
- Builders: extended family and friends
- Costs: 5'000 - 7'000 INR for one room house



Materials

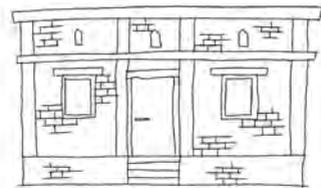
- | | | |
|--|--|--|
|  thatch |  fired bricks |  cement |
|  timber |  aluminum |  gravel |
|  bamboo |  steel | |
|  earth |  sand | |



Building materials sourced and manufactured outside the region of Bahuarwa

"Pukka" house

Material: fired bricks, cement, steel, sand, gravel
 Sourcing: regional to national
 Processing: regional to national
 Building time: several months up to years
 Builders: local contractors and workers
 Costs: 500'000 - 700'000 INR for one room house



Production Chains

- sourcing
- △ processing (& sale)
- sale
- Bahuarwa, school

“Integrating bamboo and earth is okay as long as the building is durable and looks like a pukka building.”

Inhabitant of Bahuarwa

5 Participatory Design Process: Between Raw and Fired

5.1 Planning Process

5.1.1 Introduction

The first part of this dissertation analyzed material transitions in relation to environmental challenges, socioeconomic transformations, and technological developments, outlining historical and incremental transformation processes. The focus of the work now shifts to how these findings can be utilized for the development of a hybrid solution combining vernacular and new building materials and methods, and testing the resulting conceptual approach by constructing a school building for underprivileged children in Bahuarwa.

The aim of this part is to examine whether it is possible, through the planning and implementation of a building, to liberate the widespread perception of a pukka house from the dependence of pukka materials. This includes the following research questions: (1) Is it possible to build a pukka house from kutchra materials?; and (2) Can a building primarily made of bamboo and earth achieve the same – or even exceed – the level of social acceptance of fired bricks, concrete, and steel? In addition to a better understanding of the social acceptance, the realization of the building is hypothesized to reveal the relevant legal frameworks, as well as the availability of materials, crafts, and industry related to these material choices, which are crucial for the application and eventual upscaling of the developed construction method.

First, I describe the negotiation of a hybrid solution for the building components of the foundation, the walls, and the roof. The subtitles indicate the confrontations of conflicting requirements, which cannot always result in an equal consideration of all relevant design factors. Before discussing the choice of building materials and methods for the individual building components, the given site, the required spatial program, the building volume and layout are then explained.

The building site is located to the north of the village center and is separated from it by a small bamboo forest (Figure 63). The plot of land, owned by the Bahuarwa Foundation to build the school, is around 12 meters wide and 30 meters long. It is located behind the house of the Kumar family, the founders of the Bahuarwa Foundation, so it is set back one building depth from the main road. The narrow eastern side of the plot borders the neighboring house; the other three sides border a small pond and a bamboo forest to the south, a field to the west, and an undeveloped plot to the north, which is currently used as a playground for the school. The temporary school that will eventually be replaced by the hybrid building venture is located on the neighboring property, which keeps the building site free and avoids having to interrupt school operations during the construction process.

To avoid a lengthy approval process with the local authorities, we decided that the new school would only be a single-story building, as no permit is required for single-story buildings, regardless of their floor area. The program was specified by the Bahuarwa Foundation and should include at least six classrooms, a staff room, multifunctional areas and two toilets.

It quickly became clear that developing the program as a single-story building leaves little room for anything else. There was therefore limited scope for positioning the building on the site and playing with its volume. The rough outline of the building was thus defined by these constraints.

Yet despite the simplicity of the program, the design of the floor plans underwent several iterations (Figure 64). We initially proposed a layout in which three classrooms of around 40 square meters alternated with two multifunctional rooms of a similar size. The project partner was pleased with the design, despite deviations from the initial program, as he recognized the potential of adding a partition wall to each of the three classrooms, creating six classrooms instead of three. He underlined that, for the operation of the school, he preferred a larger number of small classrooms over a smaller number of large classrooms.

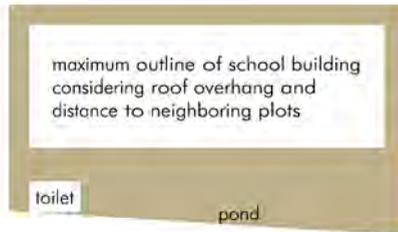
Figure 63: Situation of the proposed school in Bahuarwa.



0 50 100m

00 given framework

plot 475m²
6-7 classrooms
1 room for staff
multipurpose area(s)
separate toilet block
one storey building



01 design

3 classrooms, each with partition option
2 multipurpose rooms
2 separate toilets

> required adaptations:
smaller, but more rooms,
less multipurpose area



02 design

6 classrooms
1 staff room
1 multipurpose area with 2 partition options

> required adaptations:
ideally 7 classrooms,
but less multipurpose area



03 design

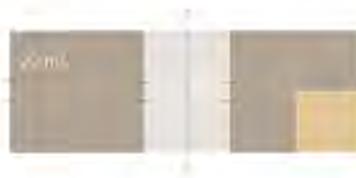
7 classrooms
1 staff room
2 entry areas

> required adaptations:
smaller classrooms, but
a large multi-purpose area



04 design (implemented)

7 classrooms
1 staff room
1 multipurpose hall



Room Program

- classrooms
- staff
- multipurpose

Figure 64: Development of the spatial organisation in coordination with the requirements of the Bahuarwa Foundation, the given site and the condition that the building should only be planned as a single storey.

In the next step, we designed a smaller layout with seven classrooms, a staff room, three small common rooms and two toilets. This layout seemed spatially appealing, but too small. We drew up another proposal in which the classrooms and the staff room were larger, and the common areas would be reduced to two small cloakrooms, in order to provide access to either four or three classrooms respectively.

In response to this proposal, the Bahuarwa Foundation expressed the wish to combine two cloakrooms, to create the largest possible multifunctional room. As a result, the classrooms could be made slightly smaller. This led to the final layout: two clusters of four rooms, each measuring 20 square meters, and a central multifunctional room of almost 60 square meters. Four of the rooms are accessed from the multifunctional room, and four from the east and west sides of the building (Figure 64).

The central hall provides access from the south and north sides, which means that the play space on the neighboring northern plot remains accessible, but the flexible entry situation from two sides can also respond to a future development of the plot. The simple and clear layout allows for a great deal of freedom in the choice of materials, as no particularly large spans need to be bridged.

This proposed layout also meets the requirements for earthquake-proof construction. Legal requirements mandate a compact and simple volumetry, a low building height, and a uniform layout with few wall offsets. A single-story building with a round or square floor plan comes closest to meeting these requirements.

The uniform layout also best meets the requirements for earthquake-proof walls. Openings should not be positioned at the corners of the building, as the horizontal loads intersect at corners in the event of an earthquake. Instead, the corners of the building should be reinforced with additional bracing. The openings are positioned along the north and south-facing longitudinal facades, in order to allow uniform natural lighting of the rooms, as well as to prevent intense direct light from the flat morning and evening sun. Windows and doors are positioned in such a way that the corners of the building remain free for additional bracing.

As the requirements of our partner organization and those for earthquake-proof construction largely coincide, we took this proposal as the basis for further detail planning. The following paragraphs describe the relevant factors for the choice of appropriate building materials and methods.

5.1.2 Relevant Design Factors for the Users

Based on the findings of the ethnographic analysis in the first part of this research, durability became a central design factor. Residents desire a building that can withstand natural conditions. In the case of Bahuarwa, this means special considerations for rainfall, flooding, and earthquakes, as well as insects. The wish for a durable house goes hand in hand with the wish for a building that requires low maintenance. Annual repair work after intense rains and floods requires time, which residents must take from agriculture or earning a living.

The use of regenerative materials should therefore not negatively affect the durability of the building and, consequently, its maintenance requirements. Based on the responses of the inhabitants, durability and minimized

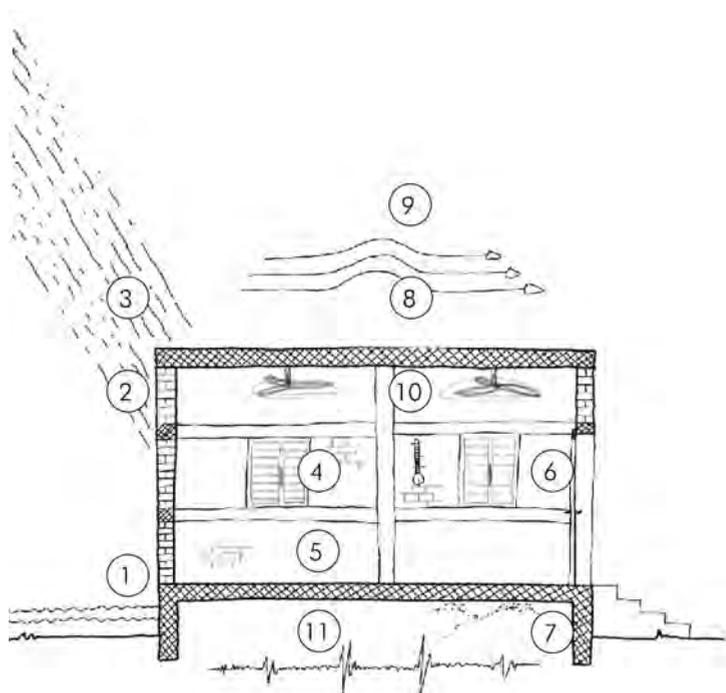


Figure 65: Evaluation of the kutcha house through the local community. Pros: wind-proof through hipped roof and buffering thatch (1), pleasant interior temperature through insulating and breathable roof and walls (2), earthquake-resistant due to low and compact shape, light-weight roof, and flexible bamboo structure (3). Cons: Erosion of earth foundation (4), erosion of earth walls (5), leaking thatch roof (6), dark interior (7), dusty floors (8), limited safety (9), insect infestation of bamboo & earth (10), fire-prone thatch roof (11).

maintenance of the building are those aspects most lacking in their vernacular buildings (Figure 65). Thus, they desire a durable house that they do not have to repair or even rebuild after each rainy season.

According to Bahuarwa's residents, thermal comfort is also a relevant design factor, although not as relevant as durability. Hence, higher summer temperatures in houses made of bricks and reinforced concrete, which heat up more due to the higher thermal storage capacity of the materials, are accepted in favor of better protection from fires, rain, and insects (Figure 66). Conversely, the disadvantages of a house made of earth and bamboo outweigh the advantages, such that better thermal comfort is not able to compensate for them. Thermal comfort is therefore welcome if it is not achieved at the expense of the durability of the building. Nevertheless, the aim of this dissertation is to achieve thermal comfort through design measures such as choice of materials, building orientation, and the positioning of the openings, rather than through technological measures such as air conditioning systems.

Figure 66: Evaluation of the pukka house through the local community. Pros: erosion proof foundation (1), erosion proof walls (2), waterproof roof (3), bright interior (4), maintenance-friendly floor (5), safe doors and window grilles (6), protection from insect infestation (7), fireproof (8), and wind-proof (9). Cons: dependence on air conditioners and fans for pleasant interior climate (10), conditional earthquake resistance depending on interlocking of bricks and concrete structure (11).



Residents desire the appearance of a “proper” house made of fired bricks and reinforced concrete to avoid the stigma associated with regenerative building materials. Thus, regenerative materials should be used in a way that does not negatively affect the social status of underprivileged people. Vernacular building methods are seen as outdated. The residents know them and want something new. Too much reliance on the expression of vernacular building methods therefore seems to make little sense when considering these factors. This also applies to the expression of regenerative materials such as earth, which is regularly painted by the residents to disguise its materiality.

The desire for a pukka house is reinforced by government housing programs, leading many residents to embark on the construction of their houses using bricks, concrete, and steel with the financial incentive from the state. This construction process usually occurs in stages depending on the residents' financial situation and often spans years or even decades. A more cost-effective, and therefore faster, implementation of the house would be desirable, especially for residents from poorer backgrounds. The use of regenerative materials should come with significant cost savings compared to conventional construction methods. The high cost of bricks, cement and steel compared to bamboo, earth and thatch cannot be afforded by the poorest segment of the population. If those are to have adequate homes, hybrid designs of vernacular and new construction methods are needed that can reduce costs using regenerative and locally available materials and provide opportunities for self-construction.

Another criterion that proves to be relevant out of the previous analysis of building transformations is the availability of building materials, and the skills required to process and apply them. Fired bricks, cement, and steel, along with the industries that produce these materials, are increasingly dominating the markets of remote regions such as Bahuarwa, too. As the use of locally available, regenerative building materials such as earth, bamboo, wood, and thatch are being displaced, the ability to process and use these materials is also being lost. Therefore, when developing a hybrid construction, it is also important to plan based

on available resources – materials as well as skills. However, the impact of “deskilling” and lacking infrastructure for the reintroduction of regenerative building materials and the development of a hybrid construction became most apparent during the implementation of the building itself. The final design factor derived from the first part of this dissertation is the vertical expandability of the buildings. This factor is a consequence of the changing family structures and demands for more interior space, typically answered by the capabilities of cement and steel otherwise. A house with a flat reinforced concrete roof can be extended vertically. In this case, the reinforced concrete slab first takes on the function of the roof and later becomes the floor of the next story. Especially for households living on small plots, the vertical expandability is a relevant advantage of building with bricks and reinforced concrete, which also contributes to a reduction in sealed surfaces.

However, this factor was of little importance for the planning and construction of the school, since the project partner wanted a single-story building that would not require a building permit, in contrast to a multi-story building. Nevertheless, this factor was considered when evaluating the building with residents and craftspeople, in order to gain insight for a possible upscaling and application of the developed construction method for residential buildings.

5.1.3 Base: Flood Resistant, Cool, or Clean

As described in the first section, Bahuarwa is in a zone highly vulnerable to flooding. Numerous rivers originate in the Himalayas and flow through the northern part of Bihar before joining the Ganges (Figure 17). During the monsoon season between July and September, floods can occur and cause significant damage to buildings with an earth base. In combination with intense rainfalls floods lead to an accelerated erosion of the earth bases and in individual cases to the subsequent collapse of walls or the entire building. The foundation is therefore a central component to ensure the durability of a building.

Earth erodes quickly, and cannot meet the requirements for a durable foundation without annual, time-consuming repairs. It is therefore advisable to search for possible

alternatives – at least for the outer, rain-exposed layer of the base. Stones would be a natural material of choice. However, there is almost no natural occurrence of stones throughout Bihar. The sediment in the rivers has eroded into fine sand when it reaches Bihar. Consequently, there is a lack of knowledge in stone craftsmanship. Missing knowledge and long transport distances of a relatively heavy building material are obvious reasons to avoid the use of stones for the foundation.

Another option would be to place the building on bamboo supports and thus lift it off the ground. During a flood, only the supports would stand in water. This solution is traditionally used, among other places, in the Indian state of Assam (Figure 12). Contemporary architects such as Marina Tabassum (2020) from Bangladesh have further developed such solutions and added new bamboo connections. These are particularly suitable for smaller, temporary buildings that are characterized by flexibility and lightness and allow for fast replacement of the more sensitive bamboo components. For larger, permanent structures this concept is less suitable because of the higher weight that must be distributed among a few supports and the difficulty of replacing bamboo supports, which must be done regularly due to moisture and ground contact. Most importantly, however, Bahuarwa is in the most earthquake-prone zone, which means that elevating the building would at best be an advantage in the event of flooding, but would be a disadvantage in the event of earthquakes. Seismic design requires a good connection to the ground and a concentration of heavy components near the ground, which would be counteracted by an elevation of the building.

Considering the local availability of materials, the use of fired bricks is a viable option. Made from local clay and fired in the village brick kiln, this material requires minimal transport. The firing process does, however, produce higher carbon emissions and has ethical implications, as also described in the first part of this dissertation. At the same time, it is accepted by the residents as a common and progressive building material. In discussion with the residents and the future operator of the school, it became clear that the use of fired bricks in combination with cement mortar and

reinforced concrete was the most viable and practical solution to build the foundation of the school. The other proposed materials raised doubts regarding durability and maintenance. The residents have had too many bad experiences with earth and bamboo in relation to rain, floods, and earthquakes. Brick and concrete have proven to be more resistant, and architecturally, the benefits of utilizing these “less sustainable” materials outweighed the costs.

The next question concerns the height of the foundation and the materiality of the floor. The first is defined by determining the maximum water levels based on the residents’ experiences. The materiality of the floor proves to be a more controversial point of discussion, where the design factors of thermal comfort and maintenance collide. Regarding improved thermal comfort, a compacted earth floor would be a suitable solution. These are traditionally plastered with cow dung, which leads to higher strength and protection from insects. In the discussion with the future operator of the school, and after observing daily practices in Bahuarwa over several days, it turns out that an earth floor offers advantages regarding thermal comfort but comes along with disadvantages regarding maintenance: it must be renewed regularly, is difficult to clean, and does not provide adequate protection against termites. A floor made of fired bricks, a thin unreinforced concrete layer and a cement coating in turn, is easy to clean and protects the interior from termites. A reduced thermal comfort is accepted for these qualities.

5.1.4 Walls: Fired Look, Raw Core

Provided that the foundation permanently protects the walls from flooding and ground moisture, and that the roof is watertight and has a wide overhang, the walls offer the greatest potential to integrate regenerative materials. Interior walls are particularly suitable for the use of earth or bamboo, as they are well protected from moisture and rain. More caution is needed with exterior walls: despite the wide roof overhang, the lower part of the walls often remains exposed to rain. Especially during the frequent monsoon winds, a wider roof overhang only offers limited protection against rainfall. For this reason, the opinions of future users and operators

regarding the use of bamboo and earth for the exterior walls were critical. They were, again, in favor of using fired bricks in combination with reinforced concrete. This conventional and now widely used construction has proven to be durable in their experience, although not ideal for the indoor climate.

The goal was to develop an alternative construction method that allows for the use of regenerative building materials – albeit in a limited extent – without neglecting the acceptance of the target groups. One possibility of doing so is orienting towards the existing building traditions when developing a hybrid solution. This has the advantage that residents do not have to acquire many new skills and thus can take on a significant portion of the work themselves. However, there is also a risk that such a strategy may lack innovation and therefore not be accepted by the residents. After numerous discussions with village residents, it was decided that the skepticism towards bamboo as a construction material was significantly lower than towards earth.

However, as bamboo needs to be protected from water, the use for exterior walls without further protective layers would not lead to a durable solution. This raised the question of whether bamboo should only be used for protected interior walls and the less exposed load-bearing structure of the roof, while the exterior walls should be built with fired bricks and reinforced concrete. This would offer a durable solution that corresponds to the aspirations of the residents who want a building that looks contemporary, or at least different from the earth house they know.

After further research (Kaminski, Lawrence, Coates, & Foulkes, 2016; Kaminski, Lawrence, & Trujillo, 2016) and discussions with bamboo experts (Bamboo House India; Centre for Indian Bamboo Resource and Technology; Thumbimpressions) in India, we decided that instead of the entire exterior wall, only the “skin” of it needs to be built in a waterproof manner. Bamboo slits in combination with a cement plaster provide sufficient protection for the load-bearing structure of bamboo. This method also has a lot in common with the vernacular building methods in Bahuarwa. However, the decisive argument for the future operator of the school and other interviewed residents is that

the building is protected from rain and at the same time receives a contemporary expression. The protected interior walls, in turn, do not affect the appearance of the building and can be constructed with bamboo, earth, and thatch. Referring to the design factors mentioned, the exterior walls are determined by durability and aspiration, while the interior walls ensure thermal comfort and a more cost-effective construction.

The school operators were open to suggestions regarding the materials for the doors and window shutters. Both wood and metal are suitable for them, as both materials meet their expectations for the materiality of a contemporary building.

Their only requirement was that it should not be possible to break into the school. Finally, we decided to use local Jamun wood, which can be obtained and processed by carpenters in Bahuarwa. While this does not reduce costs compared to the use of aluminum, it does increase the integration of regenerative materials. In addition, the regional economy is supported and durability is not negatively affected due to the protective roof and foundations. Figure 67 reflects the design process through sketches.

Group discussion with around 20 Dalits, mainly women and children, mixed age groups, in “Kathbe Toli” (Field notes, Bahuarwa, February 2, 2023).

During the home visits and meetings with residents and future operators of the school, they are shown pictures of different buildings, each based on a different type of construction. They can choose which of the buildings shown they would prefer to live in. Surprisingly, two contrasting construction methods meet with the greatest approval from the residents. A building made almost entirely of bamboo receives the most votes, closely followed by a plastered building made of bricks and reinforced concrete. In contrast, the buildings shown made of earth are met with more disapproval.

5.1.5 Roof: Waterproof but Hot

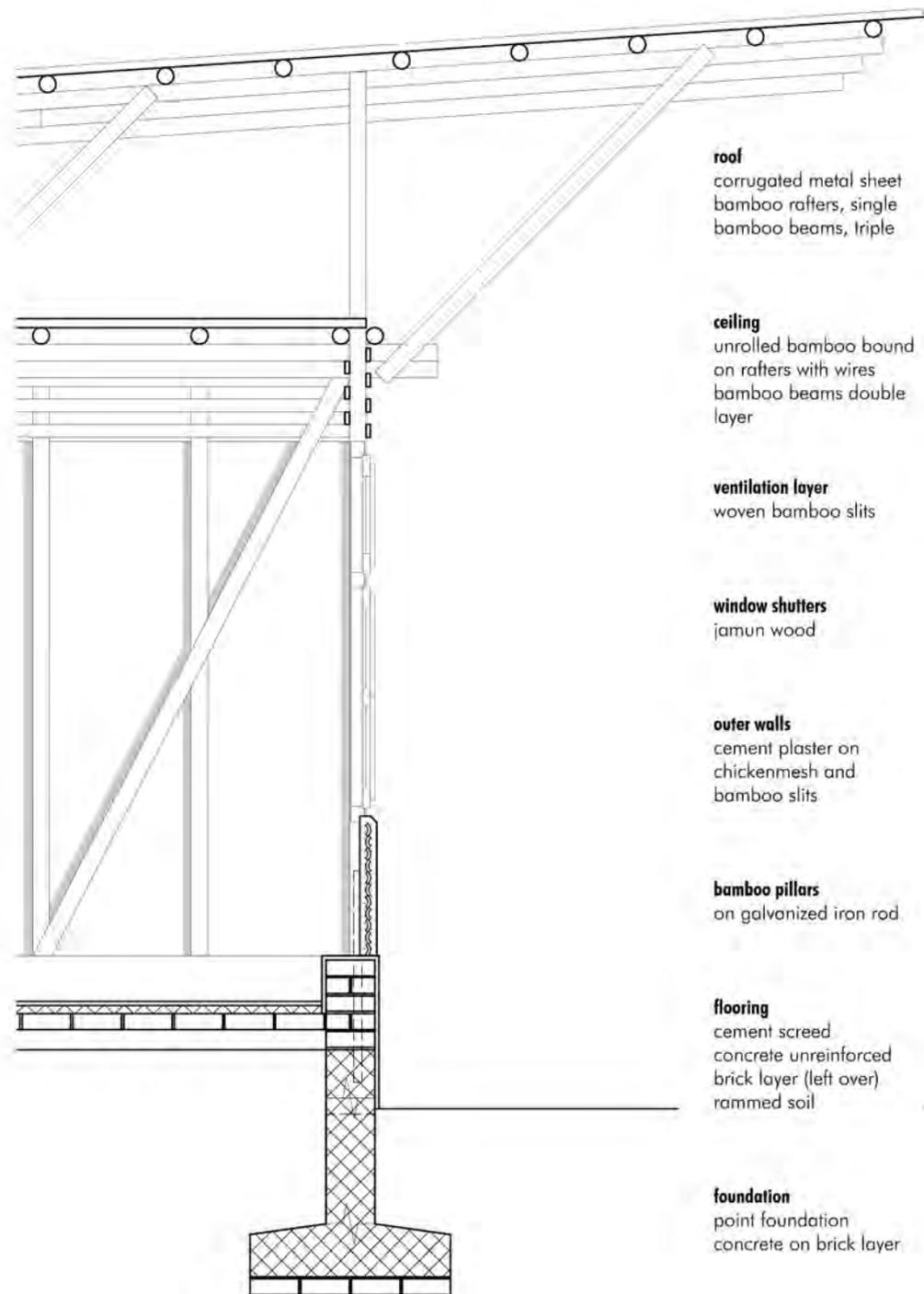
The vernacular use of thatch offers adequate insulation from the heat, but it is often insufficient in protecting the inhabitants from intense rainfalls, and can quickly spread fire from the open fireplaces in courtyards. To ensure waterproofing, the roof angle of thatch roofs must be steep, and the thatch must consist of several layers. Only then can the water be drained fast enough, and prevented from entering the interior. Moreover, the roof needs to be repaired yearly, and replaced every few years. Some inhabitants install plastic sheets on the thatch roof to improve the waterproofing. However, the high maintenance efforts remain. A change in the choice of materials seems inevitable, given the maintenance should be reduced and the durability prolonged.

