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Spatial Analysis in The Process of Housing Development: Use and Role of 3D Measurement Technology through The Case of Prey Veng Province, Cambodia

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ABSTRACT

In the realm of housing development, particularly within informal settlements, spatial analysis is a crucial tool for engaging residents and multiple stakeholders. It extends beyond merely providing technical input to built environment professionals such as planners and architects. With the advent of the 'Digital Twin' technology over the last decade, acquiring spatial and 3D data of the built environment has become more affordable and diverse. This paper explores the relevance and potential of 3D measurement technologies in the development of informal settlements, focusing on a case study from Neak Loeung, Prey Veng Province, on the outskirts of Phnom Penh, Cambodia. The research involved conducting 3D measurements at the Neak Loeung housing development site and acquiring detailed 3D data of the area. While addressing the challenges associated with these measurement methods, the study also examines the use of 3D data in early-stage housing development processes such as community networking and strategic incremental planning. Moreover, the paper discusses the broader challenges related to the technological limitations in accessing and operating visual information, as well as the role of 3D data in the learning and skill development of both community members and professionals, with a particular focus on young community architects.

1. Introduction

1.1 3D Measurement Technology for the Development of Informal Settlements

The escalating effects of globalization have profoundly altered economic, social, political, and cultural landscapes, as well as the environmental conditions within which we live. The Asia Pacific Region, in particular, has experienced an unprecedented rate of urbanization. Compounded by global climate change, these transformations pose significant threats to cities and communities worldwide,

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with informal settlements—often lacking in infrastructure and situated in hazardous locales such as flood plains or riverbanks—being especially vulnerable.

In addressing the development challenges of informal settlements, spatial analysis emerges as a crucial tool. Beyond its technical contributions, spatial analysis facilitates communication among residents, stakeholders, and professionals such as urban planners and architects. This collaborative approach is essential for fostering resilience against climate-related disasters. Drawing on John F.C. Turner's insights from *Housing by People* (1976), the empowerment of the community, or the 'user/popular sector,' is pivotal[1]. In this self-governing model, the community holds significant responsibility in decision-making, enhancing its autonomy and governance capacity(Fig.1).

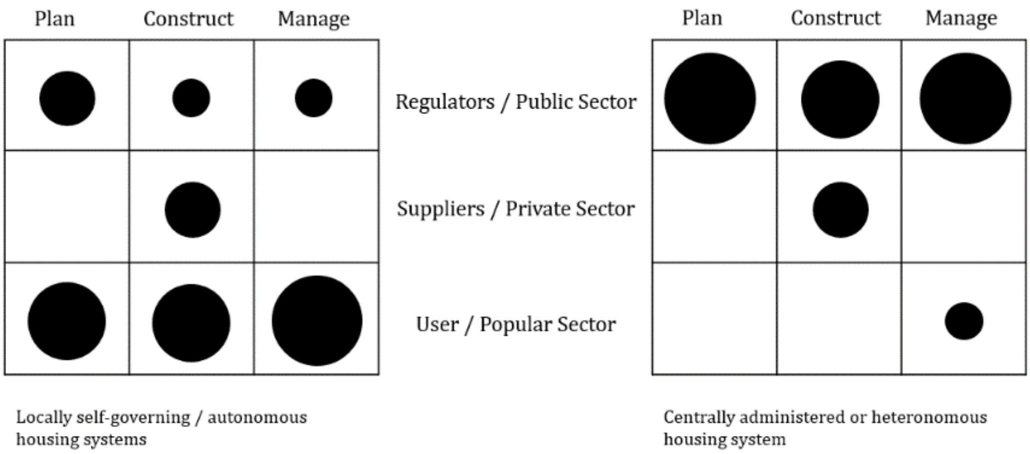

Fig. 1. Process of decision making in Housing, comparing institutional and grass-roots model *Housing by people*, by John F.C. Turne

The Asian Coalition for Community Action program (ACCA) also highlights the critical role of communities in leading development projects. This process involves a diverse array of professionals, including community architects who prioritize consultation and emphasize the importance of participatory design practices. These practices encompass horizontal networking, community mapping, surveys, and participatory planning and design workshops, which are integral to the architectural process.

This paper explores the application and benefits of 3D measurement technology in the development of informal settlements. By focusing on a case study from Neak Loeung, Prey Veng Province, on the outskirts of Phnom Penh, Cambodia, the research highlights how this technology can enhance community involvement and support the work of local architects in these critical development processes.

1.2 Research Background

The concept of the 'Digital Twin' has gained prominence over the past decade, significantly enhancing the accessibility and affordability of 3D data acquisition, mapping, and surveying technologies. These advancements have made it easier for young architects and small practices to engage with the built environment. Notably, Prof. Tanaka's research group at Meiji University has conducted a project in the 3D measurements and informatization of existing built environments[2].