In the case of the roof, too, stones like slate would offer a durable alternative, but they are not part of the regional building traditions for good reason, as they do not occur naturally. Reinforced concrete slabs, corrugated fiber cement or metal sheets, and fired roof tiles are common solutions for the roofs of buildings in Bahuarwa. The load-bearing structure is either made of bamboo, timber, or reinforced concrete.

Due to the abundant availability, low costs, and environmental friendliness, bamboo was considered a suitable material for the roof structure. The choice of the roofing material is, however, less obvious. The use of corrugated metal sheets allows for low roof angles, whereas the use of roof tiles requires steeper ones. The thin and light metal sheets are also more earthquake-resistant than the heavier brick tiles (Prion, 2001). Regarding the thermal properties in turn, roof tiles offer a better protection from the heat and condensation is less likely to occur. Furthermore, the roof tiles have a lower environmental impact than the corrugated metal sheets (KBOB et al., 2022).

Finally, we decided to use corrugated metal. This fulfills the requirements for durability, waterproofing, and earthquake resistance better than the alternatives. However, it is necessary to develop constructive measures that counteract the heat radiation and condensation. To achieve this, the mono-pitched roof is raised, and an additional ceiling level

Figure 67: Collage of sketches from the design process.



roof
 corrugated metal sheet
 bamboo rafters, single
 bamboo beams, triple

ceiling
 unrolled bamboo bound
 on rafters with wires
 bamboo beams double
 layer

ventilation layer
 woven bamboo slits

window shutters
 jamun wood

outer walls
 cement plaster on
 chickenmesh and
 bamboo slits

bamboo pillars
 on galvanized iron rod

flooring
 cement screed
 concrete unreinforced
 brick layer (left over)
 rammed soil

foundation
 point foundation
 concrete on brick layer

Figure 68: Detail section showing the different building parts and their materiality.

ing and the roof is not enclosed by walls and therefore well ventilated. This should prevent a buildup of radiated heat during sunny hours. Additionally, heat transmission is reduced by the increased distance from the roof to the interior spaces and by the bamboo ceiling, which absorbs some of the heat and reflects some back into the ventilated space. Furthermore, the ceiling catches occasional water drops that occur during the morning hours of the winter months when the warm air condenses on the cooled roof. Lastly, it provides a more attractive underside than the corrugated metal sheet, thus also having a positive visual impact on the room atmosphere. Figure 68 provides an overview of the material choice for different building parts and the ways they are connected. A set of plans well as the degree to which the design requirements were taken into account, are shown in Figure 69.

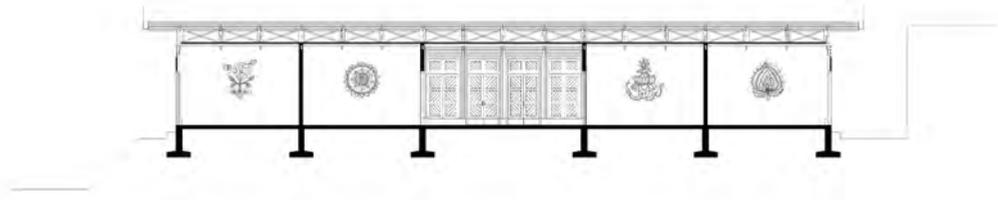
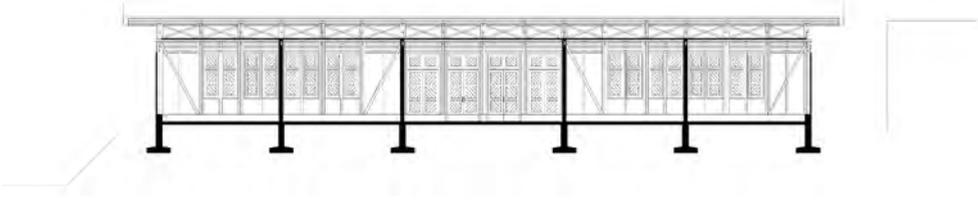
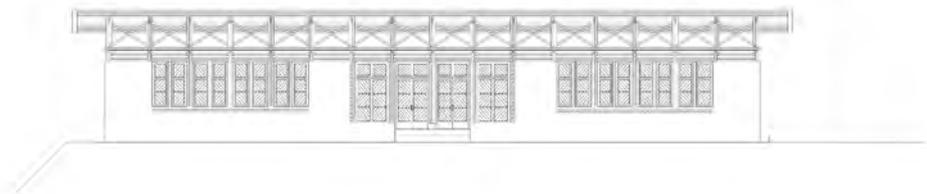
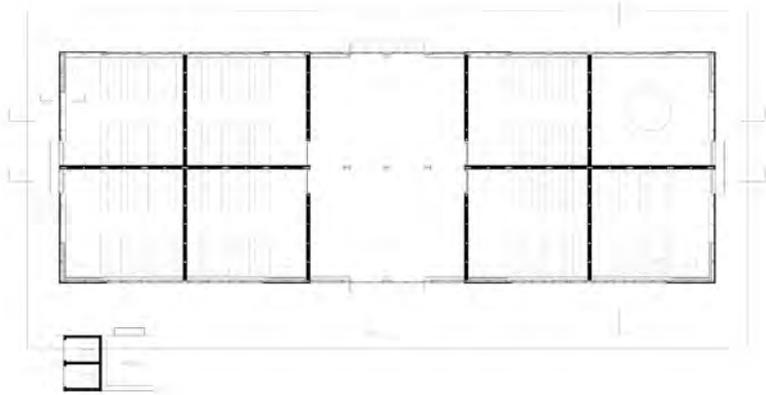
5.1.6 Conclusion

The design factors described in this chapter are derived from the ethnographic analysis of Bahuarwa's building transformations in the first part of the book. They encompass those concerns that are most emphasized in the daily observations and conversations with residents and craftspeople regarding the integration of regenerative building materials in the hybrid construction of the school.

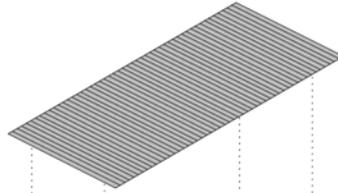
The integration of regenerative building materials should result in a building that is durable and requires little maintenance. It must meet the residents' increasing demands for interior and private space. Its expression must not stigmatize the users. Furthermore, it should be affordable and implementable with the available infrastructure and little training. The thermal comfort of the building is not the first priority, but should also be considered, provided that this has no negative consequences for the other requirements. If the integration of regenerative building materials has a largely positive impact on these requirements, it is welcome.

The relevance of expandability is less relevant for the construction of the school than for the residential buildings analyzed and remains of secondary importance in the planning.

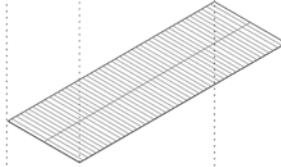
Figure 69 (following double page): Floorplan, south elevation, longitudinal sections and axonometric view with different building parts and materials of the school.



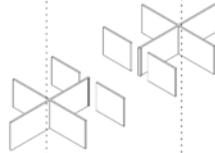
roofing
corrugated metal sheets



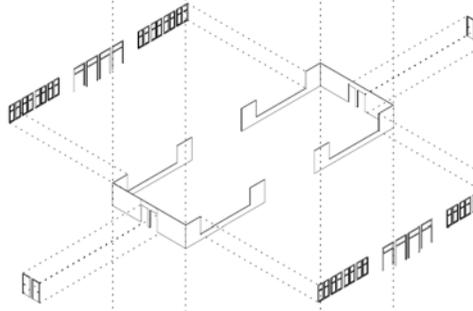
ceiling
bamboo



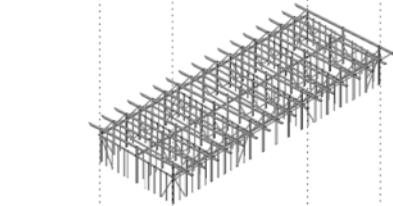
inner walls
earth, bamboo, thatch



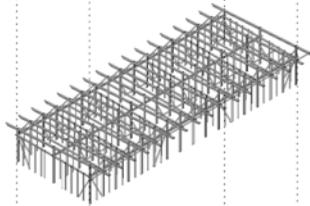
windows and doors
jamun wood



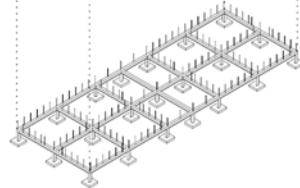
outer walls
blue paint, cement, chickenmesh, bamboo slits



structure walls, ceiling and roof
bamboo poles

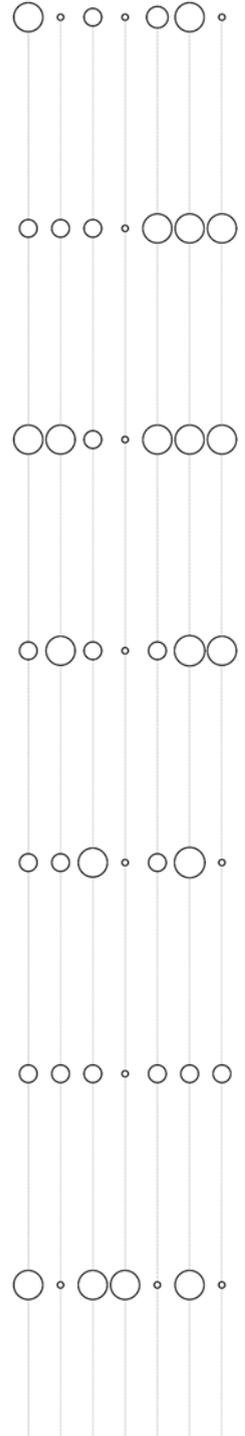


foundation, floor and plinth
reinforced concrete and fired bricks, cement plaster



Relevance/Fulfillment of Design Factor

- high
- middle
- low



durability
thermal comfort
aspiration
expandability
affordability
availability
regenerability

5.2 Building Process

5.2.1 Introduction

After determining appropriate building materials and methods in the previous chapter, the technical details used in the construction of the school are described in what follows. The construction details are not entirely new. They have been applied in similar ways and some of them are well documented (Kaminski, Lawrence, & Trujillo, 2016). The novelty lies more in their combination with vernacular constructions and materials, as well as in their application in the context of Bahuarwa. The following explanations aim to enable others to learn from, improve upon, and further develop this hybrid solution of vernacular and new construction methods and materials. It provides a more sustainable alternative to the increasingly-used construction methods of fired bricks, concrete, and steel, which still meets the needs of building occupants, makes use of local resources and techniques, create affordable housing, promotes regional value creation, and better protects the environment. The proposal described here should not be seen as a solution that can be copy-pasted for other contexts. The relevant design factors must always be determined and evaluated against each other in any location under consideration.

Except for three bamboo specialists from CIBART in Gujarat, all people involved in the construction come from Bahuarwa and the surrounding villages. Many of them are parents or grandparents of the children now attending the school and thus belong to underprivileged groups, most of whom are Dalits or members of tribal communities. Care was taken to include as many interested residents as possible in the building process. Most participants were men; however, wherever possible – particularly in tasks involving earth – we also engaged women. All workers were compensated according to locally customary wages and were free to arrange their working days flexibly according to their availability. No overtime was expected. Occasionally, small meals were provided on site, and at the end of the project, a bonus was given to those who contributed to the construction for more than one week. In addition to monetary

Figure 70: Bricks laid out as a base for the reinforced concrete ring anchor.

compensation, participants also gained insight to bamboo construction techniques.

5.2.2 Foundation

To protect the building and the immediate surroundings from flooding, the site is elevated with soil from a local pit by around half a meter. Backfilling is carried out more than a year before the start of construction, so the ground can settle well during two rainy seasons. This prevents the soil from settling later. The backfill means that the brick and reinforced concrete base can be lower and costs can be saved.

The building sits on 18 reinforced concrete point foundations, each located at the intersections of the walls and extending 1.2 meters deep into the ground. A loosely-laid





layer of bricks serves as a base under the one-by-one meter foundation feet. The point foundations are connected to each other using a reinforced concrete ring anchor. Like the supports of the foundations, the ring anchor has a cross-section of around 25 x 25 cm and is at the level of the ground. The levelling is carried out using a cord frame and the base is again formed by a layer of bricks (Figure 70). To connect the bamboo supports to the foundation, galvanized iron pipes with a diameter of 40 millimeters and a length of 1.1 meters, surrounded by reinforcing steel bars, are connected to the reinforcement of the ring beam. The pipes are aligned vertically with a plumb line. Before installation, the pipes are drilled at the top end with two holes at right angles to each other with a diameter of eight millimeters at a distance of ten centimeters. These serve for the

Figure 71: Gaps between galvanized iron pipes are filled with bricks that act as a lost formwork for the concrete around the pipes.

Figure 72: Brick layer on rammed ground as a base for a thin unreinforced concrete layer of five to six centimetres and a fine layer of cement.

subsequent connection to the bamboo supports. As the pipes can still move a little in the reinforcement, they are checked again for vertical alignment during concreting and realigned if necessary.



According to the bamboo experts, the bamboo supports can also be integrated directly into a concrete foundation, protected with a layer of bitumen. This would save 165 meters of iron pipes and many hours of installation time. However, we decided against this, as the bamboo supports set in concrete cannot be replaced later and are at greater risk of rotting if water collects in the foundation.

The sections between the galvanized iron pipes are lined with a double layer of brickwork and the area around the iron pipes is then filled with concrete (Figure 71). Consequently, a formwork of wooden boards is only required on two sides. Acting as lost formwork, the masonry interlocked well with the concrete. The plinth, which is five layers of bricks high, is then plastered with cement and sand. For this purpose, the cement is mixed with finely sieved river sand in water in a ratio of 1:4. Before the plaster is applied, the masonry is pre-wetted well and after application, the plaster is wetted twice a day for about one week to allow it to harden better.

The floor is not laid until after the shell is completed to prevent damage during the construction process and to allow the additional layer of soil to set well. To ensure that the soil settles well, it is soaked with water for several days. It is then rammed and covered with a layer of bricks (Figure 72). These are rammed again before a layer of unreinforced concrete around five to six centimeters thick is poured and covered with a fine layer of cement to provide a level, robust and easy-to-clean floor for the school.

Apart from the connecting detail of the galvanized iron pipes, the construction of the foundation, plinth and floor corresponds to a conventional construction method using fired bricks and reinforced concrete, as it is increasingly used in the Bahuarwa region. The local construction workers are familiar with the requirements and are able to complete the work well within a period of just under two months. However, the precise execution of the connection detail of the plinth and bamboo structure using galvanized iron pipes is time-consuming as it is unfamiliar to the local construction workers.

Figure 73: Pressure vessel at CIBART's workshop in Ukai, Gujarat, to treat the bamboo.

5.2.3 Structure

The design of the supporting structure and its infill offers the greatest scope for using regenerative materials. Following the recommendations of CIBART, the bamboo used is treated in a pressure vessel with a chrome-copper-borax compound (CCB), which protects the bamboo from insect infestation and fixes the treatment agent in the bamboo (Figure 73). The treatment is executed by CIBART employees in Vyara, Gujarat. Before treatment in the pressure vessel, all internodes of a bamboo are provided with two holes of three millimeters diameter, one at both ends, so that the treatment liquid can penetrate the whole bamboo from inside and outside. The bamboo poles are then stacked in the pressure vessel. By creating a vacuum of approximately 1 kg/cm², the treatment liquid is sucked into the pressure vessel. The liquid has a concentration of around four to eight percent. A pressure of around 8.5 kg/cm² is then generated, which opens the capillaries of the bamboo and allows the treatment liquid to penetrate the bamboo. After a treatment time of at least one hour, the treatment liquid is drawn



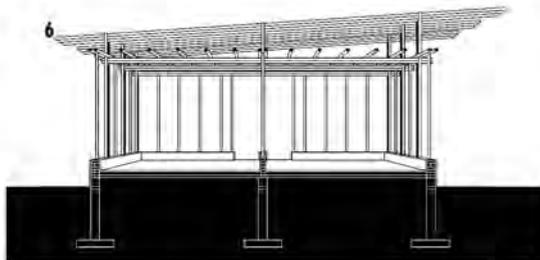
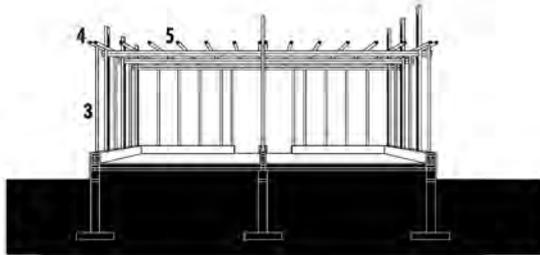
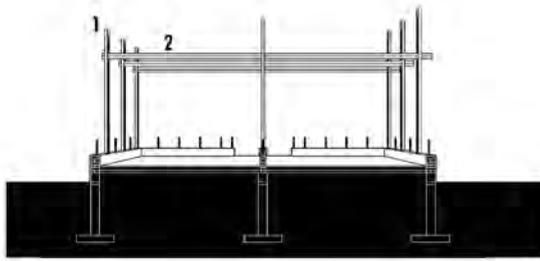
off again using a vacuum again. The bamboo poles are removed and stored in the shade to dry. A more detailed explanation of the treatment options for bamboo goes beyond the scope of this dissertation, which is why reference is made here to other works (Gauss, 2020, pp. 62–76; Kaminski, Lawrence, & Trujillo, 2016, pp. 28–30; Scharfenberg et al., 2021; Stamm & Vahanvati, 2018, pp. 8–14). The nearly 1,500 required bamboo poles are then delivered to Bahuarwa by two trucks. All columns, ceiling and roof beams are assembled on site during the construction of the foundation. For this purpose, the treated bamboo poles are first sorted according to their diameter and shape:

(1) Large diameter and straight shape: used for primary triple supports, ceiling and roof beams, secondary supports for exterior walls for straight window stops, bracing in building corners. (2) Large diameter, fairly straight shape: used for secondary supports for interior walls, ring beams. (3) Smaller diameter and straight: used for ceiling and roof rafters. (4) Small and large diameter, slightly damaged or bent: Use as battens or unrolled for infill walls and ceilings.

The supporting structure consists of three rows of columns along the length of the building. The distance between the three rows of columns is 4.5 meters. The primary supports made of three bamboo poles are positioned at a regular distance of 1.6 meters from each other. Between each of them is a secondary bamboo support, which consists of one bamboo pole and serves as a supporting structure for the infill walls and the installation of the windows. The secondary supports also form the cross walls at a distance of 75 centimeters.

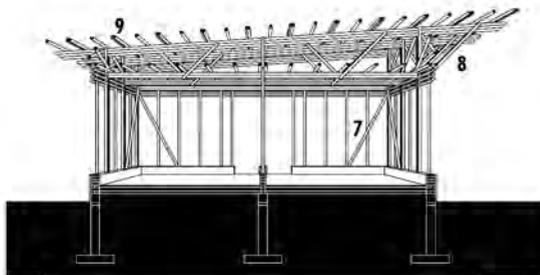
The bamboo poles are connected using threaded rods with 8mm nuts and washers. In CIBART's experience, it is important to ensure that the connecting parts are made of galvanized or even stainless steel, otherwise they will begin to corrode due to the copper-based preservative. The bamboo poles are pre-drilled and then joined together. Care is taken to ensure that the bamboo is not drilled through at the nodes, as these contribute significantly to the stability of the bamboo. Figure 74 illustrates the components of the bamboo structure described in the following paragraphs.

Figure 74: Cross section showing the components of the bamboo structure.



Bamboo Structure

1. primary columns (triple)
2. ceiling beams (double)
3. secondary columns (single)
4. ring beam
5. ceiling rafters
6. roof beams (triple)
7. bracing walls
8. bracing roof
9. roof rafters



The primary supports are each made up of three bamboo poles with a diameter of seven to eight centimeters. The ceiling and roof beams, which are made up of two and three layers of bamboo respectively, rest on the middle bamboo pole of the primary columns. The bamboo poles are 5.0 to 5.5 meters long due to the dimensions of the pressure vessel but also due to the changing diameter along the length of a bamboo pole. If building elements exceed this length, they are extended in combination with other bamboo poles. The greater the distance of the beam to be bridged, the more bamboo poles must be stacked to reduce movements of the beams as much as possible when forces are applied (Figure 75).

Alternatively, the beams can also be designed as trusses to bridge longer distances (Figure 76). This is particularly suitable for bamboo with a smaller diameter, as we tested it prior to the construction together with the craftspeople from CIBART. Compared to a stacked beam, a truss is structurally more efficient and requires less bamboo. On the other hand, it requires more time and knowledge to produce the numerous connections, which makes it more difficult for the local population to adopt. In addition, bamboo with a smaller diameter does not exist in Bahuarwa. For these

Figure 75 (left): Stacking of bamboo with a bigger diameter.

Figure 76 (right): Truss with smaller diameter bamboo.





Figure 77: Bamboo structure with primary and secondary columns. The primary columns support the double layered ceiling beams. The line of alternating primary and secondary columns is connected with bamboo poles on both sides.

reasons and the short distances of 4.5 meters between the supporting columns, we opt for the stacking technique. After being assembled on site, the 51 primary triple columns are positioned on the iron pipes and connected through threaded rods in the pre-drilled holes. This requires precise measurement of the holes in the bamboo supports, as the holes in the iron rods are no longer visible once the bamboo supports are positioned. In the next step, the two-layer, 9.6-metre-long ceiling beams are installed, connecting three supports to form a frame. The 17 frames are then connected with individual bamboo poles along both sides of the column rows. The secondary columns are positioned between the main columns and along the transverse walls. The ceiling rafters are then laid (Figure 77). These provide a good base for the workers to lift and install the three-layer, 13-meter-long roof beams. Finally, the roof rafters and bracing is installed between the ceiling and roof, under the canopy and in the corners of the building. Three experts from CIBART and three local helpers build and erect the bamboo structure in less than two months.

5.2.4 Walls and Openings

The load-bearing structure must be defined prior to the start of construction to consider the connection of the vertical supports during the construction of the base. The construction of the wall infills, however, is developed during the construction process on the basis of four 1:1 test variants (Table 4). The first “local variant” is based on the existing wall constructions of vernacular residential houses and consisted of half bamboo poles, bamboo strips, and flattened unrolled bamboo, which complemented each other in a distinct hierarchy (Figure 80). The second “fine wattle” consists of a combination of two types of bamboo with different diameters and bamboo strips. The bamboo strips are woven around the thinner bamboo canes, which in turn are clamped between two thicker bamboo canes like a ladder (Figure 79). The third “horizontal strips” option consists of horizontal bamboo strips pressed against the supporting bamboo poles by vertical strips (Figure 80).

	Local Variant	Fine Wattle	Horizontal Strips	Coarse Wattle
Stability	*	***	**	****
Building Time	*	**	****	**
Availability	****	*	**	****
Affordability	****	***	***	****
Earth Infill	**	****	**	****
Cement Plaster	*	**	****	*
Aspiration	*	***	***	***

While comparing the first three options, we came across a fourth option. Instead of creating a secondary structure for the wattle that we could place between or along the supports of the load-bearing structure, the bamboo experts suggested that we use the supporting structure directly as a base for the wattle. Therefore, the bamboo strips were woven directly around the load-bearing supports without any further substructure (Figure 81). Thus, the fourth “coarse wattle” variant is a simplification of the fine wattle.

Table 4: Comparison of the four wall variants in terms of (1) stability, (2) required building time, (3) availability of required tools, materials and expertise, (4) affordability, suitability for (5) earth infill or (6) cement plaster, as well as (7) aspiration regarding the expression. Rated as bad (*), medium (**), good (***) and very good (****) by the experts, the workers, Mr. Kumar of the Bahuarwa Foundation, and the design team.

Figure 78: Local variant for wall infill based on vernacular wall constructions made of several layers of bamboo poles, slits and flattened un-rolled bamboo.



Figure 79: Fine wattle variant made of two types of bamboo with different diameters and woven bamboo slits.



Figure 80: Horizontal strips variant made of horizontal bamboo slits held between vertical bamboo poles and slits.



The variants were constructed by the bamboo experts from Gujarat and three workers from Bahuarwa within two days. They were then evaluated with the experts, the workers, Mr. Kumar of the Bahuarwa Foundation, and the design team (Table 4). All variants required a similar amount of bamboo, with the local variant and the coarse wattle requiring none, the fine wattle requiring a few, and the horizontal strips requiring slightly more screw fasteners. In terms of time, the order was reversed: the horizontal strips are the quickest to attach, followed by the coarse wattle, the fine wattle, and the local variant, which appeared to take the most time. The costs for the different variants are similar, with the local variant costing slightly more for labor and the horizontal strips costing slightly more for screws.

Figure 81: Fourth variant with bamboo slits directly woven around main bamboo supports.





Figure 82: Local worker preparing bamboo slits with a bamboo machete.

All kinds of construction are suitable for the application of earth plaster, especially the wattle variants give the earth more opportunities to interlock. For cement plaster, the horizontal strips are more suitable, because they do not require as much cement and sand to fill the walls as the wattle

variants while still providing a stable substructure. For visible structures, the wattle and the local variant are suitable due to their aesthetically pleasing expression.

For visible but closed bamboo walls, the fine wattle or horizontal strips are suitable, while the coarse wattle is suitable for perforated wall sections with ventilation purposes. In terms of stability and durability, the coarse wattle proves to be the best option, followed by the fine wattle, the horizontal strips, and the local variant.

In terms of suitability for self-construction, the local variant and the coarse wattle are the best, followed by the fine wattle and the horizontal strips. The latter requires more screws and tools. In addition, the load-bearing structure is more often punctured, which requires a certain amount of care and knowledge to avoid cracking the bamboo.

Social acceptance is difficult to assess as it depends mainly on the visibility of the structure from the outside. In general, the local version is more doubted than the others because it is less stable and takes more time to build. Furthermore, it does not bring novelty and is associated with negative connotations. The wattle variants are appreciated for their stability and look.

In the assessment of the four options, it becomes clear that the local variant does not appear to be durable enough and does not meet the aspirations of the local population. The fine wattle loses out compared to the coarse wattle in terms of the screws, tools, and the time required for construction. Furthermore, the required bamboo with a smaller diameter is not locally available in Bahuarwa. This leaves the coarse wattle and the horizontal strips. These two variants evince different qualities, which determine their use. The coarse wattle is particularly suitable for infill with earth and therefore for the interior walls, while the thinner wall construction of the horizontal strips is to be used as a base for a cement render and therefore for the exterior walls.

The next step was to produce the strips for the infill walls. With the help of bamboo machetes, the local workers split the bamboo poles along their length into five to seven similarly wide bamboo strips. They then removed the thickenings at the nodes so that the strips are uniform in their thickness (Figure 82).

Figure 83: Local inhabitants weaving the bamboo slits around the pillars of the supporting structure. The lower part of the wall is filled with an earth straw mix.



The inner walls were built first, as weaving the bamboo strips requires more space and is therefore easier while the outer walls are still missing. Two to three workers weaved the slits between the supports of the inner walls (Figure 83). Without any additional tools or screw connections, the weaving technique leads to a strong stiffening of the supporting structure. In addition, the implicitness of this principle allows the local workers to work independently.

The infills of the wall constructions with an earth-straw mix and a cement-sand plaster were tested directly on the building. It quickly became apparent that the infill of the woven interior walls posed no problem for the local laborers. They quickly became familiar with it without any further instructions on mixing ratios of earth, thatch, and water.

Figure 84: Woman preparing rice straw to be mixed with earth and water.





Figure 85: A group of local men mixing earth, straw and water for the infill of the walls.

In contrast to the design team, who only know the materials in theory, local workers feel their properties with their hands, as they have already internalized how to use them over many years.

Earth materials were extracted from local pits within a radius of around one kilometer using shovels and excavators and transported to the construction site on tractors with trailers. There, a group of three to five men processed it into an earth-straw mixture. The dry earth was spread out on the ground and soaked in water overnight. The water was then extracted from the ground using hand pumps. As soon as the earth was soaked, it was mixed with thatch. To do so, the rice thatch was cut into small pieces, the length of which corresponded roughly to the thickness of the walls (Figure

84). Earth and straw were mixed with the help of hooks and shovels, but also by stepping on it with our feet (Figure 85). The physically demanding mixing process was repeated several times. If necessary, additional straw or water was added until the mixture had the right ratio and a workable consistency. This becomes apparent when it is applied to the walls: If the mixture crumbles during application, it is too dry, if the earth settles so much that it almost drips off the wall, the mixture is too wet. It is particularly important to add enough straw and mix it well with the earth, as the straw forms the reinforcement for the earth and ensures good interlocking with the bamboo wattle.

Figure 86: Woman filling the bamboo wattle with an earth and straw mix.





Figure 87: Women applying the earth straw mix on the upper parts of the walls.

The finished earth and straw mixture was carried by a worker to the walls where it was applied. The application is less physically demanding than the mixing, and allowed the integration of women interested in participating in the building process (Figure 87). The mixture could then be pressed or thrown into the gaps of the bamboo weaving. It is important to ensure a good interlocking of the bamboo weaving and the earth straw mixture and to avoid cavities in the walls. During infill, care is taken to fill the undulating course of the weaving to even the wall. It is worth ensuring that the walls are made evenly and straight from the infilling phase forwards, such that they do not require significant improvements with earth plaster at a later stage. The upper parts of the walls were filled with the help of a bamboo scaffolding (Figure 87). After the infill, the approximately 15-centimeter-thick interior walls were left to dry out for around two months. Due to the loss of water, the walls shrink and cracks

form. However, this is normal, and the cracks are filled when the earth plaster is applied, and the walls are evened out.

The infill of the outer walls was carried out using horizontally attached bamboo strips on the outside of the supporting structure (Figure 88). These were pressed against the supports using wider bamboo strips. Consequently, each individual strip does not have to be drilled or nailed to the supports, which can damage the supporting structure. To prepare the substructure for the application of the cement plaster, a chicken mesh was installed on both sides of the outer walls and attached to the bamboo strips with wires in a grid of around ten centimeters. The cement plaster could then be applied.

Figure 88: Outer walls made of horizontal bamboo slits that are attached on the outside of the structure.





Figure 89: Application of cement sand plaster in several thin layers.

To do this, the substructure was first sprinkled with a liquid cement-water mixture, which makes it easier to apply the plaster the next day. In contrast to the masonry, the bamboo structure required more careful application, as the plaster bounces off if it is thrown at the bamboo strips too hard. Care is taken not to apply the plaster in too wet a state. Although this would be easier in terms of application, it would also result in a weaker plaster. In addition, the plaster was applied in several layers of no more than one centimeter thickness, which were then roughened to ensure a good bond with the next layer (Figure 89). Before applying the next layer, the previous one was wettened. The first layer is never applied on the inside and outside on the same day to prevent the plaster from falling off on one side when applied

to the other. The sand-to-cement ratio of the plaster is about 1:4. After the complete application, the plaster was wet-tened for about a week in the morning and evening. Further details and precise explanations of this construction method can be found in the work of Kaminski, Lawrence et al. (2016), which provides an important basis for the infill of the exterior walls described here.

Doors and windows are made from timber by local carpenters. The carpenters felled two Jamun trees a few hundred meters away from the construction site. The door and window frames were adapted to the distances between the bamboo supports and connected to the supports using the same threaded rods as for the bamboo joints (Figure 90). Once again, it becomes clear how important it is to align the bamboo supports as vertically as possible. Unlike

Figure 90: Window frames made of local Jamun timber in between the bamboo pillars.





Figure 91: Perforated window shutters allowing air flow while providing shadow. The diagonal slits act as bracing and constructive ornament at the same time.

bamboo, wood can be cut straight thanks to its solid cross-section, while bamboo poles retain their natural unevenness. To ensure that the bamboo supports and wooden frames align, the bamboo supports must be as vertical and straight as possible, which is also why the initial sorting of the bamboo poles is a crucial step. Similar to the iron rods used to connect the foundation and supports, the challenge of dealing with an unknown construction detail emerged here. The local carpenters found it difficult to attach the frames to the bamboo with threaded rods, as they usually fasten them with screws and into brick walls.

Different options were evaluated for the design of the shutters. Our suggestion was to design the shutters such that they can be folded upwards in two parts. Thus, when open, they would not interfere with the exterior or interior, and could act as additional sun protection when sun angles are low.

This proposal was considered unusual for those responsible at the Bahuarwa Foundation. They saw a disadvantage of smaller being unable to open the shutters themselves, and that they could injure themselves when closing them. For



this reason, we decide on side-opening, single-leaf shutters that can be opened outwards. Consequently, shutters protrude into the outside space when open, but can be easily operated by the children themselves. Diagonally mounted strips brace the shutters while forming a constructive ornament, the expression of which highlights the carpenters' skills and is appreciated by both the users and the craftspeople. Small gaps between the strips allow indirect light to enter and ventilation even when the shutters are closed (Figure 91). The gates and walls of the central hall are made in the same way. The doors of the classrooms are also made of Jamun wood, but have no perforations.

The cement plaster of the exterior walls is covered with fine white cement plaster in order to even out irregularities and create a smooth surface for the application of the paint. Based on the colors commonly used in Bahuarwa, we created a palette of blue, yellow, purple, and red tones, from which the Bahuarwa Foundation could select their favorite color for painting the facades. Blue was chosen, as it is nowadays frequently used in painting the earth plaster of vernacular buildings in Bahuarwa (Figure 33). The inside of the exterior walls in each classroom is painted in a different combination of three colors, with the surfaces defined by the

Figure 92: The inside of the exterior walls is painted in each room with a different combination of two to three colors to give the rooms, which are identical in size, an individual character.

Figure 93: Schoolchildren exploring patterns for the facades of their new school.

diagonal bamboo reinforcements in the corners (Figure 92). This gives the classrooms, which are identical in size, a colorful distinction. Two painters, originally from Bihar but who have been working in Delhi for several years, were responsible for the painting work.

To increase the social acceptance of the building and give the school's children the opportunity to take ownership of their new school, we let them design white motifs that we painted on top of the blue facades. During a free period one afternoon, we invited a group of about twenty schoolchildren – comprising all genders – to design motifs that they would like to see on the school walls. First, they drew their visions on a blank sheet of paper. Later, we gave them drawings with the outlines of the facades and asked them to transfer their ideas on the facade drawings (Figure 93).





In the process, it became clear that girls were much more interested in this task than boys. Over the course of two or three days, they designed different “henna tattoos” for their school. We photographed all the drawings submitted and combined them on the computer to design the east and west facades, which provided the biggest uninterrupted surfaces. In doing so, we tried to incorporate as many of the schoolchildren’s ideas as possible. We transferred the outlines of the motifs onto the facades with chalk, and then invited the children again to add further details.

Thus, something new was created, and all interested children could participate again. Finally, we painted the designs with white color. While the west facade is characterized by circular “flowers” or “fireworks” of different sizes (Figure 96), the east facade is covered by a dense network of interlocking patterns (Figure 100).

Figure 94: Schoolchildren designing “henna-tattoos” on the facades of their school.

Figure 95: Villagers creating wall reliefs out of clay, cow dung, wheat husks and water on the earth walls inside the school.

The earth interior walls also offer the opportunity for inclusive design. We invited villagers who are skilled in creating wall reliefs out of clay, cow dung, and straw. Two women designed another wall relief for one earth wall of each classroom, and for the earth walls in the multipurpose hall, together with the daughter and son of one of the women (Figure 95).

The wall reliefs are applied in a three-stage process: First, clay (*chikni miti*), wheat husks, and water are mixed. The ratio of clay to wheat husks is roughly 5:1. Water was added until the mixture became malleable. It must not be overly liquid, as excess water causes shrinkage and cracking during the drying process. The mixture is rolled by hand and then applied to an earth wall. The wall does not need to be wetted in advance. If the mixture holds together well, the amount of water is right. Then, the relief needs to dry. The drying is recognizable when the relief takes on the same color as the rest of the wall. In our case, this took about two days.

In the next phase, cow dung and clay were mixed in a ratio of 4:1 with water. This time, more water was added, such



that the mixture took on the texture of a paste, and could be applied in a thin layer. This step improved the relief's adhesion to the wall and protected it from cracking. This layer must be allowed to dry again, which, depending on the relief and weather conditions, takes at least two days. Due to the high proportion of cow dung in the mixture, the result was a different color than the rest of the wall.

In the final phase, clay was mixed with a lot of water and applied very thinly to the relief, using a cloth. This refined the relief and lent it the same color as the wall.

5.2.5 Roof and Ceiling

The roof is made of corrugated iron sheets. This is available in the nearest town of Jhanjharpur, around 15 kilometers northeast of Bahuarwa, and could be delivered by a small pick-up truck. Once again, the construction joint detail with bamboo – in this case the rafters – poses a challenge, as corrugated metal sheets are usually connected to metal rafters. When attached to a bamboo structure, craftspeople in the region of Bahuarwa use J-hooks. These have the advantage that the bamboo does not need to be pierced, which would increase the risk of cracks. However, fastening with J-hooks also entails that the connection between the corrugated metal sheets and the bamboo structure remains relatively loose, allowing the sheets to move in strong winds and produce noise. The manufacturers of corrugated sheets therefore recommend fastening with screws. However, their instructions do not take application to bamboo rafters into account. Here too, additional research and development of easy-to-use connection details is required.

It is possible to attach the sheets to the bamboo rafters using screws, but there is a risk that the screws will no longer be firmly attached to the bamboo after some time due to temperature differences, moisture and wind because of the hollow cross section of the bamboo. In contrast, wooden battens have a full cross-section, which makes them more suitable for fastening the corrugated metal panels. In our case, the bamboo rafters are laterally supplemented at points with similarly high wooden battens, thus forming the connecting piece between the corrugated sheeting and the bamboo



Figure 96: West facade filled with “flowers” designed by the schoolchildren. The protruding roof provides protection from the sun and the rainfalls. A ventilation gap between ceiling and roof counteracts the heat radiation of the metal roof.

rafters. This solution allows for a more permanent connection and a reduction in the amount of wood required, which is more expensive than bamboo.

The corrugated metal panels, with their lightness and impermeability to water, provide an effective earthquake-proof solution that protects the interior from rainfall. The disadvantage, however, is that metal heats up quickly and radiates heat to the interior. In addition, during the morning hours of the cooler winter months December and January the moist air condenses on the corrugated metal, which cools down at night. To counteract condensation and overheating, a ceiling is installed to absorb dripping condensation and radiation from the roof. The gap between the roof and ceiling allows good ventilation, which prevents heat build-up and allows condensation to be reduced by the air flow. The ceiling is also made from bamboo. The bamboo poles are split evenly along their length with axes, unrolled and fastened to the ceiling rafters with wires. As no other tools or fasteners are required, this work can be carried out



by local labors without any further instructions. The use of the unrolled bamboo results in a finely perforated ceiling, which not only counteracts heat radiation and catches eventual water drops from the condensation but also provides a more attractive room closure than the metal sheets (Figure 97).

5.2.6 Conclusion

The construction process allows the findings of the ethnographic analysis to be applied and tested in practice. Locally-made bricks are used in combination with reinforced concrete point foundations and a ring beam connects the foundation and plinth. The floor consists of a layer of bricks, a layer of unreinforced concrete, and a cement coating. The structural system of the walls, ceiling, and roof is made of bamboo. Interior and exterior walls are infilled with bamboo strips. For the interior walls, these are woven into the supporting structure; for the exterior walls, they are screwed onto the structure. The interior walls are filled with an earth-straw mix, while the exterior walls are plastered with cement and sand. The ceiling is made of flattened bamboo, the roof

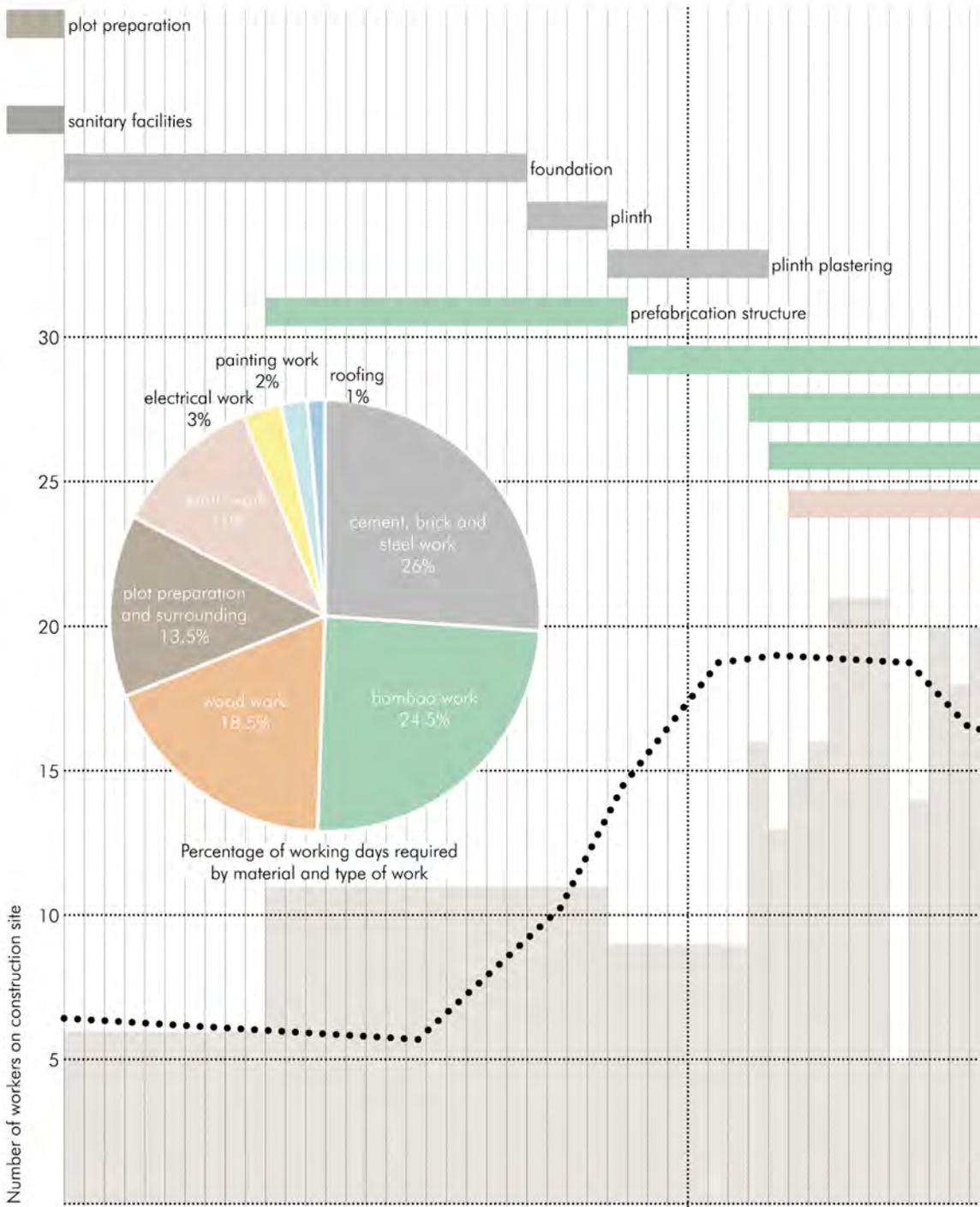
Figure 97: Ceiling made of split and unrolled bamboo to reduce the heat radiation from the metal roof, absorb eventual condensation drops and create a more attractive room closure than the underside of the metal sheets.

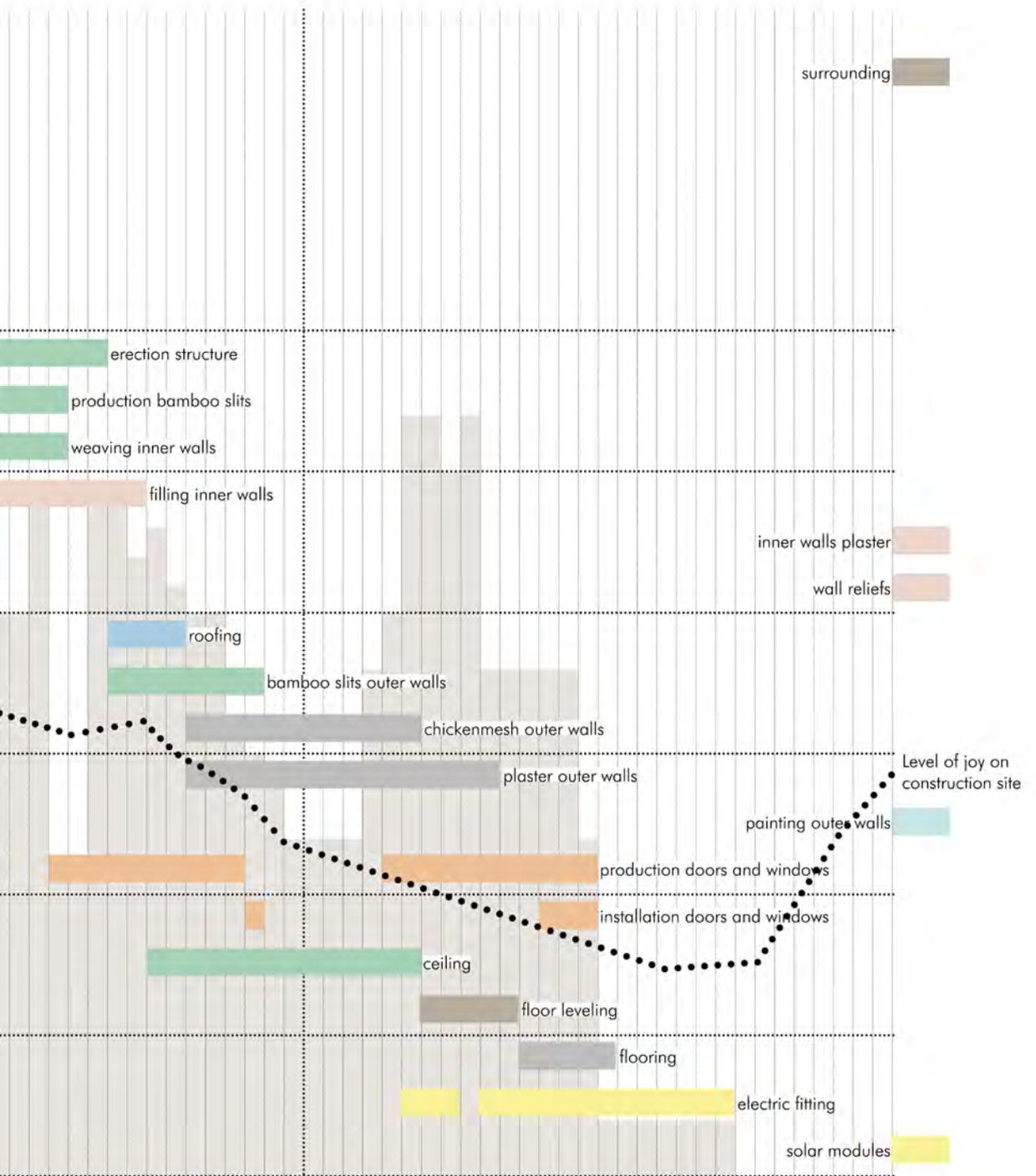
of corrugated metal sheets. Window shutters and doors are made of local Jamun wood.