Parallel to these technological strides, Prof. Tanaka has also facilitated workshops for elementary school students, where they use 3D scanning and visualization technologies to explore and analyze the topography and built environment surrounding their schools[3].

In contrast, Chawanad Luansang has documented the role of community architects in informal settlement development in Asia, particularly through his involvement with the Asian Coalition for Community Action (ACCA). His paper, *The Role of Community Architects in Upgrading; Reflecting* *on the Experience in Asia*, highlights the engagement of new generation community architects and universities[4]. However, his findings suggest that their methods are often traditional, limited to paper models and simple scaled drawings.

Given the increasing availability of personal devices like smartphones and tablets, there is a crucial need to explore how 3D measurement technologies and informatization can be integrated into the development processes of informal settlements, particularly in terms of community involvement. Moreover, it is essential to evaluate the potential of 3D data technology not only in supporting community architects in their professional development but also in enhancing their learning and skills. This investigation will focus on how these technologies can be effectively employed to strengthen the roles of community architects and other professionals involved in the development of informal settlements.

2. Methods

2.1 The Site: Informal Settlement in Cambodia

The research was conducted with help of the Community Development Foundation (CDF) in Phnom Penh. The team selected the Proiay Tek Community, a 160-meter stretch along the Mekong River, approximately 60 km southeast of Phnom Penh, for a comparative study on the acceptance of technological interventions. This community was responsive and had previously undergone housing reconstruction on the same site with CDF's support (Fig2 and Fig.3). CDF's primary role involved establishing a community savings group to manage funds and facilitating community meetings, along with appointing a community leader.

Fig. 2. Proiay Tek Community before reconstruction program by CDF. Photo from Presentation *City wide settlement survey and inclusive city development* presented on 30th July, 2019 by CDF

Fig. 3. Housing built on the same canal post reconstruction program. Photo from *Book of ACCA housing* by CDF

A hypothetical second phase of housing development was envisioned by the research group to analyze post-reconstruction upgrades, identify current issues, and propose design interventions for the existing housing.

2.2 3D Measurement Techniques

The research group employed three distinct methods of 3D measurement to capture the existing conditions of the housing and its surroundings, demonstrating the capability to analyze at different scales. The first method is photogrammetry by using drone-captured images (Fig. 4). The second, medium scale method is using 360-degree camera with LiDAR, Matterport Pro2 camera to capture both 360 walk through as well as 3D constructed point cloud (Fig. 5). The third method, smallest scale 3D model construction, is using tablet devise with LiDAR, iPad pro with Snaniverse application (Fig. 6).

Fig. 4. Point Cloud model constructed with photogrammetry from pictures taken by a drone

Fig. 5. Point Cloud model captured by Matterport pro2 camera and viewed in AutoDesk Recap

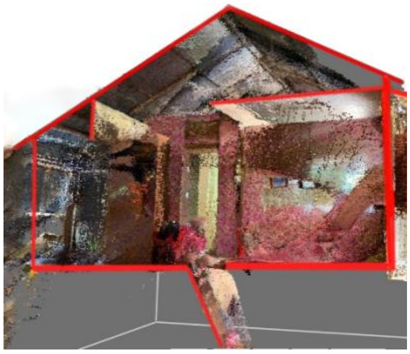

Fig. 6. Point Cloud model captured by Scaniverse on iPad.

2.3 Data Usage, Sharing, and Viewing Methods

This paper focuses on the methods of 3D data usage, sharing, and viewing, assessing their effectiveness as analytical tools and their capacity to facilitate communication among the three key sectors/stakeholders: the user/popular sector, suppliers/private sector, and regulators/public sector.

The research explores three paired methods and viewing platforms (Tab. 1). The first method is web whiteboard and web-based viewing platforms, such as Miro and Matterport viewer. The second method is combination of cloud file sharing, such as google drive and dropbox, or using file transfer services to bring the 3D date onto local desktop. Once the files are on local desktop, the files are open, viewed and edited by using Open-source point cloud editing software, such as Cloudcompare. The third method is opening files, which is shared via could file sharing service, with CAD/BIM software such as Autodesk AutoCAD, Revit and so on.

While the first method provides significant advantage in terms of accessibility and intuitive operation, as it does not demand specific skill and knowledge to operate and navigate within the platform to view shared 3D data. Whilst the other two methods provide customized viewing projections and additional analytical tools, sectional view and dimensioning tools. CAD/BIM software is required advanced knowledge and skill to handle 3D model/point cloud. What it distinctly different from Open-source source point cloud editing software is that point cloud ready CAD/BIM allows professional to integrate point cloud model into their existing workflow.