This construction method allows for a relatively quick construction of the shell within three to four months. Except for three bamboo experts from CIBART in the state of Gujarat, all the workers and craftspeople involved came from Bahuarwa and the surrounding region. In particular, the work with earth and bamboo enables the villagers to be integrated in the construction process. However, it also became apparent that younger villagers are no longer as skilled in working with regenerative building materials as their parents or grandparents. In addition, most male villagers view working with earth as inferior, and therefore leave it to women. Nevertheless, many of those involved emphasize that they prefer working with bamboo and earth to brick and concrete, as these materials are more pleasant to the skin, the lungs and not as heavy. The positive effects on their physical health might also be the reason that the mood on the construction site is best when working with renewable materials. Although it was not possible to quantify this within the scope of this research, several observations indicated an increased sense of joy when working with regenerative materials (Figure 98). To ease the physically demanding task of mixing clay, straw, and water, for instance, workers would often sing songs and perform an earth dance (*miti dance*), which made the mixing with their feet noticeably easier. At other times, the sense of joy manifested itself when workers playfully threw clay balls at one another, almost as if childhood memories were being revived. In contrast to working with cement and bricks, the workers took fewer and shorter breaks and were less eager to leave the construction site at the end of the day.

The challenges and opportunities identified during the building process help to determine the measures necessary to further develop and disseminate the applied construction method. In the next chapter, where the construction process and the design factors are evaluated retrospectively, these measures are explained in more detail. Figure 98 provides an overview of the construction process from October until December 2023, when most of the work was implemented.

Figure 98 (following double page): Timeline of construction process from October until December 2023, when most of the construction was realized. The diagrams also show the number of workers on the construction site, the number of working days spent per work type, and the researcher's subjectively perceived level of joy of the workers.





5.3 Evaluation of Design Factors

5.3.1 Introduction

Constructing a school instead of evaluating everything in theory aimed to provide a concrete piece of evidence as to whether the use of regenerative and locally-available materials could be combined with new building materials in the context of Bahuarwa, without compromising the living conditions, valid concerns, and aspirations of the local population. While in the first part of this dissertation, a comprehensive understanding of ongoing material transitions in the region of Bahuarwa was developed, based on which relevant design factors for achieving social acceptance were derived, the second part involves the practical application of these findings.

Even if the target groups accept the use of other building materials and construction methods, this does not necessarily mean that the proposed construction practices will be adopted, as this also depends on the availability of necessary infrastructures and skills. Furthermore, locally available raw material is not necessarily usable as a building material without further processing. The local availability of a resource in turn does not guarantee that the processing can also be done locally. Regenerative building materials may require chemical treatment or varnishing for long-term use, which can deteriorate the material's regenerability. A hybrid solution of different building materials requires constructive connections that need to be developed and implemented considering local limitations. The further development of building traditions involving regenerative materials requires knowledge and skills that are increasingly being lost. This chapter addresses the challenges in fulfilling the identified design factors to reach social acceptance and further adoption of the applied construction methods.

5.3.2 Durability

Due to the local availability, the embedding in vernacular building methods, the low costs and environmental footprint, we decided to use bamboo for the structural elements of walls, ceiling, and roof, as well as for the filling of walls

and ceiling. Besides the many advantages of this fast growing and abundant material, the main challenge was to improve its durability, as this was perceived as a major disadvantage in vernacular constructions. After consultations of several bamboo experts (Bamboo House India; Centre for Indian Bamboo Resource and Technology; Thumbimpresions) and extensive research (Espelho & Beraldo, 2008; Gauss, 2020, p. 59; Kaminski, Lawrence, & Trujillo, 2016, pp. 23–31), we found that using bamboo without chemical treatment was likely to result in infestations by insects and fungal attack, thus significantly reducing the durability of the building.

Traditionally, people in Bahuarwa soak bamboo in water for ten to fifteen days. Thereby some of the starch, responsible for attracting beetles and termites, gets washed out. However, these measures provide insufficient protection for the targeted long-term use of bamboo. While in colder climates, where the risk of damage through insects is smaller, structural measures such as wide eaves and protective bases could suffice as protection against beetles and termites, subtropical and tropical climates require chemical treatment (Kaminski, Lawrence, & Trujillo, 2016, p. 27).

Whereas treatment with boron is common for interior applications, copper-based wood preservatives are often used for exterior applications. Unlike Boron, these chemicals are fixed in the bamboo through fixing agents such as copper or chrome so that they leach out less upon contact with water. The bamboo experts from CIBART apply a CCB treatment for exterior applications, which is a compound based on copper, chrome, and boron. This treatment method is widespread in many countries and considered effective in protecting bamboo against insects and fungi (Espelho & Beraldo, 2008; Kaminski, Lawrence, & Trujillo, 2016, p. 30; Tiburtino et al., 2015). However, it poses a risk to the environment and prevents the otherwise unproblematic regeneration of a natural building material (Scharfenberg et al., 2021). Gauss (2020) emphasizes that despite the numerous advantages of bamboo, it should not be overlooked that chemical treatment methods require further research in terms of safe applicability, quality control, and impact on

the environment in order to use this abundant material in a sustainable way.

The example of bamboo illustrates the conflict between regenerability and durability of building materials. The chemical treatment changes the material's properties, creating a material transition, which eliminates its regenerability in favor of its durability. However, since the environmental impacts of the intended construction were still significantly lower than those of conventional masonry and reinforced concrete constructions, as shown in analyses of comparable cases (Bundi et al., 2024; Murphy et al., 2004; Rincón et al., 2023), the original intentions were not deviated from. Not least to promote the potential of bamboo as a building material and gain the findings described here.

The situation regarding the use of earth and thatch was different. These materials were mixed with water and then used for infilling the interior walls (Figure 99). The materials did not undergo any chemical treatment. Since they were only used for the interior walls protected from the weather, they were not mixed with cement, which would increase weather resistance in case of external applications but would also prevent their re-naturability. Regarding the desired durability, the risk remained that termites could infest the earth straw mixture of the walls. However, this risk could be reduced by constructing a concrete slab on a brick base. This forces termites to enter the interior by climbing the facades, where they can be easily spotted, and their corridors removed.

It goes beyond the scope of this research to precisely evaluate the durability of the construction method used. The statements made here can only refer to values of similar construction methods in comparable contexts that have already been considered over longer timespans. Even the bamboo experts at CIBART can only refer to a maximum experience period of fifteen years to assess the durability of their buildings, as they had not used bamboo in such a way for construction purposes before. When visiting some of their oldest buildings, which initially consisted mainly of small pavilions and bungalows, the traces of weathering are clearly visible, but according to the CIBART experts, the structural function is completely intact. Kaminski et al.



Figure 99: Interior walls made of a bamboo structure filled with an earth straw mix.

(2016, p. 27) state that treated bamboo – for indoor applications with boron and for outdoor applications with fixed preservatives – has a service life of over thirty years without contact with the ground. However, the authors also emphasize the limited test results and the reference to rough

estimates, some of which also come from wood tests (Kaminski, Lawrence, & Trujillo, 2016, p. 27). The limited experience and lack of references are among the reasons for the skepticism of the inhabitants of Bahuarwa towards regenerative building materials. The only examples they know of are usually the vernacular buildings in their villages, which they do not consider to be success stories. Their preference for fired bricks and reinforced concrete – often the only alternatives – therefore remains. More empirical data are needed to convince the inhabitants of Bahuarwa to persuade them to adopt similar building methods. If bamboo buildings can withstand the challenges of the natural environment – heat, earthquakes, flooding, rainfall, termites – at least as well as buildings made of fired bricks and reinforced concrete, then the reputation of building materials and methods could change in favor of bamboo and earth. Although fired bricks and reinforced concrete are more durable than bamboo, earth or thatch when unprotected from the weather or in ground contact, the durability of the materials cannot simply be transferred to buildings. This is where construction and design measures come into play that can extend or shorten the durability of the building. The high plinth, the protruding roof and the cement rendering of the exterior walls are relevant characteristics of the hybrid construction method used here to increase its durability. The building is protected against rainfall, flooding, and earthquakes. In contrast, the durability of buildings made of fired bricks and reinforced concrete cannot be considered a given, regardless of the structural details, as the destruction of past earthquakes has shown (Duggal & Sato, 1989, pp. 95–97).

Regarding ease of maintenance, which is closely linked to the durability of a building, an attempt was made to use building materials appropriately according to their strengths and weaknesses and to combine them in such a way that they can be replaced if necessary. The floor, foundations and plinth are likely to be the most durable components, but at the same time those that cannot be replaced without significant demolition work. The other components – supporting structure, windows, doors, walls – consist of mechanical connections through threaded rods and screws

that allow the individual components to be replaced, except for the cement plaster on the exterior walls. The supporting structure of the roof in particular, which is more exposed to the weather and condensation from the corrugated roof sheets, can be replaced with relatively little effort and cost if necessary.

5.3.3 Thermal Comfort

Thermal comfort inside the school is a factor that was often mentioned during the initial analysis of the existing buildings and during the planning phase but was not considered a priority. Above all, durability, low maintenance requirements and a contemporary appearance were considered more important. Thermal comfort was usually the only advantage of vernacular buildings compared to those made of fired bricks and reinforced concrete and was lost among the numerous disadvantages. From the point of view of the pukka house residents, the disadvantage of summer heat could be mitigated with raised rooms and ceiling fans.

However, when the school was evaluated retrospectively with craftspeople, villagers, teachers, schoolchildren and the Bahuarwa Foundation, the thermal comfort was emphasized the most. In contrast to the pukka houses, the school remains pleasantly cool even during the hot summer months (Figure 100). The ceiling fans are only used on a few days. "We have a cool school," the schoolchildren shout when they meet sweaty children on their way home who have spent the day in more expensive private schools made of fired bricks and reinforced concrete.

In the context of climate change, the factor of thermal comfort, which is not yet given much weight in Bahuarwa, could become more important. Although it is possible to ensure thermal comfort in buildings made of fired brick and reinforced concrete using technological measures such as fans and air conditioning, this is also associated with higher costs. These are reflected in the purchase of the necessary equipment, in the operating costs and in the design measures required to install the equipment. For example, pukka houses require rooms about three meters high to allow the installation of ceiling fans. The rooms of vernacular



buildings in Bahuarwa, with a room height of hardly two meters, create a more pleasant indoor climate.

While a ceiling fan requires 20 to 120 watts, depending on its energy efficiency rating, a small, mobile air conditioner can easily consume between 1000 and 2000 watts, which means a 10 to 50 times higher electricity demand to operate. For the air conditioner to be effective, rooms with closed windows and doors must be quite air tight. However, this requirement is rarely met even in pukka houses in Bahuarwa, because doors and windows usually have no seals. Windows often consist only of shutters anyway. Being able to seal off interior rooms airtight accommodates the requirements of a technological solution with air conditioning systems, but at the same time it goes against the vernacular low-tech principles that build on light and open structures to allow good ventilation (Figure 101).

The advantages of open wall structures and perforated window shutters, as used in the school, are relativized by disadvantages in terms of reduced security, a lack of acoustic separation and increased dust accumulation. For example, the perforated wooden window shutters and bamboo

Figure 100: A ventilation gap between the ceiling and the roof counteracts the heat radiation from the metal roof during the hot summer months and, together with the perforated shutters and clay walls, ensures a pleasant indoor climate without the need for air conditioning, as is the case with the brick building in the foreground.

Figure 101: The perforation of the window shutters and gates to the multipurpose hall allow a good ventilation and natural lighting. The way the light enters the rooms already became a characteristic and favourite element among users and visitors of the school.

ceiling mats offer less protection against burglars than solid shutters and reinforced concrete ceilings. Acoustic separation of the classrooms could only be achieved with almost air tight rooms with massive walls. Without the use of air conditioning, this proves difficult regardless of the building materials and methods and is therefore not to be considered a disadvantage of the building method used compared to the common building methods with bricks and concrete. Even though these materials have more mass, which is advantageous for protecting against airborne sound, it is also in these buildings, which tend to overheat, that windows and doors are always open to counteract overheating with cross-



ventilation. Consequently, dust can also accumulate in pukka houses. However, while this can be at least partly reduced by the closed walls, ceilings, doors and window shutters, for example during the absence of the users, dust will accumulate permanently in an open structure like that of the school. During the evaluation of the school, however, the accumulation of dust inside the rooms was particularly noticeable during the dry winter months, but it was not mentioned as a disadvantage because it is common in all houses. To deter burglars, the school, like other buildings, is illuminated a little at night. In addition, more expensive items such as laptops or beamers are stored in the homes of the teachers and the Bahuarwa Foundation. Ultimately, it is a matter of balancing the requirements for security, cleaning effort and thermal comfort, with the latter being the priority according to the respondents when comparing the three.

5.3.4 Availability

With the firing of roof tiles as a fireproof alternative to the thatch roofs that were commonly used until mid-20th century, a division of labor started, which was expanded into entire production chains with the further introduction of new building materials and components. The desired durability of the building materials required, in many cases, a higher degree of processing, leading to an increasing differentiation of raw resources and applied building materials. This material transition, also reflected in the terms *kutch* and *pukka*, becomes especially apparent through the raw earth transforming into a fired brick through firing in the brick kiln. Unlike earth, bamboo did not experience such a material transition in the region of Bahuarwa. It is still used in its raw form and therefore only for temporary purposes and for the homes of poorer population groups. Unlike brick kilns, bamboo treatment facilities are scarce in India. While there are more than 100,000 brick kilns (Lalchandani & Maithel, 2013, p. 7), the opportunities for bamboo treatment are limited to a few. For the treatment of bamboo, the facilities of the project partner CIBART were used. These are located, like one of their training centers, in the village of Ukai in the state of Gujarat. The bamboo, in turn, CIBART mostly

orders from the state of Assam, so that the locally available bamboo in Bahuarwa could not be used for the school construction.

This resulted in the paradoxical circumstance that the use of a locally available raw material required a transport distance of approximately 4200 kilometers to ensure its durability through chemical treatment. This unexpected situation contradicted the goal of this research to promote the use of regenerative and locally available building materials. It also raised the question of whether the use of locally sourced and processed bricks might be more sustainable than bamboo transported over long distances. Since it was also a goal of this research to identify obstacles regarding the promotion of regenerative or low processed building materials, the long transport distances were accepted.

The low weight of the material in relation to its structural capacity allowed it to be transported in two loads with a small truck. Despite its use for the entire load-bearing structure of walls, ceiling and roof, as well as the substructure of all wall infills, the weight of bamboo only accounts for around 8% of the entire building. According to a study by Zea et al. (2018, pp. 8–10), due to its low weight, bamboo has a lower environmental impact than fired bricks, cement or steel even when longer transportation distances are taken into account. Despite the easier transportability of the material, the establishment of a local treatment facility in the region of Bahuarwa seems necessary if the use of bamboo as an alternative to readily available bricks is to be promoted. In contrast to brick or cement production, the treatment of bamboo does not require a large infrastructure. The pressure vessel used by CIBART, for example, is available for around INR 8 to 10 lakhs²⁴. The chemicals for the treatment are also affordable. A small hall is required for the protected storage of the bamboo. Stamm and Vahanvati (2018) have published detailed instructions on how to treat bamboo with boric acid and borax in healthy and environmentally friendly ways with minimum equipment.

²⁴ 1 lakh = 100'000, 8 – 10 lakhs INR = 8'000 – 10'000 CHF, considering an exchange rate of 0.01 (XE, 2024).



Instead of the vernacular connections using holes and notches, which do not require any other fasteners other than the use of cords, threaded rods, nuts, and washers made of stainless steel were used to build the school (Figure 102). This enabled permanent connections with which larger supports and beams could be made. However, like the bamboo treatment plants, threaded rods are only available in a few places in India. When we ran out of them, we tried in vain to get them from more than twenty stores and workshops in Darbhanga, the capital of the district where Bahuarwa is located. “You won’t find these rods anywhere in

Figure 102: Durable bamboo connection with threaded rods, nuts and washers made of stainless steel to prevent corrosion through the treatment chemicals. The protruding rods are yet to be cut.

Figure 103: CIBART's bamboo experts and local people working together.

the state of Bihar. They are only available in Delhi or Mumbai," was the reaction of a workshop owner. And indeed, in the end we had the threaded rods delivered from Delhi. The limited availability of this detail illustrates the difficulty to promote alternatives to the widely available bricks, cement, and concrete. However, it also shows that the effort required to change this situation is relatively small.

Although the structure was planned to be built using simple connection techniques with threaded rods, nuts, and washers and a few tools – drill, circular saw, hacksaw, hammer, machete – experts from CIBART had to be called in to carry out the bamboo work together with the local community (Figure 103). CIBART is one of the few organizations in India that has expertise in using bamboo as a building material. Many organizations and companies use bamboo to

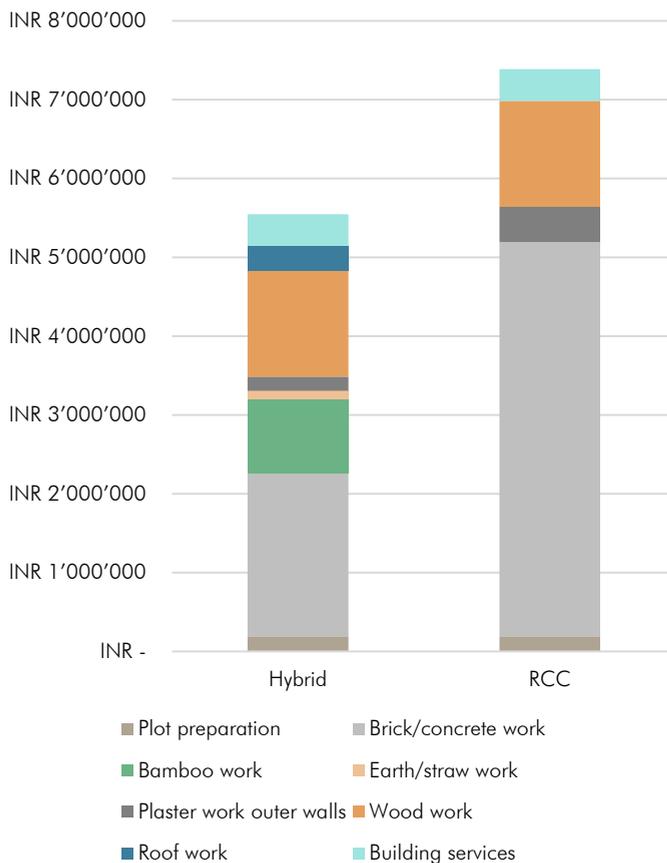


make furniture or everyday items such as bottles or lamps. To further develop the use of bamboo as a building material, additional training centers are required. Furthermore, the studies of architects, civil engineers and other planners must be geared towards the use of bamboo as a sustainable building material.

5.3.5 Affordability

The construction of the school has shown that a key advantage of using bamboo and earth is that these materials are considerably cheaper than brick, concrete and steel. By replacing fired bricks and reinforced concrete for the construction of the walls, ceiling and roof through bamboo, earth, straw and a corrugated metal roof, the construction costs were around 25% lower (Figure 104). The relatively high cost of bricks, concrete and steel made the foundation

Figure 104: Comparison of the cost proportion of individual materials (in INR) between the hybrid construction and a conventional construction method using fired bricks and reinforced concrete (RCC).



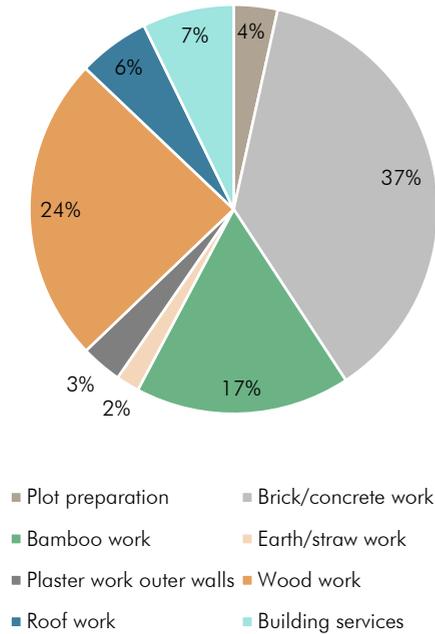


Figure 105: Cost of individual building parts. Brick and concrete work have the highest share in the total costs, followed by wood and bamboo work. The work with earth and straw accounts for the smallest share of the total costs.

with plinth and floor as well as the toilet facilities the most expensive components with a share of 37% of the total building costs (Figure 105). Consequently, a two-story construction and a compact volume could increase the proportion of bamboo and earth and further reduce the costs by approximately a third in relation to the built volume.

Disregarding the requirements of most occupants for the expression of a contemporary house, costs could be further reduced if the exterior walls were filled and plastered with earth and straw instead of cement and sand. Provided the walls are protected from flooding and rainfall by a high foundation and a large roof overhang, the durability of a single-story building should be only slightly affected using earth for the exterior walls. The lower costs could speed up the incremental construction process so that poorer families could afford a roof over their heads instead of just a few walls.

The assessment of affordability must also be qualified in close connection with the assessment of durability, by weighing the lower acquisition costs against the still uncertain maintenance costs. Just as the strong pukka appearance of the building does not yet guarantee its durability,

the lower construction costs do not yet ensure lower overall costs, which also take into account maintenance and operating costs. The argument of better affordability only applies if the lifespan of the building is not limited compared to a brick and concrete building. However, the Bahuarwa residents currently lack the experience and built references to verify this. Even for us or the bamboo experts at CIBART it is difficult to provide a guarantee at this time.

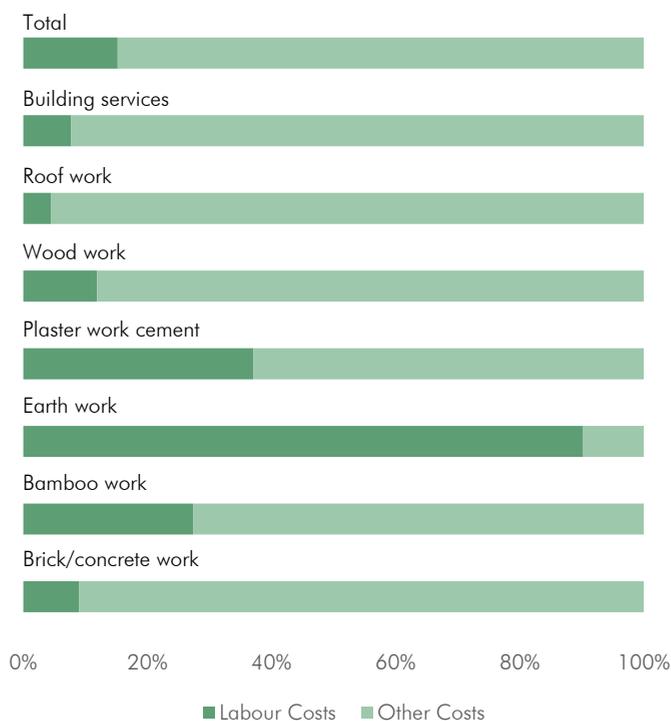
5.3.6 Aspiration

Lower building costs are a strong argument for convincing the local population of the potential of regenerative building materials. However, they will only be effective if they meet the requirements for durability, maintenance, and availability as well as the aspirations of the residents. The interviews with the local population have shown that the use of regenerative materials is not rejected as long as the materials are not too visible from the outside. Most residents were critical of the building when it was under construction and the outer walls made of bamboo were still unplastered. When they found the building a few weeks later with plastered walls, they almost did not recognize it anymore. Now the comments were no longer “Why are you building a kutch house?” but “That looks like a pukcha house, very nice!”

The coloring further improved the acceptance of the school building. If it had been just a matter of our personal taste, we would probably have painted the building in a terra cotta red. But this would have contrasted with the preferences of people in Bahuarwa for more colorful designs that are as far removed as possible from earthy tones. So, we decided to put together a palette of four colors that were commonly found in the village and let the Bahuarwa Foundation choose a color for the facades of the school. While the facades were painted blue as requested by the Bahuarwa Foundation, the inside of the exterior walls in each room was painted in a different combination of two to three colors that we often encountered in Bahuarwa. The subsequent design of the facades with the white “henna tattoos” created by the schoolchildren led to further enrichment and a sense of ownership among the users.

Figure 106: Ratio of labour costs on the construction site to other costs for materials, processing and transport in the case of the implemented hybrid construction.

The respondents were not bothered that the interior walls were filled and plastered with earth and straw. On the contrary, most of them saw this as a combination, where the cement plaster gives the building a contemporary appearance on the outside, while the earth filling ensures a pleasant indoor climate on the inside. The distinctiveness of this hybrid solution became particularly clear when a group of about fifteen girls and fifteen boys shouted “pukka” and “kutcha” simultaneously when we asked them about their impression of the school building. The overlapping and mixing of these expressions resulted in “kukka” and “putcha,” in which a merging of these polarizing categories into a new expression took place. “Outside pukka, inside kutcha!” or “The school building is pukka but made of kutcha materials!” were some of the comments. All those interviewed agreed that the building makes a safe and firm impression, which most also consider to be the main criterion for categorizing it as a pukka building. However, a few also criticized that the walls are not as straight and even as those of a wall made of fired bricks and reinforced concrete.



The color scheme, the wall reliefs, the ornamental expression and the light coming in through the perforated window shutters were mentioned by many as appealing features of the school building. These are design elements that can be achieved with regenerative building materials. Even though we used synthetic colors due to a limited availability of regenerative alternatives and the application on cement plaster, the use of natural colors would also be possible considering a higher procurement effort, slightly higher costs and a reduced color palette.

Here, too, a close connection to the topic of durability became apparent. For example, some representatives of the Bahuarwa Foundation and villagers of Bahuarwa repeatedly suggested to paint or varnish the bamboo structure, the earth walls, the window shutters and doors – in short, all the components made of regenerative materials. On the one hand, because they would like this better aesthetically, but on the other hand, because they see it as an important measure to protect these parts against termites and beetles. Since the bamboo has already been treated and, according to the local carpenter, doors and window shutters are not at great risk of insect infestation, we did not pursue these occasional requests. Otherwise, it would also raise the question of the extent to which the use of regenerative building materials still makes sense, or rather, to what extent we can still speak of “regenerative” materials if they need to be chemically treated, painted or varnished.

Although the expression of the developed hybrid solution largely corresponds to the aspirations of the residents, it is nevertheless crucial that a tightening of the dichotomy between *kutchra* and *pukka*, bad and good building materials and methods is not further promoted. This requires that government housing programs and building guidelines not only allow alternative construction methods but actively promote them. Training courses and fair wages should raise the profile of professions related to regenerative building materials such as earth and bamboo. Not only men who master the use of bricks, concrete and steel should earn the title of a *mistri*, but also people – women and men – who build with bamboo, earth and other regenerative building materials.

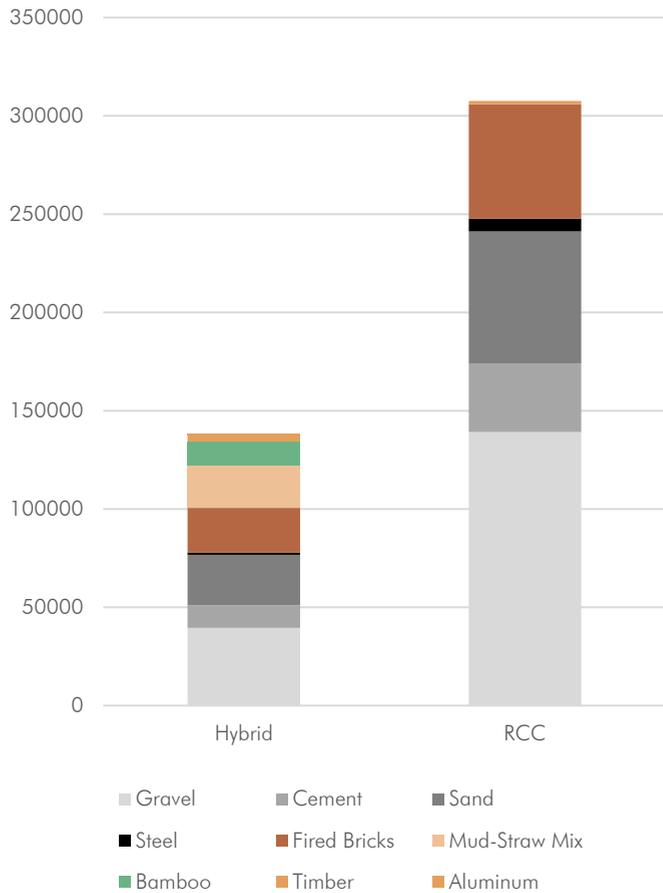


Figure 107: Comparison of the material demands (in kg) of the applied hybrid and a conventional method with walls and roof made of reinforced concrete and fired bricks (RCC).

Apart from the lower prestige and wages of jobs involving regenerative building materials, most construction workers appreciated working with these materials. The people interviewed do not work with bricks, steel and cement because they find this work more appealing, but because there is a demand for it. However, many stated that they would prefer working with bamboo, as working with fired bricks, cement, and steel is physically more strenuous and more aggressive for the skin. The weight and skin compatibility of the materials are important factors in the assessment of the work, as almost all work processes on a construction site in a village like Bahuarwa are carried out manually. There is no crane to lift materials from one place to another. Mortar, plaster and concrete are often mixed by hand. The mistri only rents a small concrete mixer temporarily for larger concreting stages. By using bamboo, the weight of the building could

be reduced by over 55% compared to an RCC construction with a reinforced concrete roof (Figure 107) and by over 30% if the roof of the RCC building was also made of a corrugated metal.

5.3.7 Expandability

Interviews with the residents and labors involved revealed skepticism about the limited expansion possibilities of the proposed construction method. The inhabitants of villages like Bahuarwa are used to continuously adapting their houses to changing family situations. The dynamic adaptation of buildings has increased further with the switch to new and more expensive building materials and methods, as limited financial resources often force residents to adopt an incremental building process. While brick and reinforced concrete walls can be exposed to the weather for long periods of time without suffering significant damage, bamboo and earth structures must be protected from rain to ensure their durability. This requires a quick construction of the house including a good roofing during the dry season, while the construction process with fired bricks and reinforced concrete can take several years.

If the residents do not have the financial resources to erect a complete building with the proposed hybrid construction between two rainy seasons, either the installation of temporary water protection, for example in the form of tarpaulins, or an adapted planning of the construction process become necessary. Instead of separating the construction process into individual components, with the foundation, walls and roof of the whole house being built in consecutive years, it could be structured based on single rooms so that one room can be fully constructed in each dry season. Both practices are common in the region of Bahuarwa and depend on the needs and capabilities of the occupants. The lower cost of the proposed hybrid solution also makes it easier for residents to shorten the construction process.

The greater challenge, however, is that many households – especially poorer ones – are dependent on making efficient use of their land through multistory construction. Even more than the horizontal expansion of a residential building, the vertical expansion takes place over a period of several

Figure 108: Reinforced concrete slabs as walkable roofs. In case of a vertical expansion of the building the roof will become the floor of the next story.

years, if not decades. While a reinforced concrete ceiling can easily serve as a roof as well as a floor of an eventual next story (Figure 108), a corrugated sheet metal or bamboo ceiling can only serve as a roof or ceiling respectively. If the proposed construction method is to be used for the construction of a two-story building, which is technically possible, the entire construction should preferably be completed within one dry season or be well protected from the rains during the monsoon before the construction proceeds again in dry conditions. Even if a building made of bricks and reinforced concrete cannot be extended vertically at will, a sensible maximum for the proposed method is achieved with two to three stories. In contrast to a reinforced concrete roof, the roof of the hybrid construction presented here cannot be walked on, which means that a relevant area for everyday activities such as laundry, drying grain and clothes, as well as for storing purposes.



The implications on the construction process, expandability and availability are among the major disadvantages regarding the upscaling of the proposed hybrid solution. Although the lower costs can counteract these challenges to a certain extent, it is relevant to develop innovative solutions that enable both flexible expandability and good utilization of hybrid construction methods.

5.3.8 Environmental Impact

The precise calculation of a life cycle assessment of the built school is difficult due to a lack of reliable data on the building materials used. Nevertheless, with reference to other studies (Zea Escamilla et al., 2018), relevant parameters can be determined that allow an approximation of a life cycle assessment. To this end, the weight and volume of the materials used were calculated and the implemented hybrid construction was compared with an RCC building with the same built area, building volume and requirements for earthquake-resistant construction. The two variants differ in the construction of the walls, ceiling, and roof. While bamboo, earth, thatch, and corrugated metal sheets are used in the built case, fired bricks and reinforced concrete are used in the RCC comparison variant. Cement plaster is used in both variants, only for the exterior walls in the built variant and for the interior and exterior walls in the RCC comparison. The same material and labor requirements were assumed for the foundation, plinth, floor, windows, doors and building services for both variants.

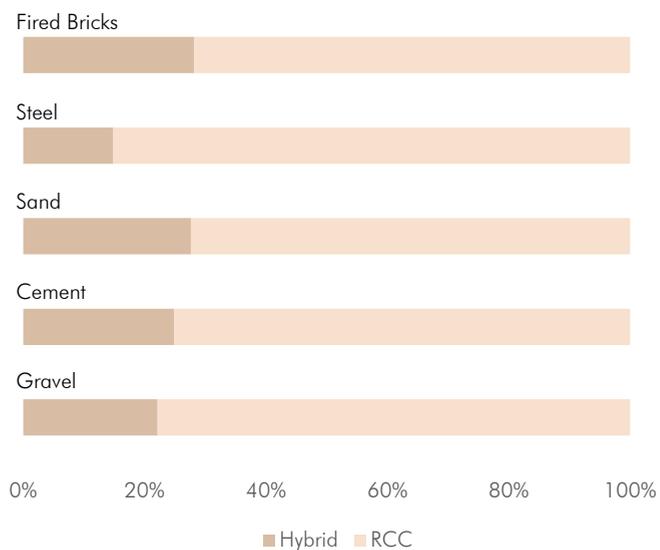
Compared to a conventional RCC construction with a reinforced concrete roof, the school was built with about 70% less concrete, 80% less reinforcement steel, 60% less fired bricks and about 85% less cement mortar and 45% less cement plaster (Figure 109). Other studies (Zea Escamilla et al., 2018, pp. 7–12) show that it is primarily these materials that count in the calculations of grey energy and greenhouse gas emissions of the construction of a building. In contrast to bamboo, earth and thatch, these materials require high temperatures in processing, 900-1100° Celsius for firing bricks, 1300° Celsius to produce steel and even 1450° Celsius for cement, which contribute to the high emissions and grey energy demands. In addition, the

Figure 109: Percentage of carbon-intensive materials in the hybrid construction compared to the conventional construction method (RCC) using fired bricks and reinforced concrete.

extraction of lime and iron ore for the production of cement and steel is also energy intensive.

However, the considerable savings in cement, steel and fired bricks are somewhat relativized in the case of the hybrid version by the use of corrugated metal sheets for the roof, as aluminum has a relatively high environmental impact per kilogram. Nevertheless, Zea Escamilla et al. (2018, p. 8) came to a reduction in the environmental impact of comparable construction methods measured in kgCO₂ Eq/m² for single story buildings of 50% to 60% in the overall balance compared to construction methods using fired bricks or hollow concrete blocks.

This calculation must also be put into perspective, considering the limited number of a maximum of three floors made of bamboo compared to multi-story buildings made of reinforced concrete. The limited possibility of the applied construction method for vertical expansion requires horizontal expansion, which in turn leads to more sealed surfaces and thus fewer unbuilt areas that could be used for food production, for example. In less densely populated areas, such as the region of Bahuarwa, it is still feasible to build one or two-story buildings. In more densely populated and more urbanized areas, however, there is generally not enough space, or the plots of land are too expensive to build just a single-story building.



Even if an exact calculation of the required transport distances is not possible due to incomplete information on the places of extraction and processing of the materials, it can be assumed that the bamboo required the longest transport distances due to the distant extraction and treatment sites. Due to the low weight of bamboo and with reference to Zea Escamilla et al. (2018, pp. 8–10), transport-related emissions of bamboo have less of an impact than the manufacturing-related emissions of cement, fired bricks or steel, even over longer distances. Nevertheless, for a future project local sourcing and treatment with environmentally friendly boric-borax (Stamm & Vahanvati, 2018) should be aimed for, since this requires simple means, little knowledge and hardly any transportation.

5.3.9 Conclusion

The evaluation of the planning and construction process of the school with the craftspeople and users involved showed the extent to which the design requirements – durability, thermal comfort, availability, affordability, aspiration, and expandability – identified on the basis of the preceding ethnographic analysis were relevant and could be considered. Feedback from craftspeople and users has shown that the school is considered a strong and safe building. An appropriate term for it, however, seems to be missing, as feedback rounds with schoolchildren and craftspeople reveal. The simultaneous mixed shouts of “pukka” and “kutcha” when the children were asked, and the resulting fusion of their shouts into “kukka” or “putcha” might serve as new terms for the used hybrid method, overcoming the existing polarization. “It is both: Outside pukka, inside kutcha.” “It is kutcha, because of the use of bamboo and earth, but it is also pukka, because of its strength.” Apart from the use of bricks and reinforced concrete for the foundation, cement for the plaster of the exterior walls and corrugated iron for the roof, according to the interviewees this is also due to the strong bamboo joints with threaded rods and nuts. “The building appears safe. That is why it is a pukka building for me,” Mr. Kumar, head of the Bahuarwa Foundation concluded. The state officers came to similar conclusions when they evaluated the new infrastructure of the school and

decided to provide it with an official affiliation. Furthermore, the size of the school is proof that it is a pukka house, since kutcha houses usually consist of only a few small rooms. Two of the craftspeople involved were already convinced during the construction that they would build their house the same way. Another resident of Bahuarwa is considering using a similar construction for the building of a workshop and the carpenter in charge has been asked by another resident if he can build him a house in a similar style. This shows that the categorization of a pukka house does not necessarily depend on the (exclusive) use of more carbon-intensive materials and the avoidance of regenerative materials. Furthermore, the integration of regenerative materials allowed a reduction in the use of emission-intensive building materials such as fired bricks (60%), concrete (70%) and steel (80%) compared to a conventional RCC construction, which contributes to a smaller ecological footprint. Even though the lower construction costs, the contemporary look and the thermal comfort convince the respondents of the construction method, they also express doubts. One main reason for this is that the school's roof is not accessible, and the school cannot be extended vertically. Other doubts concern the durability of the building. Despite the school's impressive size, they do not have enough proof on whether it is also durable, which is why most will continue to rely on the use of bricks and reinforced concrete despite higher financial costs. Further dissemination of the construction method therefore also requires a longer assessment period and the withstanding of environmental challenges to prove the durability of the construction method. However, a crucial factor is also that materials, infrastructure and expertise regarding the construction method used must be more readily available in order not only to motivate residents to use the method, but also to empower them to do so. Lacking and wrong incentives in government housing programs further complicate the dissemination. Figure 110 provides an overview of the relevant design factors, evaluating and juxtaposing them to highlight their roles in the reintegration of regenerative building materials.

Figure 110 (following double page): Overview of the relevant design factors and their interrelationships for the reintegration of regenerative building materials.

ensuring the durability of a building with regenerative building materials requires more expertise as the materials are often more sensitive to errors than fired bricks, cement and steel.

regenerative building materials have the potential to improve thermal comfort and thereby reduce the costs to buy and operate energy intensive building services, such as air conditioner.

lower building costs do not necessarily mean lower lifecycle costs. however, the life expectancy of buildings made with regenerative building materials is often not (yet) clear and convincing references for clients and users are rare.

affordability

regenerative building materials are often cheaper than highly processed ones, due to the low labour costs they can lead to lower building costs. they promote regional value creation and offer opportunities for self-construction, which can further decrease the building costs.

when applied skillfully, e.g. in combination with vernacular building methods, regenerative materials can improve thermal comfort by balancing temperature and humidity without the need for expensive and energy intense technology.

thermal comfort

regenerative building materials alone do not guarantee better thermal comfort. only when applied skillfully, regenerative building materials can improve thermal comfort. however, the required expertise is decreasing.

the required structure protecting roof for incremental expansion building can increase costs. however, the costs can also reduce of incrementality for financial reasons.

durability

the higher the rate of building materials, the renewability of a lower is usually achieved and the higher are maintenance efforts can be solved through combination with other

use of regenerative building materials

skills and knowledge regenerative building decrease. infrastructure contemporary treatment processing of materials lacking. training craftspeople and design methods further an

availability

since the lack of thermal in houses made of reinforced concrete improved by building thermal comfort is secondary to other

Challenging and Supporting Relations

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in case regenerative building materials are not well protected during an incremental expansion of the building, the durability of it might be negatively effected.

expandability

in contrast to reinforced concrete slabs and fired brick walls, regenerative building material need protection from the weather, which makes an incremental building process and a vertical expansion more challenging and requires more expertise and planning.

regenerative building materials also convey a social message. to avoid stigmatizing users it is recommendable to make these materials not too visible from outside, color or paint them and use them with their natural expression rather on the inside.

aspiration

the people's aspirations are also shaped by what they see in nearby towns or through digital media. convincing references for a contemporary use of regenerative building materials are rare.

the necessary measures for an incremental expansion of buildings made of regenerative building materials results in a different expression which might not align with the users' aspirations regarding a contemporary look of a building.

ensuring an incremental expansion of a building with regenerative building materials requires more planning and expertise which is often not available.

“We have a cool school,”

the schoolchildren proudly proclaimed,
as they compared themselves to students
from more expensive private schools,
whose brick and concrete rooms
absorbed and retained heat, leaving
them sweaty and uncomfortable.

6 Conclusion

6.1 Research Objectives and Questions

The dissertation started by situating the building sector within the framework of the Paris Agreement (2015) and highlighting India as an example of the rapid shift from locally rooted vernacular building traditions to global construction industries. The case study of Bahuarwa reflects these dynamics on a local and peripheral scale, where building methods based on bamboo and earth were common until the late 20th century but are now increasingly displaced by fired bricks, concrete, and steel, with profound environmental and social implications.

The first aim of this dissertation was to develop a deeper understanding of the multiple factors influencing building practices in Bahuarwa and driving the shift from regenerative toward more carbon-intensive materials.

The second aim was to design and implement a hybrid construction combining vernacular and new ways of building. This approach was applied in the participatory construction of a school for the Bahuarwa Foundation. The evaluation of this practical intervention was intended to identify the potential of a context-specific application of regenerative materials, with respect to issues of social acceptance as well as political, and economic frameworks that shape building practices in Bahuarwa.

The third aim was methodological in nature. The dissertation was guided by principles of transformative research (Schneidewind & Singer-Brodowski, 2013; Wittmayer & Hölscher, 2017), seeking to examine the potential of participatory action research (Greenwood & Levin, 2007; Sanoff, 2000), and research by design approaches (Borgdorff, 2005; Hauberg, 2011) not only for the generation of scientific knowledge but also for the creation of tangible benefits for the research participants and target groups. These overarching aims are reflected in the following three research questions:

What factors shape the transition from vernacular to new building practices – from kutcha to pukka houses – in Bahuarwa?

To what extent can a hybrid construction method that combines regenerative and carbon-intensive materials challenge the prevailing dichotomy of kutcha and pukka houses in Bahuarwa?

How does the construction of a school for underprivileged children contribute to the dual production of scientific knowledge and local social benefits?

The subsequent sections outline the extent to which the three research questions have been addressed and situate the findings within the broader conceptual framework of the dissertation. In doing so, the conclusion highlights not only the theoretical relevance for ongoing debates on the use of regenerative materials but also the impact on the target groups. This is followed by a critical reflection on limitations and open questions, which consider identified shortcomings, methodological, and practical constraints. A set of recommendations for a context-sensitive application of regenerative building materials is listed, thereby offering guidance for future research, policymaking, and architectural practice in comparable contexts. A final personal reflection illustrates the impact this research has had on me and how the search for a compromise between kutcha and pukka, raw and fired, took on a much broader significance.

6.2 Summary of Key Findings

What factors shape the transition from vernacular to new building practices – from kutcha to pukka houses – in Bahuarwa?

The cob construction method, which was still predominant a few decades ago, is no longer used today and no cob walls can be found in Bahuarwa anymore. The durability of these walls was too low, and the effort required to repair the houses after intense rainfall or to rebuild them after floods and earthquakes was too great. Instead, a less labor-

intensive bamboo structure was used for the walls. Thatched roofs fared similarly to the solid cob walls. They too are hardly used anymore. This was initially due to the material's high flammability, which regularly led to devastating village fires at a time when most buildings were thatched. Today, where only a few houses are still covered with a thatch roof, the intensive rainfall of the monsoon poses a greater problem. Even if the thatched roof protects the inhabitants from the summer heat better than roof tiles or corrugated sheets, the maintenance efforts are too high, and the waterproofing is insufficient to fulfill the needs of the inhabitants. While roof tiles or corrugated sheets made of fiber cement or metal are durable and affordable alternatives for poorer households, they are often only an intermediate step in an incremental construction process on the way to a building made of reinforced concrete and fired bricks. These materials meet the central need of the inhabitants for a durable and low-maintenance building that withstands the rains of the monsoon, offers protection from flooding, and cannot be damaged by insects and fungi.

While protection against natural hazards is the central motivation for adaptations, especially for poorer residents, wealthier households, whose houses already offer sufficient protection against environmental challenges, are more concerned with expanding interior spaces due to increased needs for privacy and changing family structures. Fired bricks and reinforced concrete allow the construction of larger rooms, bigger openings, accessible roofs, and multi-story houses, which allows more efficient land use. Plaster and paint enable the individualization of the house counteracting the convergence of this globally occurring construction method. The inspiration for new ways of building comes from nearby towns as well as from more distant metropolitan regions, which are often visited by male family members in search of work. In addition, residents are influenced by the internet, which also brings less-mobile residents – such as women and children – closer to more urban ways of building and living, at least digitally.

Summary of Factors Influencing Changes in Building Practices in Bahuarwa

Influencing Factor	Key Aspects	Explanation
Environmental Challenges	durability, maintenance, hazard protection against; fire, rain, flooding, earthquakes, pests	cob walls and thatched roofs have largely disappeared due to poor durability against monsoon rains, floods, earthquakes, fires, and pests. although bamboo structures offered lighter alternatives, they too required constant upkeep. industrial materials such as bricks, cement, and steel provide durability, low maintenance, and resistance to hazards, meeting the core needs of households.
Socio-economic Transformations	changing family structures, needs for privacy, labor migration, digital media, individualization, social stratification	poorer households prioritize hazard protection, while wealthier families focus on fulfilling increased needs for private space and individuality, by expanding rooms, building multistory houses, and individualizing facades. inspirations stem from labor migration, and digital media. bricks and concrete symbolize progress and higher status, experienced in urban areas where people earn more money, whereas regenerative materials are associated with poverty and marginalization.
Technological Developments	cement and steel industries, brick kilns, policy-driven polarization, deskilling, availability	the proliferation of brick kilns, cement, and steel industries ensures steady supply of these materials, reinforced by state housing programs that equate kutcha with backwardness and pukka with progress. this displaces local crafts and regenerative practices, while higher material costs drive incremental construction processes that often leave households in unfinished buildings.

The changes in the choice of materials and construction methods are also determined by the available supply. The numerous decentralized and informally organized brick kilns, along with the country's cement and steel industries, meet and stimulate the demand for new construction methods. This demand is further increased by government housing programs that enhance the polarization of kutcha and pukka buildings (Roychowdhury et al., 2022, p. 21), with the former being considered backward and the latter progressive. However, this is less about evaluating the buildings than the building materials used, or rather the industries producing them, so that the housing programs are primarily boosting the construction economy. The building industries in turn displace locally rooted crafts and the use of regenerative materials. The supposedly advanced building materials require longer production chains, higher processing temperatures and longer transportation distances than their vernacular predecessors, which also makes them more

Table 5: Summary of the factors influencing changes in building practices in Bahuarwa.

expensive. The high prices in turn lead to an incremental construction process, especially for poorer households, which can extend over years and decades, eventually leaving inhabitants with a pukka foundation but no proper roof over their heads.

These developments demonstrate how environmental challenges, socio-economic transformations, and technological developments drive the shift from kutcha to pukka houses, and how this transition is embedded in broader structural processes beyond the village context (Table 5).

To what extent can a hybrid construction method that combines regenerative and carbon-intensive materials challenge the prevailing dichotomy of kutcha and pukka houses in Bahuarwa?

A central persuasive criterion of regenerative building materials in the Bahuarwa region lies in the lower costs compared to fired bricks and reinforced concrete. By using bamboo, earth and thatch, the school could be built at least 25% cheaper compared to an RCC construction method. In addition, the integration of regenerative building materials allows more work to be carried out by the residents themselves, which results in further savings. The savings, in turn, can speed up the construction process and ensure that the residents do not have to wait in a half-finished house, while saving more money for the completion. The use of bamboo allows a rapid and relatively affordable construction of a shelter, which can be extended at a later stage. This is a major advantage, especially in emergency situations following disasters, compared to building methods using bricks and reinforced concrete, which are more expensive and require longer construction times due to the installation of formworks and necessary drying times.

In terms of financial savings, the use of regenerative building materials also comes with a higher potential for achieving thermal comfort. Bricks and reinforced concrete heat up more and store heat. In a subtropical climate with rather low day-night temperature differences, the building does not drastically cool overnight. This leads to constantly high indoor temperatures and an increased need for fans and air conditioning systems, which are not affordable for people

from underprivileged backgrounds. The choice of suitable building materials in combination with climate adapted design measures is a more cost-effective option than the use of expensive air conditioning systems. This factor will become more important in the context of climate change and could boost the integration of regenerative building materials and more climate-adapted construction methods.

The use of bamboo, earth and thatch also promotes regional value creation. Compared to the production of fired bricks, bamboo could be planted, treated and processed regionally with much less infrastructural effort. Locally available earth could be used even more simply and without further treatment. The same applies to thatch, which is a by-product of agriculture. The material properties of bamboo, earth and thatch are also advantageous for a healthier and more inclusive construction process, as they are gentler on the skin and lungs, and more physically comfortable to work with than fired bricks, cement and steel. Thus, elder and female villagers in particular, who generally have little connection to construction methods using bricks and reinforced concrete or are even excluded from handling them, could also participate in construction.

The central need for a durable house that is fireproof, survives the monsoon, withstands earthquakes and is not eaten by insects does not necessarily have to lead to a complete rejection of regenerative building materials, as is currently the case, but can continue to be used sensibly through an adapted use in combination with more carbon-intensive building materials. While more heavily processed and therefore often more water-resistant materials are suitable for the components that are more exposed to the weather, such as the plinth, facade and roof, the better protected interior walls and ceilings allow the use of regenerative building materials. The decisive factor is the appropriate use of building materials depending on the specific material properties and considering the necessary design measures, such as protruding roofs and high plinths.

The situation is similar with the residents' ideas about the expression of a contemporary house and the social status associated with it. The desire for a house with a plastered facade that can be individually decorated does not preclude

the use of regenerative building materials. The exterior walls of the school were plastered and colored to meet the aspirations of the target groups. However, the load-bearing structure of the walls, ceilings and roof were made of bamboo. Earth and thatch were used for the infill and plastering of the interior walls. This hybrid solution was not just accepted by the local population as a compromise but was perceived as a successful combination of their demands. While the cement-plastered and colored exterior walls meet the requirements for durability and contemporary expression, the interior walls, infilled with earth and thatch, contribute to the thermal comfort of the building.

Although the environmental impact is insignificant for the inhabitants of Bahuarwa in their assessment of building materials and methods, it does have an impact on their living conditions. The growing demand for concrete, mortar and plaster, is leading to illegal overexploitation of sand from numerous riverbeds in Bihar. Destroyed riparian zones increase the risk of flooding and endanger surrounding villages. The risk of flooding is further exacerbated by an increased occurrence of extreme weather events as a consequence of climate change. Compared to a conventional RCC construction, the school used around 60% less fired bricks, 70% less concrete and 80% less reinforcement steel. The savings potential can be further increased with the construction of multistory buildings or by using earth instead of cement for well-protected exterior walls. These savings lead to lower carbon emissions and reduced demand for sand, which besides its general positive impact on the environment reduces the risk of flooding in Bahuarwa.

By aligning material choices according to their technical properties and social significances, it was possible to balance durability, social aspirations, and affordability while significantly reducing environmental impacts. This negotiated integration not only enabled broader participation in the construction process and enhanced thermal comfort but also demonstrated the potential for hybrid methods to challenge the prevailing polarization of regenerative kutcha versus more carbon-intensive pukka building materials, thereby pointing towards more context-sensitive and sustainable pathways of building (Table 6).

List of Advantages of Regenerative Building Materials

Potential	Key Aspects	Explanation
Cost Efficiency & Accelerated Construction	lower costs, faster building, rapid shelter	building with bamboo, earth, and thatch reduced costs of school by at least 25% compared to RCC. self-build opportunities further reduce expenses, speed up construction, and provide immediate shelter – crucial in post-disaster situations and for poorer households.
Thermal Comfort & Reduced Energy Demand	climate responsiveness, lower energy demand, lower costs	regenerative materials prevent heat storage and maintain cooler indoor temperatures, reducing reliance on fans and expensive ac. this is particularly important for underprivileged households in a subtropical climate and gains further relevance under climate change.
Regional Value Creation & Inclusive Labor	local sourcing, more jobs, improved working conditions, inclusivity	bamboo, earth, and thatch can be produced and processed locally with low infrastructural investment. their physical properties allow safer, less strenuous handling, enabling participation by women and elderly villagers and fostering regional economy.
Context-sensitive Hybrid Applications	weather protection, visibility, appropriate combination	durable, weather-exposed components can be built with processed, carbon-intensive materials, while protected building parts integrate regenerative resources. the school exemplified this hybrid model, balancing social aspirations and environmental performance.
Environmental Benefits & Risk Reduction	lower emissions, reduced sand extraction, climate resilience	compared to conventional RCC construction, the school saved 60% fired brick, 70% concrete, and 80% reinforcement steel. this reduces carbon emissions, lessens sand mining, and helps mitigate flood risks linked to environmental degradation and climate change.

How does the construction of a school for underprivileged children contribute to the dual production of scientific knowledge and local social benefits?

The link between research and design motivated me to work on this project over a period of almost five years with great passion, as it expanded the scientific purpose of the research and gave it social significance. Even when I sometimes lost my enthusiasm for the research, I never doubted the purpose of building the school. The school ensured a fair exchange between me and the target groups, with me gaining data and the target groups benefiting from an improved educational infrastructure. While the research made little sense to the target groups, the school did. Knowing that their data would contribute to the construction of the

Table 6: Summary of the advantages of regenerative building materials in challenging the prevailing focus on pukka construction.

school, the research participants were motivated to engage in conversation or show their homes.

The school construction also helped to make the research tangible. During the construction process, the research, which was previously abstract for most participants, took on a concrete form. The joint construction work provided a natural starting point for conversation, while questioning the residents with interviews sometimes seemed forced. The connection to the topic was suddenly given by a meaningful activity and not by an unexpectedly asked question.

In addition to the craftspeople, curious villagers were on the construction site every day, not afraid to express their opinions about what was happening and perhaps even start a discussion with other onlookers or craftspeople. Since we were usually present at the construction site ourselves, coordinating the work and lending a hand, we heard the sometimes loud, sometimes secret comments, memories, suggestions, complaints, and questions.

The school represented a common goal for all involved, the achievement of which was only possible through communication and cooperation. The hybridization of regenerative and more carbon-intensive building materials represented a negotiation of a compromise between different values, and thus also provided a source of friction which often resulted in the most relevant findings and in a deeper awareness not only of the research context but of my own origin. It became a central means of communication, or, as Hauberg (2011, p. 48) puts it, "an equal agent in the production of knowledge."

The construction process also allowed for a concrete experience of the conditions that complicate the use of regenerative building materials in Bahuarwa. For example, an unsuccessful search lasting several days for experts in contemporary bamboo construction in the region of Bahuarwa, despite the abundance of bamboo, demonstrated how far deskilling in this field has already progressed. Another time-consuming search process was necessary when the bamboo experts ran out of threaded rods and we finally had to ship them in from Delhi, since this supposedly simple joining material was not available in the entire Bihar.

Another striking experience, which would hardly have become apparent through interviews and participatory observation, was the atmosphere on the construction site, which varied depending on the building material being processed and was most joyful when working with earth and bamboo. About fifteen to twenty people worked on the school's construction daily for three months, mostly from Bahuarwa and nearby villages, except for three bamboo experts from Gujarat. Many parents and grandparents of the schoolchildren contributed to the construction. While men carried out most of the construction, the earthwork was mostly done by women. The participants were paid according to standard wages in the area. In addition to receiving wages, the participants gained hands-on experience with the hybrid construction methods, especially innovative techniques for working with bamboo.

The research resulted in the construction of a school that, as of the time of printing in Fall 2025, is attended by around 150 children. According to the Bahuarwa Foundation, the number of students is expected to increase when more people become aware of the school. With its seven classrooms, a teacher's room, a multipurpose hall, and two sanitary facilities, the school can be used by as many as 250 children, according to the estimate of the Bahuarwa Foundation.

Even though the classrooms, with an area of around twenty square meters each, may seem small compared to the standards in other countries, they are still one-third larger than before, and meet the requirements of the Bahuarwa Foundation. The three-meter-tall rooms are almost double as high than the previous temporary structure, which further contributes to a spacious feeling.

Students as well as teachers have continually underlined the thermal comfort of the classrooms in surveying done since they began occupying the construction. Even in the hot summer months when temperatures reach more than 40° Celsius, ceiling fans rarely need to be turned on. This differentiates the school from others, such that the schoolchildren started to brag about their "cool school" when they encounter other children covered in sweat, on their way home after a day in more expensive private schools made of fired bricks and reinforced concrete.

List of Dual Benefits

Potential	Key Aspects	Short Explanation
The School as a Motivator	motivation for researcher, motivation for target groups, fair exchange	the school maintained the researcher's long-term engagement and gave social significance to the research; participants were motivated knowing their data contributed to the school.
Design as a Data Generator	tangible research, natural start for conversations, practical observations	construction made research tangible, stimulating discussions, observations, and exchanges that would not occur through interviews alone.
Test of Insights and Identification of further Gaps	practical challenges, material availability, site experience	construction revealed local expertise gaps, logistical challenges, and the emotional atmosphere of working with different materials.
Regional Value Creation and Knowledge Transfer	local employment, skill sharing, fair compensation	around 15–20 local people were employed, received wages, and gained insights into bamboo construction; women participated in earthwork.
Improved Educational Infrastructure	room sizes, weather protection, thermal comfort	school built with seven classrooms, multipurpose hall, and sanitary facilities; larger, well-ventilated, and thermally comfortable spaces improved learning conditions.
Promotion of Educational Opportunities	accreditation, gender equality, community use	school gained state accreditation, increasing enrollment (especially girls); multipurpose hall serves educational and community needs, improving social benefits.

The new infrastructure not only improved learning conditions but also led to the school being accredited by the state, which had previously been refused due to the lack of sanitary facilities and the temporary and fragile nature of the classrooms. The school building and the official recognition of the education mean that more parents are convinced to send their children to school instead of putting them to work at home or in the fields.

Even less disadvantaged families started to send their children – especially girls – to the comparatively inexpensive school of the Bahuarwa Foundation, as they would not want to spend much money on their education. Thus, the school not only contributes to overcoming the divisions between castes, but also to improving gender equality. However, this is primarily an achievement of the Bahuarwa Foundation, which places particular emphasis on these issues.

The new building provides an additional incentive for children to attend school, as it provides better protection from the weather than many of the children's homes. This is why many children also spend a large part of their free time at

Table 7: Summary of the dual production of scientific knowledge and local social benefits achieved through the participatory construction of the school.

school doing their homework and playing. Due to the participatory planning process, the construction could be well aligned with the needs of the teachers and other users. One result of this collaboration is the multipurpose hall, which also serves as a community center where, for example, medical treatments, wedding ceremonies, and community assemblies are conducted.

By making research tangible, fostering dialogue, and motivating participation, the school project demonstrated how design and research can be mutually reinforcing, producing both academic knowledge and meaningful local impact (Table 7).

6.3 Contributions

Towards a Context-Sensitive Approach

The dissertation investigated buildings “without architects” (Rudofsky, 1964), regenerative materials, and the everyday practices of Bahuarwa residents – supporting the view of discourses around habitat and vernacular ways of building (Roesler, 2013, pp. 215–277) that the ordinary house is a relevant source to inform more sustainable, climate adapted ways of building (Oliver, 2006; Piesik, 2017). The research expands architectural ethnography by moving beyond observation to co-production of a building, thereby situating knowledge-making in both fieldwork and design. Rapoport’s (2002, pp. 46–49) insistence that single causes such as climate, materials, or technology alone are insufficient to explain building practices is mirrored by this dissertation showing that material shifts in Bahuarwa are driven by a multilayered, interdependent set of factors. Different from Rapoport (2002, pp. 18–45), however, who privileges cultural and social determinants over environmental ones, in Bahuarwa, the primary driver for a change of building practices is protection from natural hazards. This finding challenges Rapoport’s ordering and suggests that weightings between factors are context-sensitive and depend on the socio-economic conditions of the residents. In low-income, hazard-exposed contexts, for instance, the environmental drivers can supersede socio-cultural ones.

Although Bahuarwa appears at first glance to be a rural village with few urban characteristics, the research shows how peripheral contexts are shaped by urban aspirations, digital media, and construction industries. The transformation from kutcha to pukka constructions is embedded within these dynamics, which materialize concretely in buildings. The questioning of the kutcha-pukka dichotomy thus aligns with broader debates that challenge categories such as rural-urban (Denis & Zérah, 2017), agrarian-urban (Bathla, 2024), and, more broadly, Global North-South (Robinson, 2002; A. Roy, 2005). It represents an effort to transcend such simplifying and generalizing polarizations through context-specific fieldwork tailored to place and community, employing appropriate tools.

Reading Social Changes through Material Transitions

The hybrid construction developed in this dissertation illustrates Semper's Stoffwechseltheorie (Chestnova, 2018), as it recombines materials such as bamboo, earth, and cement in ways that reconfigure both their symbolic and functional meanings. In doing so, it demonstrates how the polarized perception of regenerative versus carbon-intensive materials can be challenged. For example, the cement-plastered and color-painted bamboo wall appears like the masonry or concrete wall of a pukka house, thereby escaping stigmatization and enhancing social acceptance.

At the same time, the research reveals the risks associated with a metamorphosis of materiality. While the disguise of renewable materials within a pukka aesthetic increases social acceptance, it also diminishes the potential lighthouse effect that could foster broader dissemination of the hybrid construction approach integrating regenerative materials. This tension underscores the need to negotiate a critical balance between visibility and concealment, raising the question of whether material transformation alone is sufficient, or whether a fundamental shift in aesthetic attitudes toward renewable materials – and the transience they embody, which ultimately affects us all – is required.

Semper's proposition that material identities can be transformed through "human judgement and ingenuity" (Chestnova, 2018, p. 118) aligns with the practice of plastering

bamboo to mimic masonry. Yet, this metamorphosis necessitates chemical treatment of the bamboo and the application of cement plaster and paint, thereby reducing the renewability of the materials and disturbing a metabolism (Daly, 1993) between building practices and the environment within the “planetary boundaries” (Rockström et al., 2009). Government subsidies, building industries, and markets channel material flows toward high embodied-energy resources. Simultaneously, environmental concerns such as illegal sand extraction (Narendra, 2023), river degradation (Bhadbhade et al., 2020), rising temperatures, and more frequent flooding events illustrate the overextension of local ecological absorption capacities.

The dissertation shows that material transitions cannot be understood in isolation from broader socio-ecological dynamics. Instead, they provide a lens to read social practices and values. The material transitions analyzed in this research and the obstacles encountered when trying to integrate regenerative building materials in new ways of building, reflect a broader metabolism between humans, society, and nature (Burkett & Foster, 2010, p. 227).

Hybridization

The development and testing of a hybrid construction method addresses the displacement of regenerative materials by cement, steel, and fired bricks in India’s rapidly growing construction sector (IEA, 2021, p. 82). The research contributes to calls (Roychowdhury et al., 2022, pp. 20–22) for overcoming the kutch-pukka dichotomy by demonstrating concrete ways in which hybrid approaches can combine the thermal advantages of regenerative materials with the durability of more carbon-intensive ones.

The dissertation supplies quantified and practice-based evidence – 25% cost savings; half the building weight, 60–80% reductions in uses of cement, steel, and fired bricks; thermal comfort reported by users – that support existing research (Praseeda et al., 2014; Shubham & Kolhatkar, 2020; Zea Escamilla et al., 2018) and more theoretical claims about hybrid regenerative benefits (Roychowdhury et al., 2022). These numbers help to operationalize the hybrid argument for policymakers and designers. However, the

research also shows that individual lighthouse projects are not enough to upscale alternative construction methods unless they are supported by adequate taxation of more carbon-intensive materials, subsidy rules, artisan training and recognition, advancement of infrastructures and technical expertise.

6.4 Limitations and Open Questions

Durability – Regenerability Conflict

In contrast to fired bricks, cement and steel, bamboo, earth or thatch are not fired at high temperatures and therefore retain their original, natural properties. This allows the materials to be easily regenerated. At the same time, it is the regenerability that reduces the durability of the materials. The lack of durability, in turn, is the main reason mentioned by the residents interviewed for replacing regenerative building materials with non-renewable ones.

This contradiction proved to be a challenge in the context of this research, particularly regarding the use of bamboo. To ensure its long-term use, the material must be chemically treated, otherwise it risks falling victim to termites or beetles. While treatment for indoor applications with boron salt is relatively harmless, for outdoor applications the material must be treated with additional fixing agents such as copper and chromium, which ensure that the insect-repellent boron is not washed away by rain (Kaminski, Lawrence, & Trujillo, 2016, pp. 28–30). Scharfenberg et al. (2021) show that these chemicals – primarily the copper and chromium components – have a negative impact on the environment. Even if they are bound in the material and therefore should not leach out, the question still arises as to where they end up at the end of their life cycle. Either they rot in landfill, or they escape into the air as gases when incinerated.

The contradiction between regenerability and durability also applies to the materials earth and thatch. Earth walls and thatched roofs must be continuously maintained to withstand rainfall and floods during the monsoon season. Even if the infestation of a massive cob wall by termites does not have a significant impact on its load-bearing capacity, it still has negative consequences for the livability of the building,

as the termites gain access to other organic components of the house, such as furniture made of timber or books and documents, through tunnels in the walls. This tension raises the question of the extent to which durability can be enhanced through treatment, or blending with more carbon-intensive materials, without compromising regenerability.

Infrastructure and Expertise Limitations

The need to treat bamboo for the construction of the school demonstrated the importance of availability of necessary infrastructure. While bamboo is locally available in the Bahuarwa region, there are no nearby treatment facilities to ensure the durability of the material. As a result, despite its local availability, the material had to be extracted in the eastern Indian state of Assam, treated over 2000 kilometers away in Ukai in the western Indian state of Gujarat and transported 1600 kilometers back to Bahuarwa. Although the locations for sourcing and treating the bamboo and therefore the distances were influenced by the cooperation with CIBART, it became clear that the treatment options for bamboo or the availability of treated bamboo are negligible compared to the availability of brick kilns or cement and steel supply.

Like the treatment options, craftsmanship and knowledge regarding a contemporary use of bamboo and earth are also limited. This was one of the reasons why bamboo experts from Gujarat had to be called to help build the school in Bahuarwa. Although there are still some villagers, especially older ones, who are familiar with the vernacular use of bamboo for building houses, they are not familiar with new joining techniques.

In general, bamboo in India is mainly used for furniture, furnishings and everyday objects. Only a few companies and organizations use bamboo for construction purposes. The survey of CIBART employees showed that structural applications of bamboo are almost exclusively in connection with the tourism and hospitality industries. Contemporary bamboo construction has hardly been used for residential buildings and social purposes in India to date. As a result, there is a lack of lighthouse projects that could relativize the negative associations of regenerative building materials.

Consequently, not only buildings but also work with regenerative materials such as bamboo and earth are associated with a low social status. Although many of the residents encountered prefer working with bamboo and earth to bricks and reinforced concrete, most still work mainly with the latter, due to the higher demand. Limited employment opportunities, low status and lack of training mean that vernacular crafts are increasingly being lost.

Limited Technical Possibilities

Bamboo and earth are associated with dark and cramped spaces, while the use of fired bricks and reinforced concrete allows for high rooms and large openings. Changing family constellations and increased demands for privacy lead to a need for additional interior space, so that families with small plots of land often build over them completely. Thus, the traditional courtyard (angan) must make way for a covered corridor (gully), and the walk-on reinforced concrete roof takes over the functions of the built-over courtyard. Regenerative building materials, as the inhabitants of Bahuarwa know them, do not allow for increased land utilization through multistory construction. The lack of multistory construction and the fact that the roof is not accessible was also one of the main points of criticism of the newly built school. Although multistory buildings can be constructed from bamboo and earth, there remains a relevant disadvantage compared to bricks and reinforced concrete, namely that incremental expansion is difficult to implement. As bamboo and earth must always be well protected from the rain, the construction process cannot easily be carried out in stages. This would mean that all components already built would have to be protected by a (temporary) roof during the rainy season. In contrast, a brick wall or a concrete slab, which represents floor, ceiling and roof in equal measure, can be exposed to the weather over a longer period without suffering major structural damage before the building gets extended.

List of Challenges regarding the Integration of Regenerative Building Materials in Bahuarwa

Challenge	Key Aspects	Explanation
Durability – Regenerability Conflict	design measures, insect protection, chemical treatment, ecological risks	regenerative materials are easily renewable but lack durability under monsoon rains, floods, earthquakes, or termite infestations. protective design measures help but rarely match the performance of industrial materials. chemical treatments improve longevity but introduce ecological risks at end-of-life.
Infrastructure & Expertise Gaps	lacking facilities, deskilling, low social recognition, decreasing demand	despite local availability, bamboo had to be transported long distances for treatment due to missing local infrastructure. knowledge of new joinery techniques is limited, requiring outside experts. regenerative building methods carry low social prestige, leading to a decline of crafts and limited employment opportunities.
Limited Technical Possibilities	limited vertical expansion, problematic incremental construction	residents increasingly demand multistory houses, and accessible roofs, which are more difficult to achieve with bamboo and earth. incremental construction is problematic, as regenerative materials require protection from rain, unlike bricks or concrete that can remain exposed during staged building.
Institutional & Educational Influences	polarizing housing programs, limited awareness, media influences	state housing programs promote brick, cement, and concrete by equating pukka houses with progress. this fosters dependency on costly, carbon-intensive materials and energy-intensive appliances, while neglecting alternatives. limited education and polarizing media hinder acceptance of regenerative materials.

Institutional and Educational Influences

The perception of building materials and methods depends on more than just the personal experiences of Bahuarwa's inhabitants. It is also shaped by state housing programs, which enhance a polarization of vernacular building methods based on regenerative materials and new building methods using fired bricks, cement and reinforced concrete. The state supports poorer sections of the population to replace a kutchra house with a pukka house. Although the government does not explicitly prescribe the choice of building materials, it propagates the use of fired bricks and reinforced concrete. This boosts the industries that produce these building materials but also pushes households into a dependency on expensive building materials – and air conditioners – that prevents the further development of context-specific construction methods. Furthermore, limited public understanding of interactions between building practices

Table 8: Summary of the identified challenges in integrating regenerative building materials into new construction methods.

and environmental degradation, combined with insufficient education and polarizing media content, hampers the adoption of climate-adapted construction methods. Table 8 summarizes the challenges identified regarding the integration of regenerative building materials into new construction methods.

Considerations regarding the Research Design

The combination of ethnographic research and school construction required more time and resources than would be necessary for research without a built intervention. The preparations for the construction of the school, such as the search for suitable partner organizations for its operation, construction, and financing, were time-consuming and had to be carried out in addition to the ethnographic research. For this reason, it was crucial to design the research in such a way that some of the required processes could also be used as data sources.

The research depended on external factors, such as project partners, donors and weather conditions, which made it challenging to develop a schedule and adhere to it. For example, it was still uncertain at the end of the preliminary study whether the foundations approached to finance the construction of the school would do so. After that, it was unclear how much time the construction would take, how many villagers would participate and how many bamboo experts would be available. These numerous external factors posed a risk, yet they were also essential for transformative research, enabling the testing and generation of findings in a real-world context.

The varying expectations of our partners and target groups regarding the use of regenerative building materials illustrate another challenge: While the use of bamboo and earth was an important reason for donors in Switzerland and Liechtenstein to support the project, as they focused on environmental aspects of sustainability, the residents of Bahuarwa initially met this intention with great skepticism, as they preferred a building made of fired bricks and reinforced concrete. The differing expectations of those involved required the development of compromises and a great deal of mediation tailored to each respective audience. At the

same time, these conflicts were also relevant sources of data, as they underscored the context dependent understandings of sustainability.

Cultural differences affected the understanding of research. For most of the inhabitants of Bahuarwa, research was an incomprehensible term, as were the associated methods and requirements such as interviews or consent forms. A translation was required in the sense of an appropriate adaptation of the research design to the context. To meet both the requirements of the target groups and the (Western-influenced) scientific standards, transparency and reflection were central, as Wittmayer and Hölscher (2017, pp. 67–69) also demand in transformative research.

Dealing with a foreign culture involved numerous unfamiliarities in terms of language, climate, food, and cultural specificities. Overcoming these challenges required a sufficiently long stay of around four months in the research context and working with trustworthy translators and partners who are familiar with the local context. In this case, my wife Isha played a central role in both the data collection through interviews and home visits, as well as the implementation of the school. Without her network, her translations and mediation between me and the research groups, neither the research nor the school construction would have been possible. This makes it clear that such a research design requires many prerequisites and therefore cannot be easily replicated.

Due to time pressure and the limited availability of bamboo experts, the intended knowledge transfer through workshops during the building process was only possible to a limited extent. Dependence on the project partner CIBART, who could not provide its experts for a longer time, as well as our limited timeframe to be physically present on site, did not allow this goal to be achieved as planned.

Overall, the research design demonstrated that combining ethnographic study with a built intervention requires significant time, resources, and careful coordination with partners, donors, and local communities. External factors, cultural differences, and varying expectations highlight the importance of flexibility, transparency, and context-sensitive adaptations (Table 9).

List of Considerations regarding the Applied Research Design

Consideration	Key Aspects	Description
High Resource and Time Demand	searching project partners, organizing construction, securing of financing	the research required more time and resources than studies without a built intervention, making it crucial to design processes that could also serve as data sources.
Dependence on External Factors	project partners, donors, weather conditions	external factors created risks and scheduling difficulties, but also provided valuable data sources essential for transformative research.
Diverging Expectations of Stakeholders	understanding of sustainability	conflicting expectations required compromises and tailored mediation, highlighting context-dependent understandings of sustainability.
Cultural Differences	research design, interview recordings, consent forms	research design needed adaptation and transparency to bridge western scientific standards and local comprehension.
Navigating Foreign Culture	language barriers, climate, food, local customs, trusted networks	successful research required long-term presence, language skills, and trusted translators/partners; personal networks were essential for implementation.
Limited Time for Knowledge Transfer	availability of bamboo experts, project partner constraints, limited on-site presence	workshops for knowledge transfer were limited; future projects should allocate more time and provide treatment facilities to support dissemination of methods.

6.5 Recommendations

To conclude I identified eight recommendations for future research, practice and policymaking on the use of regenerative building materials in Bahuarwa and contexts with similar socio-economic and climatic conditions:

1. *Do not view contexts in the Global South as a testing-ground for a radical integration of regenerative building materials.*

The use of regenerative building materials should be coordinated with the needs and aspirations of users to achieve widespread social acceptance. Contexts in the Global South must not serve as experimental fields for testing radical approaches. The needs of the residents should be placed in the foreground and hybrid solutions of differently processed materials should be developed depending on the material properties and their social significances. The perception of regenerative building materials in connection

Table 9: Summary of considerations regarding the applied research design.

with (rural) areas of the Global South should be decolonized and de-romanticized. This dissertation is not a plea for the exclusive use of regenerative materials but for an appropriate choice and combination of building materials considering their strengths and the requirements to be met. Depending on the intended use, there are good arguments for the use of regenerative building materials, as well as for the use of more carbon-intensive ones.

2. *Develop a context-specific understanding of sustainable construction: In a place like Bahuarwa, sustainable construction primarily means durable construction.*

Sustainable building in the sense of building that has a positive impact on people's living conditions requires different measures depending on the context and target groups. Sustainable building in the Global North generally requires more environmentally friendly construction – one that preserves the natural environment more or draws from it less. In places like Bahuarwa, it requires durable construction, one that preserves protection from the natural environment. However, durability and regenerability often cannot be combined in a single material. Durability usually requires a higher degree of processing, for example through firing processes with high temperatures, which results in reduced regenerability. To ensure the durability of a building, design optimizations in combination with regenerative building materials should therefore be preferred to their replacement with emission-intensive building materials. While building components such as the roof and foundations are more exposed to the elements and therefore often require the use of more carbon-intensive materials, the walls, especially the interior walls that are well protected from the weather, allow the use of more weather sensitive regenerative materials, which can also improve thermal comfort.

3. *Consider the social significance of building materials as much as their technical properties: Weigh up visibility and durability, lighthouse effect and stigmatization.*

When using regenerative building materials, their social associations must not be neglected. Environmental challenges

such as the rainy season, floods and earthquakes have often led to major destruction of vernacular buildings in Bahuarwa, especially those building parts made of earth, so that the material is associated with negative memories. Those residents who can afford it abandon the use of regenerative building materials in favor of fired bricks and reinforced concrete. In 2025, in Bahuarwa only Dalits and members of tribal communities live in buildings made of regenerative materials, which further exacerbates the stigmatization. However, this research also shows that the use of earth and bamboo is accepted by users despite negative associations, if the materials do not dominate the appearance of the building from the outside. Discussions with the operators of the school and the villagers of Bahuarwa made it clear that the exterior walls should appear like those of a plastered pukka house. However, a subtle integration of regenerative materials reduces the lighthouse effect of an alternative construction method which could help to disseminate its use. Here it is important to weigh up the factors of lighthouse effect and durability and thus social acceptance. A positive lighthouse effect is only likely if the use of regenerative building materials does not negatively affect the durability of the building, otherwise it rather confirms than eliminates skepticism towards them.

4. *Develop climate-adapted construction methods and promote self-build opportunities through training, rather than forcing residents into dependence on expensive, carbon-intensive materials through subsidies.*

India's one-sided focus on construction methods using fired bricks and reinforced concrete is leading to an increasing loss and lacking advancement of vernacular building methods. Policymakers are therefore urged to avoid state-driven polarization of kutchra and pukka houses, and instead focus on taxing carbon-intensive materials while promoting context-specific construction methods. Training centers should be established to empower people and promote the further development of vernacular construction methods. Equivalent wages and certificates should avoid an unequal reputation between genders and professions dealing with more carbon-intensive materials such as bricks, concrete or steel

and regenerative materials such as earth, bamboo or wood. A one room residential building in Bahuarwa without furnishing and single story built using RCC construction methods currently costs around INR 5 to 7 lakhs²⁵. Considering the savings of the school of around 25% through the use of regenerative building materials could amount to around INR 1.25 to 1.8 lakhs²⁶. These figures are higher than the INR 1.2 to 1.3 lakhs that eligible households receive as a subsidy through government housing programs. In addition, the construction method used to build the school has greater potential for self-build options, which can further reduce the cost of a home. Instead of forcing poorer sections of the population into a dependency of expensive materials through polarizing housing programs, the state should promote alternative construction methods. This would lead to savings for the state and residents, boost the regional economy, and reduce the costs of ensuring thermal comfort in buildings, which would also reduce the need for further government programs (Ministry of Environment, Forest & Climate Change, 2019) to subsidize air conditioning systems.

5. *Provide accessible infrastructure for regenerative building materials to support local aspirations and value creation, and develop bamboo treatments that ensure durability without compromising regenerability.*

Just as important as the availability of knowledge and craftsmanship is the availability of the necessary infrastructure. To scale up the construction method used in this project, the availability of treatment plants for bamboo must be improved. Furthermore, there is a need to develop more environmentally friendly treatment methods for bamboo that ensure the material's durability. Compared to the infrastructure for the production of fired bricks, cement or steel, these plants are cheap and compact, which could enable decentralized and widespread use. For a price of INR 8 to 10

²⁵ 1 lakh = 100'000, 5 – 7 lakhs INR = 5'000 – 7'000 CHF, considering an exchange rate of 0.01 (XE, 2024).

²⁶ 1 lakh = 100'000, 1.5 – 2 lakhs INR = 1'500 – 2'000 CHF, considering an exchange rate of 0.01 (XE, 2024).

lakhs²⁷ a pressure vessel can be purchased, as was used for the treatment of the bamboo used in the course of this research. In addition, there are even more affordable treatment options (Stamm & Vahanvati, 2018). Added to this are the costs for a storage hall, the treatment equipment, tools and fasteners. The latter mainly consist of threaded rods, nuts and washers. The range of tools required is also manageable. Most of the work can be carried out with a drill, a machete, a wrench, a wood saw and a metal saw. In this way, jobs for the cultivation, treatment and processing of bamboo could be created in remote locations such as Bahuarwa with relatively little investment.

6. *Develop certification and insurance frameworks for alternative construction methods, and improve technical solutions to allow incremental vertical extensions and airtight fittings for bamboo-based designs.*

To make alternative construction methods marketable, tests and certificates are required, for example to enable building insurance to be taken out, which is not yet possible for so-called kutchra buildings based on regenerative materials. The evaluation of the construction method used for the school with residents and craftspeople from Bahuarwa has revealed that a major skepticism about using the construction method for their own homes is that the roof cannot be walked on and the building cannot be extended vertically without major effort. Although multistory buildings can technically be constructed with earth and bamboo, incremental construction and step-by-step expansion remain particularly challenging, as regenerative materials – unlike concrete slabs or brick walls – cannot be exposed to the elements without suffering significant damage. The development of measures for an incremental, vertical extension of a building using similar construction methods could increase acceptance by the local population. Moreover, methods for handling the varying cross-sections of bamboo culms should be enhanced – for instance, to allow airtight

²⁷ 1 lakh = 100'000, 8 – 10 lakhs INR = 8'000 – 10'000 CHF, considering an exchange rate of 0.01 (XE, 2024).

installation of doors and windows to improve acoustic protection and preventing dust from entering the rooms.

7. *Try to activate well-known personalities on social media as ambassadors for the use of regenerative building materials.*

Although poorer households in Bahuarwa often have no sanitary facilities, the residents usually possess smartphones and are well connected digitally. The easy and relatively cheap access to the internet influences the residents' aspirations regarding a contemporary lifestyle. One of the largest residential buildings in Bahuarwa is referred to as "Mannat" among residents, as its appearance is inspired by a house of Bollywood star Shah Rukh Khan in Mumbai with the same name. For many residents, this house is the favorite in the village, highlighting the aspirations of the local community. The promotion of alternative construction methods and renewable building materials by well-known personalities such as Bollywood stars or cricket players could have a positive effect on social acceptance. However, this is difficult to achieve as it depends on the environmental awareness of these individuals and there is no construction industry behind earth, bamboo or thatch (yet) that could finance such advertising measures.

8. *Continue to build examples that demonstrate the sustainable integration of regenerative building materials and make their advantages tangible.*

After just under a year of use, an evaluation of the school showed that many of the initial doubts about the building materials and methods had been dispelled and that the advantages, especially the thermal comfort, were noticeable. Making these advantages tangible is key to convincing people to use regenerative building materials. If the school is not only cooler than the surrounding brick and concrete buildings, but also better able to withstand earthquakes and flooding, then people will see the evidence that they cannot accept from theory alone. For this reason, further projects are needed to make such advantages tangible to a wide audience.

6.6 In Search of a Middle Way

I began this research with a strong belief in the potential of regenerative materials, shaped by my architectural studies and a personal interest in vernacular building methods. Through my wife Isha, I developed a connection to India that led me to question the purpose of architecture, and with it the responsibility of architects. I felt the urge to use my knowledge not to solve luxury problems – while at the same time contributing to much larger ones – but to address the elementary needs of those who often do not even know what an architect does, which highlights for whom architects usually work. In the deliberate combination of building materials, vernacular and new construction methods, I saw a strategy to overcome the polarization between kutcha and pukka houses, raw and fired materials in Bahuarwa, and, through the construction of a school, to make a positive difference in the lives of underprivileged people.

Despite prior research into similar projects and careful preparation, I quickly realized how strongly my perspective was shaped by a Western lens, how romantic my notions of regenerative materials were, and how easily my good intentions could risk imposing something on people that they could not identify with. I learned to understand how many factors influence the seemingly simple choice of a building material – and that, for underprivileged communities, there is often no real choice at all.

Even while I was in Bahuarwa – or especially then – I was confronted by the converging dynamics of a global construction industry and the ways of building and living of my own background, reflected in the aspirations of the villagers: “But do you yourself live in a mud house?” they asked, quite rightly. At times, it seemed as if the context-sensitive approach I sought was meaningless, when building cultures are following the blueprints drawn in distant urban centers. My initial ambition – that after the school’s construction the villagers might begin building their houses in a similar way, and that over time the building culture of this place might change – met a reality far more complex than I could have imagined.

A single building does not transform a building culture, but it has an impact on the lives of 150 children who now have

safe and cool spaces to learn and play. We can spend a great deal of time planning and envisioning sustainable futures, but ultimately, what matters is what we actually do. In this sense, the hybrid construction developed in this project and applied to the construction of a school for underprivileged children, is not just about questioning the dichotomy between kutcha and pukka houses in Bahuarwa, but also about challenging the relationship between science and society, and between the Global South and the Global North. It embodies the search for a middle ground: frugality linked to an appropriate and just distribution of resources, as well as better sharing between those who live in abundance with those who live in scarcity.

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List of Abbreviations

ASIVSJ	Anti-Slavery International and Volunteers for Social Justice
CCB	Chrome-Copper-Boron
CIBART	Center for Indian Bamboo Resource and Technology
FCBTK	Fixed Chimney Bull's Trench Kilns
IEA	International Energy Agency
NGO	Non-Governmental Organization
NPO	Non-Profit Organization
PMAY-G	Pradhan Mantri Awas Yojana – Gramin
PMAY-U	Pradhan Mantri Awas Yojana – Urban
RCC	Reinforced Cement Concrete
UN	United Nations
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen

List of Aids

Chat GPT

Parts of the conclusion were linguistically refined with the assistance of ChatGPT, while fully preserving the content as intended by the author.

DeepL Translator Pro

DeepL software was used throughout the dissertation to translate texts originally written in German by the author into English.

MAXQDA

The coding software MAXQDA was used to analyze data obtained from interviews and observation protocols through qualitative content analysis.

Microsoft Word

Microsoft Word's automatic spell check was used throughout the entire dissertation.

Proofreading

The document was reviewed by an English expert for linguistic refinement.

Annex

Interviews

The interviews listed on the following double pages were planned in contrast to numerous more spontaneous conversations that are part of the observation protocols. All respondents were happy to be interviewed, but some did not understand why they had to sign a consent form or be audio recorded, as they were not familiar with such requirements. To avoid making the respondents feel uncomfortable, audio recordings and the signing of consent forms were therefore waived in some cases. Only those who gave their consent via thumbprint or signature were audio recorded, the others were recorded with written notes.

The interviews are arranged chronologically and grouped into the four research stays. With few exceptions, names are not given to protect the identity of the interviewees. The list provides information about the interviewees' relationship to the research (e.g., inhabitant, artisan), their gender, their approximate age, their place of origin, the form of data collection, and the type of consent.

During the first research stay, primarily spontaneous visits to households and informal conversations took place to get to know the place and its residents. This initial contact between researcher and the target groups created a basis for further discussions and interviews during the subsequent, longer research stays.

<i>Interview Partner</i>	<i>Date</i>	<i>Gender</i>
--------------------------	-------------	---------------

1st Research Stay April 2022

Priyadarshan Kumar	08.04.2022	Male
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2nd Research Stay January - February 2023

Inhabitants	30.01.2023	Male
Inhabitants	30.01.2023	Female
Inhabitants	30.01.2023	Female
Inhabitants	30.01.2023	Male
Priyadarshan Kumar	30.01.2023	Male
Inhabitants	01.02.2023	Family
Mayor of Panchayat of Bahuarwa	02.02.2023	Male
Inhabitants	02.02.2023	Male
Inhabitants	02.02.2023	Female
Inhabitants	02.02.2023	Male
Bamboo Artisan CIBART	08.02.2023	Male
Kalpesh Dhodia	08.02.2023	Male

3rd Research Stay September - December 2023

Civil Engineer	05.10.2023	Male
Construction Workers	09.10.2023	Male
Inhabitants	29.11.2023	Male
Bamboo Artisan CIBART	29.11.2023	Male
Inhabitants	01.12.2023	Female

<i>Age</i>	<i>Origin</i>	<i>Data Collection</i>	<i>Consent</i>
20-30	Bahuarwa	written notes	signature/fingerprint
50-60	Bahuarwa	written notes	verbal
40-50	Bahuarwa	written notes	verbal
30-40	Bahuarwa	written notes	verbal
50-60	Bahuarwa	written notes	signature/fingerprint
20-30	Bahuarwa	written notes	signature/fingerprint
20-30, 60-70	Bahuarwa	written notes	verbal
50-60	Bahuarwa	written notes	verbal
20-30	Bahuarwa	written notes	verbal
30-40	Bahuarwa	written notes	verbal
20-30	Bahuarwa	written notes	verbal
30-40	Other Indian States	audio transcript	signature/fingerprint
50-60	Other Indian States	written notes	signature/fingerprint
30-40	Bahuarwa	audio transcript	signature/fingerprint
20-30	Bahuarwa	written notes	verbal
40-50	Bahuarwa	audio transcript	signature/fingerprint
20-30, 30-40	Other Indian States	audio transcript	signature/fingerprint
50-60	Bahuarwa	audio transcript	signature/fingerprint

Construction Workers	04.12.2023	Male
Construction Workers	04.12.2023	Male
Construction Workers	04.12.2023	Male
Construction Workers	05.12.2023	Male
Construction Workers	05.12.2023	Male
Construction Workers	06.12.2023	Male
Construction Workers	06.12.2023	Male
Construction Workers	07.12.2023	Male
Building Contractors / Mistris	11.12.2023	Male
Carpenter	13.12.2023	Male
Inhabitants	08.12.2023	Female
Inhabitants	09.12.2023	Female

4th Research Stay September - December 2024

Schoolchildren Boys	13.12.2024	Male
Schoolchildren Girls	13.12.2024	Female
Earth Artisans	13.12.2024	Female
Carpenter	14.12.2024	Male
Painter	14.12.2024	Male
Priyadarshan Kumar	15.12.2024	Male

40-50	Bahuarwa	written notes	verbal
50-60	Bahuarwa	written notes	signature/fingerprint
40-50	Bahuarwa	written notes	signature/fingerprint
40-50	Bahuarwa	written notes	signature/fingerprint
50-60	Bahuarwa	written notes	signature/fingerprint
40-50	Bahuarwa	written notes	verbal
40-50	Bahuarwa	written notes	verbal
20-30	Bahuarwa	written notes	verbal
20-30, 40-50	Bahuarwa	audio transcript	signature/fingerprint
40-50	Bahuarwa	audio transcript	signature/fingerprint
40-50	Bahuarwa	audio transcript	signature/fingerprint
30-40	Bahuarwa	audio transcript	signature/fingerprint

5-15	Bahuarwa	audio transcript	verbal
5-15.	Bahuarwa	audio transcript	verbal
20-30, 30-40	Bahuarwa	audio transcript	signature/fingerprint
40-50, 50-60	Bahuarwa	audio transcript	signature/fingerprint
20-30	Bahuarwa	audio transcript	signature/fingerprint
20-30	Bahuarwa	written notes	signature/fingerprint

Questionnaires

The following questionnaires served as guidelines for the interviews. Depending on the course of the interview and the interviewee's responses, the questions were slightly adapted, or additional questions were asked to explore certain aspects in greater depth. The questionnaires are arranged chronologically according to when they were used.

Research Introduction

Namaste and thank you very much for letting us visit your home. Unfortunately, my Hindi is not so good, and I will continue in English, but my wife and Priyadarshan Kumar will assist me with translations.

My name is Daniel and this is my wife Isha. We live in Switzerland, and we are both architects. As you might know, we are collaborating with Priyadarshan Kumar to build a school for the children of Bahuarwa. To build the school in a way that meets your needs, we try to get a better understanding about how you build your homes and how they influence your living conditions. That is why we would like to talk to you.

If you agree, we would record our talk so that we do not forget any of the information. You do not need to answer a question if you do not wish to do so. Whatever you mention will be kept confidential and anonymous. Did you understand all this information and do you agree with it? Do you have any questions?

Thank you very much.

Introductory Questions

What is your name?

How old are you?

What is your profession?

Where were you born?

Inhabitants – Mainly Interviewed during Second Research Stay from January to February 2023

Could you tell us more about the organization of your house: How many rooms are there, and which activities take place in them?

Could you tell us when and how your house was built?

Are you facing any kinds of problems in your house, which?

Would you like to change anything about your house, what?

How would you describe living in a pukka house compared to living in a kutchra house?

How would/did this shift affect your life?

Priyadarshan Kumar, founder and head of the Bahuarwa Foundation – Interview during Second Research Stay on 30th of January 2023

Could you tell us how a typical Dalit family in Bahuarwa looks like? What is the typical family structure and how do they usually live?

Could you tell us about your work with the Dalit community, how are you trying to support them? What are some of the main problems that the Dalit people of Bahuarwa are facing?

Based on your experience, what do Dalit people in Bahuarwa usually do to earn money? Are there enough working opportunities or do some of the villagers emigrate?

To what extent are the Dalit people in Bahuarwa underprivileged compared to other villagers in everyday life? In which parts of life are they affected the most? Could you mention some examples?

Could you tell us more about the housing situation of the Dalit people? What materials are the houses usually made of? How do people build their houses?

How does the housing situation influence the living conditions of the Dalit community? How does it affect their social status in the village? Could you mention some examples where people experience disadvantages in relation to other people due to their housing situation?

To what extent would the social status of Dalit people change if they would live in a pukka house made of fired bricks and concrete?

Based on your experience, how did the living conditions of Dalit people in Bahuarwa develop since your childhood? Did they change? To what extent?

Based on your experience, what is required to improve the living conditions and prospects of the Dalit community on a longterm perspective? What would you do first to improve their lives?

Jet, Pradhan of the Panchayat of Bahuarwa – Interviewed during Second Research Stay on 1st of February 2023

What are the main challenges that Bahuarwa is facing?

Could you elaborate on the educational situation in Bahuarwa?

How can this situation be changed?

What is the biggest income source of the inhabitants of Bahuarwa? Where do they usually work?

Could you tell us more about the recent infrastructural development in Bahuarwa? When was the village supplied with electricity, sanitary services, roads, internet, etc.?

Bamboo Artisans at Centre for Indian Bamboo Resource and Technology (CIBART) – Interviewed during Second Research Stay on 8th of February 2023

When did you start working for CIBART?

What was your motivation to work with bamboo?

What does bamboo mean to you?

What are the main challenges to promote bamboo as a construction material on a larger scale?

What are the main pros and cons of a bamboo building compared to an RCC building?

How long does a bamboo building last, given that it is constructed properly?

What would you do differently now, learning from your previous experience?

How is the profession of a bamboo artisan perceived in his community?

How is the educational situation to become a bamboo artisan? How many people are trained in this workshop?

Is it more women or men who take part in these trainings?

How much does a construction trainee earn?

Are there lots of architecture students also coming to learn about bamboo?

Are there many other options except of CIBART to become an artisan?

What are your suggestions to promote the use of bamboo as a construction material?

Do you also live in a bamboo building?

Project Manager at Centre for Indian Bamboo Resource and Technology (CIBART) – Interviewed during Second Research Stay on 8th of February 2023

When did you start working for CIBART?

What was your motivation to work with bamboo?

What does bamboo mean to you?

Who are your clients?

What are the reasons of your clients to use bamboo (as a construction material)?

What are the purposes of your work in general and more specifically related to construction (social, touristic)?

How did the demand for bamboo as a construction material develop since you started working for CIBART?

What are the main principles of your construction methods? How did you upscale your methods from the making of furniture to the construction of buildings?

How do you usually connect the bamboo pillars with the foundation?

What are the main challenges to promote bamboo as a construction material on a larger scale?

What are the current initiatives that try to promote the use of bamboo as a construction material?

Based on your opinion, is a bamboo building generally perceived as a pukka or as a kutchha building, why?

How can a bamboo building become a pukka building?

How long does a bamboo building last, given that it is constructed properly?

Do you also live in a bamboo building?

Participants in the School Construction – Mainly Interviewed during Third Research Stay from September to December 2023

Where in Bahuarwa do you live?

How does your family situation look like?

What do you do for a living?

How many days/months in a year are you employed?
How much money do you earn?
What would be your alternatives to earn money?
Have you worked outside of Bahuarwa? What, where, how long? How often did you come back? Where did you live there?
How do you like this work (at the construction site of the school) compared to other works that you have done?
Which was your favorite work in this process?
What do you mostly need your savings for?
What materials is your house made of?
What do you think about the use of more natural materials such as mud or bamboo for building purposes?
How would your dream house look like? What materials would it be made of? Do you have a favorite building in the village?
Could you imagine using these construction principles for your own building? For which parts? Why? Would you adapt anything?
What would be your favorite color to color your building?

Civil Engineer – Interviewed during Third Research Stay on 5th of October 2023

When did you found your company?
How did you learn your job?
How many people are employed in your company now?
Who is working in your company: age, gender, origin, caste?
How did your employees usually learn the work? Is there a special apprenticeship?
How high is their salary? How many hours do they work in a day?
Which materials do you mostly use on your construction sites?
Where do the materials come from? Stones, sand, steel, fired bricks, cement?
You have mentioned that you also have a team of bamboo artisans, how often do you use bamboo in your work?
What do you think about the use of more natural materials for building purposes such as mud or bamboo in general?
Do you see any purposes of these materials and traditional construction methods for the future of building? If yes, which?
Most people transform their kutcha houses into pukka houses. Do they usually do this work on their own or do they ask companies like yours to do the work? How is the professional work and the self-construction divided?
How are these buildings planned? Is there a civil engineer or an architect involved?
Who are your clients?
Have you noticed some trends / special wishes from your clients? What is important for them when constructing a new house or renovating? What are their aspirations?
How has the demand developed since you have founded your company?
How much does an average size RCC building for one family cost in the region of Darbhanga/Bahuarwa?
Do environmental concerns play a role in your work? Do you notice any of such concerns from your clients?
How does a contemporary Indian building in your opinion look like?

Bamboo Artisans from the Centre for Indian Bamboo Resource and Technology (CIBART) – Interviewed during Third Research Stay on 29th of November 2023

When did you start working with CIBART?
What was the motivation behind you joining CIBART?
How many craftspeople work in CIBART Ukai?
Where do they come from?
Does CIBART pay you on project base or monthly?
Did someone from the craftspeople CIBART also belong to a community that did not deal with bamboo in the past?
When you tell people that you work with CIBART and work with bamboo, how is there reaction? Is bamboo considered a good or bad material?
We saw here that people in Bahuarwa were quite critical of bamboo and wanted a building out of bricks. Is there also a similar mentality of people from your village? Do you live yourselves in a bamboo house? Why?
What were the problems that you facing in your bamboo house before?

Would a building with treated bamboo building be more expensive than a brick / RCC building?
How did the demand of bamboo develop since you started to work for CIBART?
What was your favorite building that you have built yourself?
What was the best thing about that building?
What do you think is necessary to promote the use of bamboo in the future?
If costs were not a problem, would you build with bricks or bamboo, for yourselves?
What are your learnings from your past bamboo projects?
As bamboo experts, what are some things that you would do differently in the construction of this building (school) in the future?
In this country, there are many who cannot afford to build with treated bamboo or with bricks. What would be your suggestions for them when building with bamboo?
Have you ever built a double story building?

Building Contractors – Interviewed during Third Research Stay on 11th of December 2023

When did you start working as a contractor?
What about the sons? How did they become contractors?
How long did it take them to become a contractor?
How do you know when a laborer is ready to become a contractor?
Is there some kind of an exam to become a contractor?
Can any laborer become a contractor then?
How many people do you usually work with?
Do you have a particular team of laborers and contractors that you usually work with?
Do you sometimes change the laborers or is it always the same ones from that particular village?
What are the main building materials that you work with?
Do you ever use bamboo, how? For construction purposes?
What do you think about the school building? Do you think it will last?
Is there anything that you find problematic in this construction method?
Nowadays there are many transformations of kutcha houses into pukka houses going on. Do people call contractors and laborers for this work, or do they also do this work on their own?
What about the planning and designing of the building, who does that in the village?
Ever since you have come back to the village from Delhi, how has the demand for pukka buildings developed?
What are the reasons for this development?
How much does a pukka building for a single-family cost on average?
Did you notice any particular trends in the clients' wishes in terms of the design of the buildings?
Do you have any favorite building?
What do you estimate would be the costs of one classroom of 16 x16 feet and 8 feet in height, a plinth of 4 feet, all made of bricks and concrete?

Carpenter – Interviewed during Third Research Stay on 13th of December 2023

When did you found your company?
How did you learn your job?
How many people are employed in your company?
Who is working in your company: age, gender, origin, caste?
How did your employees usually learn the work? Is there a special apprenticeship or is it learning by doing?
How much do you pay them? How many hours do they work in a day?
Which kinds of timber do you mostly use in your work?
Where do the different kinds of timber come from?
Do you also use timber for construction purposes, e.g., for roof structures?
Which of your products and services experiences the highest demand?
Has the demand for your products and services changed since you have founded your company, how?
Who are your clients?
Have you noticed some trends / special wishes from your clients? What is important for them when buying your products?
What are their aspirations in terms of design?
What materials is your house made of?
What do you think about the use of more natural materials such as mud or bamboo for building purposes?

Could you imagine using these construction principles for your own building? For which parts? Why? Would you adapt anything?

How would your dream house look like? Do you have a favorite building in the village?

Schoolchildren – Interviewed during Fourth Research Stay on 13th of December 2024

When you look at this building, is this a kutchra or a pukka building? Why?

Do you think this building is weak? Why?

What do you like about this building?

What don't you like about this building?

What is your favorite space in this building?

How do you use the hall?

How is the building in different seasons?

Two Local Earth Artisans – Interviewed during Fourth Research Stay on 13th of December 2024

Now that this building is fully built, would you say that this building is a kutchra or a pukka building? Why?

How would you define a kutchra and pukka building?

Would you say this building is weak or strong?

What do you like about this building?

What is it that you think could have been better/different in this building?

Could you imagine using similar construction techniques to build your house?

Carpenters – Interviewed during Fourth Research Stay on 14th of December 2024

Since you have seen the construction of the school and now after it's fully constructed and in use, for you, is this a kutchra or a pukka building?

What do you like in this building?

What do you think could be better in this building?

What do you like more, the interior walls or the exterior ones? Why?

What could we do differently next time?

Could you imagine using some of the building techniques that you saw here to build your own houses? Why?

Painters – Interviewed during Fourth Research Stay on 14th of December 2024

Is this a kutchra or a pukka building for you? Why?

What do you like about it?

What is it that you don't like in this building?

How do you build houses in your villages?

Can you imagine people in your village would like such a building for themselves?

How was your experience with painting the exterior walls (which are originally made of bamboo strips and plastered with cement)? How was it different / challenging when compared to a brick wall.

Priyadarshan Kumar, founder and head of the Bahuarwa Foundation – Interviewed during Fourth Research Stay on 15th of December 2024

Do you think this school is a kutchra or a pukka building?

Which parts of the building do you like and which are the ones that you don't or you still have to get used to?

How is it in the summers and monsoon?

Is it very loud during the rain on the metal roof?

Do the mud walls become dry and dusty here?

Now this building mostly works as a school, but does it also serve other activities? Which ones?

What is the hall used for mostly by the kids?

Your own house is already built, but if you were to build a new house, could you imagine using some of these building techniques used in the school in your own house as well.

Do you know, if anyone who was involved in the construction of the school has tried to use the same principles in their own building?

How is the reaction of villagers about this school building?

Observation Protocols

Most of the data was obtained through daily entries in the observation log. This also includes numerous notes on conversations that, unlike the interviews, were more spontaneous and often more productive, as they felt less formal for the respondents. Entries during visits to households or construction sites were recorded as handwritten notes, which were then digitized the evening of the same day. The interviews and observation protocols were analyzed using qualitative content analysis and the MAXQDA software.

5	30.01.2023, house visits, village walks and interviews with inhabitant of kutchha houses, usually Dalits
6	Visit of four Dalit families in their houses. The foundations of the houses are all made of mud. The walls consist of a bamboo structure with bamboo posts. In between the bamboo posts are either opened and flattened bamboo "mats" or in simpler cases a grid of bamboo slits which is filled with grass. The walls are usually plastered with a thin layer of a mix of mud and cow dung. The plaster is sometimes not even one centimeter thick. It is like a skin, where the skeleton of bamboo remains visible. In some cases only the lower part of the walls is plastered. The roofs are made of a bamboo structure and covered with thatch. In most cases the thatch is additionally covered by a plastic sheet. In some cases the thatch is replaced by a fibre cement sheet, which is sometimes again covered by a plastic sheet to cover its holes. In rare cases the roof is made of fired tiles. Most houses have a veranda in front of the entrance(s) to the individual rooms. The veranda is about 1 to 1,5 meters wide, 40 to 60 cm raised from the ground and often not big enough for an adult person to stand, but you can comfortably sit or lay there. The veranda usually also contains a fireplace. There are usually just one or two, maximum three rooms in one kutchha house, aligned in a row, individually accessible from the veranda. In some cases there are no doors, but only curtains to separate the rooms from the veranda. The rooms are around 2.5 by 2.5, maximum 3.5 by 3.5 meters big. Inside the rooms there are beds, shelves and belongings. There is not much space left to move. In some rooms there is also a fan. Our talks take place in the courtyards, which are a common element for all houses. Usually several houses of an extended family share a courtyard, where you can find a small temple, one to two fireplaces, a handpump, a shelter for the cattle, drying laundry. The fireplaces or kitchens are made of mud and cowdung. In some cases there is also a gas stove. There are no toilet facilities. Cleaning dishes, washing clothes, taking a shower, brushing teeth, etc. all takes place at the handpump. The "toilet" is the nearby field or forest.
76	24.10.2023, In search of stainless-steel iron rods
77	Today we set off at 6am with the tuktuk driver to drive to neighboring Ujan where the nearest train station is located. After a 15-minute drive, we arrive in Ujan. The train to Darbhanga leaves on time and takes us to Darbhanga in about an hour and a half. There, we visit numerous hardware stores to buy stainless steel threaded rods with a diameter of 8mm. These form the mechanical connecting element for bamboo. Such threaded rods are available in every hardware store in Switzerland, and we also expect to find them quickly in Darbhanga. But it's different. We are referred from store to store until finally a knowledgeable man informs us that such threaded rods are not available in Darbhanga, or even in the entire state of Bihar. However, they can be found in Delhi or Mumbai. We are very surprised that a common product in our eyes is so difficult to find. We dare not even inquire about solar modules. Tired from the search, we head back home.
78	In the evening, we take a walk through the village and come across one of the construction workers. His name is Guddu. He takes us to his house, which is located just outside the eastern edge of the village. We cross a meadow, and Guddu tells us that during the rainy season, the water here sometimes gets so high that it comes up to their waist. He has been wanting to make a better path for some time now, but a neighboring household does not allow this, as the path goes through their property. Guddu shows us his house that he built himself with brick and reinforced concrete as a construction worker. The house is not yet plastered, but the stairs for a vertical expansion and use of the roof surface have already been constructed. He plans to expand the house if the family grows and if there is enough money to do so.

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08.11.2023, Past construction methods in Bahuarwa

In a conversation with Mrs. Kumar and Jaykhand, we learn more about past construction methods in Bahuarwa. When they were children, numerous houses of wealthier families were already built with fired bricks. Since there were no brick kilns in the region at that time, households formed and burnt the bricks and roof tiles for their houses themselves. They had a carpenter make a mold and hired lower-caste or excluded-caste members to do the work for them. Later, wealthier households began to burn their own bricks. They had a mold made by the local carpenter, into which they pressed the local clay with a distinct texture. They then let the material dry in the sun and burned it in ovens they had made themselves. Brick kilns did not exist yet. Cement was also not yet available. The self-burnt bricks were then laid and plastered with a mortar made of the same clay to protect the wall from the weather. Although this new brickwork was more weather-resistant than the walls made of mud and bamboo, it still required a high maintenance effort, as both the protective plaster and the binding mortar were still made of clay. The use of concrete and steel was not yet known back then. Therefore, the houses were single-story and had hip and sometimes gable roofs made of roof tiles on a bamboo structure. Before the introduction of burnt bricks, mud, wood, bamboo, and straw were the only available building materials. Poorer families often built their homes with a centrally positioned wooden support, walls and roofs made of bamboo, which they covered or filled with straw. The use of mud was reserved for wealthier households. Making thick mud walls was time-consuming, so poorer households could not afford to spend time building mud walls instead of working in the fields. Wealthier households also hired lower-caste and dalit members for these time- and labor-intensive construction methods. In return, they received a portion of the harvest. The use of money was not yet widespread in this area at that time. In the childhood of the two now-45 and 70-year-olds, goods such as buffalo, goats, rice, and vegetables were traded. People did not own many clothes and slept on straw bales. Similar to today, poorer families could only afford a thin mud plaster. With the emergence of burnt bricks and roof tiles, the better-off households abandoned the use of mud. Mud buildings were often destroyed by floods and heavy rains, and large village fires often spread over the thatched roofs. Mud was now only used as a plaster. Therefore, it does not surprise us when an older woman passes by the construction site today and says to Isha, "Why are you dealing with this rubbish? You are a madam, why are you doing this garbage work?!" Isha continues to plaster the walls with straw and mud and replies, "Why do you think this work is bad? Why don't you help? "That's just garbage, I don't do garbage work!" The construction of the railway line and the station in the neighboring Ujan allowed the residents of Bahuarwa to work in other places, to discover a world outside Bahuarwa. Back then, it was a sensation when someone returned from work in Calcutta. "These people were treated like VIPs! They work so far away from home, in a big city!" Mrs. Kumar tells us. These people have seen something of the world and brought new ideas and knowledge to the village. Today, many villagers also work in cities like Delhi and Mumbai. However, there was still no good connection to these parts of India back then; Calcutta was the nearest metropolis. Again and again, we notice that the state of Bihar, life in the village, work with mud, and membership in excluded castes bring numerous negative associations. "Biharis" serves less as a designation of belonging to a state and more as a curse for backward and dirty people. The villagers often refer to themselves as "dehatis" with a disdainful tone, pointing out the muddy paths, poverty, and infrastructure. The caste membership of Hindu members can be read from their last names. Especially those who are excluded from the caste system, the Dalits, are recognizable by their names. To hide this, they often use other typical names. This is why many of the schoolchildren are called "Kumar" or "Kumari." They are by no means all part of the same family but conceal their real names. Along with the caste, these names also indicate the professions of the people, which are often associated with dirty, inferior "garbage work."

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11.12.2024, Miti mistris

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Today we learn from the Miti Mistris how the decorative wall reliefs are made. The process consists of three phases:

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1. First, clay (Chikni Miti), wheat husks and water are mixed. The ratio of clay and wheat husks is about 5:1. Water is added only until the mixture becomes malleable. It should not be too liquid. The mixture is rolled in the hand and then applied to an existing clay wall. The wall does not need to be pre-wetted. If the mixture holds well, it is right. Then you let the relief dry. The drying is recognizable when the relief takes on the same color as the rest of the wall. In our case, it took about two days.

Declaration of Authorship

raw, fired, and in between – कच्चा पक्का और दोनों का मेल

on regenerative building materials and participatory construction in Bahuarwa, India

I hereby declare that the present paper is entirely my own work and without the use of any unauthorised assistance. Any content which has been taken verbatim or paraphrased from other sources has been identified as such. I have named all the AI tools used with their product names and described how they have been used in the list of aids. I am aware that the use of machine-generated texts does not guarantee the quality of content and text. I assure that I have only used AI tools as an aid and that my creative influence predominates in this work. I am fully responsible for the adoption of any machine-generated text passages or other elements of the work. The insurance of independent work also applies to included drawings, sketches or graphic representations. This paper has not been submitted in any form whatsoever to an examining body nor has it been published. By submitting the electronic version of the final version of the thesis, I acknowledge that it can be checked for plagiarism with the help of a plagiarism detection service.

Buchs, 23.09.2025



Daniel Haselsberger

Biographical Note

Daniel Haselsberger is an architect and researcher whose work lies at the intersection of architecture, ethnography, and international collaboration. Born in 1990 in Chur and raised in Flims, he completed his Matura at the Klosterschule in Disentis. He studied architecture at the University of Liechtenstein, including an exchange semester at the Bergen School of Architecture in Norway. His Master's thesis was supervised by Anna Heringer. Daniel gained professional experience at architectural practices in Graubünden, including Bearth & Deplazes and Jüngling & Hagmann. Since 2020, he has been involved in research and teaching at the University of Liechtenstein, where he co-leads a design studio and the transdisciplinary teaching format Pro Bono, in which students work with real-world partners to initiate, plan, and implement projects for the common good. In 2021, he began his dissertation, which is closely connected to India and to the non-profit work he carries out with his partner, Isha Haselsberger, an architect born and raised in India. Together they founded the non-profit organization Arch Aid in 2020. Their work focuses on community-based building initiatives and explores the sensible integration of regenerative and locally available building materials to meet the needs of underprivileged user groups.

“Raw, fired, and in between” is the title of a dissertation at the interface of architecture and ethnography. It focuses on the transformation of the building culture of Bahuarwa, a village in the Indian state of Bihar. “Raw” and “fired” are literal translations of the Hindi words kutchra and pukka, which are commonly used in India to categorize buildings into “strong” ones made of carbon-intensive materials, such as fired bricks, cement, or steel or “fragile” ones made of raw, regenerative materials, such as earth, bamboo, timber or thatch. This polarization hinders the use of regenerative building materials, as well as the further development of vernacular building methods.

In the first ethnographic part of the research, the transformations from raw to fired materials are examined in the village, unpacking the interplay between environmental challenges, socio-economic transformations and technological developments. Building on these findings, the second part of the dissertation focuses on the participatory design process of a school for underprivileged children in Bahuarwa. A hybrid solution “in between” raw and fired building materials is developed, which allows the integration of regenerative materials into the process without neglecting the aspirations of the target groups.

The construction of the school is less a result than a method of this dissertation. The research is shaped through the participatory construction process, becoming tangible and accessible to the target groups. It creates a close form of interaction between the researcher and the local community, enabling a deep understanding of the social acceptance but also the feasibility of the developed hybrid. The construction of the school also aims to provide a fair exchange and real benefit for the target groups, legitimizing the engagement and creating a cooperation instead of a one-sided data extraction.

This dissertation represents the search for a middle ground: one not only between regenerative and more emission-intensive materials, between vernacular and new construction methods – but also, between the Global South and North, science and society, and attempts to bridge boundaries by building together.