Table 1
Evaluation of methods of sharing 3D data and viewing platform by sectors of stakeholders

Methods of sharing 3D data and viewing platforms	Pros	Cons	Used by community and non-professionals (Public sectors and Popular sector)	Used by professionals (Private sector)
(1) Web whiteboard to share data and web viewing platform	· does not affected by the specification computer · does not require skill to operate software · easy to share annotation and comments	· limitation of viewing projection · all data format may not be supported by web viewing service	Suitable	Access to specific information is less
(2) Cloud service to share data and view with pointcloud editing software in a local environment	· possible to view the data in a section or only part. · orthographical projection is possible · most of file formats can be viewed by an editing software	· due to many facilities, it requires skill to operate software · due to the large size of data, it requires transferring by cloud file transfer service	Difficult to operate	Enough information to access but not possible to incorporate a proposal
(3) Cloud service to share data and import pointcloud to CAD/BIM to view, edit and annotate	· able to add annotations and dimensions as it requires · able to add drawings and 3D objects along with pointcloud data	· required professional skill and knowledge · importing format of pointcloud to CAD/BIM is limited and frequently not compatible between different softwares	Not required	Suitable and essential to integrate use of pointcloud to professional workflow

2.3 Limitations of the Paper and Ongoing Research

This research initially planned to conduct in-person community workshops to engage directly with participants. However, due to the constraints imposed by the COVID-19 pandemic, a hybrid model of workshops combining online and in-person elements was adopted. These workshops aimed to connect three distinct locations: the 160m Proiay Tek Community in Cambodia, Tokyo, and Ho Chi Minh City. The primary objective was to assess the relevance and general acceptance of using advanced technological methods and workflows that were new to the community, building upon experiences from past housing reconstruction efforts.

Despite these broader goals, the focus of this paper is more narrowly defined. It concentrates on the methods of sharing and viewing 3D data, specifically evaluating the usability and quality of visual representation before these materials are utilized in community workshops. This step is crucial for ensuring that community architects can effectively incorporate these visual tools into their workflow and communication strategies with the community.

By delineating these focus areas, the paper acknowledges its scope limitations while setting the stage for future research that will explore the full impact of these technological interventions in community-engaged architectural practices.

3. Analysis of Three Methods of Sharing and Viewing 3D Data

3.1 Use of Web Whiteboard and Web-Based Viewing Platforms

This method offers an accessible means for communities and non-professionals to engage with 3D data. Its primary advantage is that it requires no large data downloads, which allows for relatively fast access and is not dependent on the specifications of the user's local computer. However, for professionals, while useful in the preliminary stages of a project, this method has limitations in the depth of information and the representation of 3D data. The major constraints are due to the limited orthographical representations and sectional views available, which may not fully meet the detailed needs of development stages. Fig. 7 and Fig. 8 are screenshots of point cloud models shared. Viewer could freely rotate, zoom-in and out of model.

Fig. 7. Screenshot of point cloud model taken by drone, showing kind of visual representation shared

Fig. 8. Screenshot of point cloud model taken by matterport pro2 camera, showing kind of visual representation shared

3.2 Use of Cloud Service to Share Data and View with PointCloud Editing Software (CloudCompare) in a Local Environment

Sharing data through this method involves downloading large files, sometimes exceeding several gigabytes, which can be challenging for community members and non-professionals to manage. Additionally, operating pointcloud editing software like CloudCompare requires specific skills and experience, posing a further barrier to non-professionals. For professionals, this method offers more comprehensive viewing options, including orthographic projections and sectional planes for detailed examination of sections and plans(Fig.9 and Fig.10). However, it lacks an interface for annotations and dimensioning, which are crucial for further development stages, such as making propositions or conducting quantity surveys.

Fig. 9. Screenshot of sectional view of point cloud model on CloudCompare software

Fig. 10. Screenshot of plan view of point cloud model on AutoDesk Recap

3.3 Use of Cloud Service to Share Data and Import Point Cloud into CAD/BIM for Viewing, Editing, and Annotating

Similar to the previous method, this approach involves sharing large data files via cloud services. The substantial benefit comes after importing the point cloud data into CAD/BIM software, where it integrates seamlessly into the planning, conceptualizing, drafting, and modeling processes (Fig. 11 and Fig.12). This integration allows professionals to fully utilize the data's potential and maximize the information extracted from it.

However, the collaborative evaluation among researchers in Phnom Penh, Ho Chi Minh City, and Tokyo revealed significant time and effort requirements to learn and develop the necessary skills to use point cloud data effectively in CAD/BIM software. Especially for community architects, there is an urgent need for educational initiatives to integrate point cloud modeling into CAD/BIM training during their architectural studies.

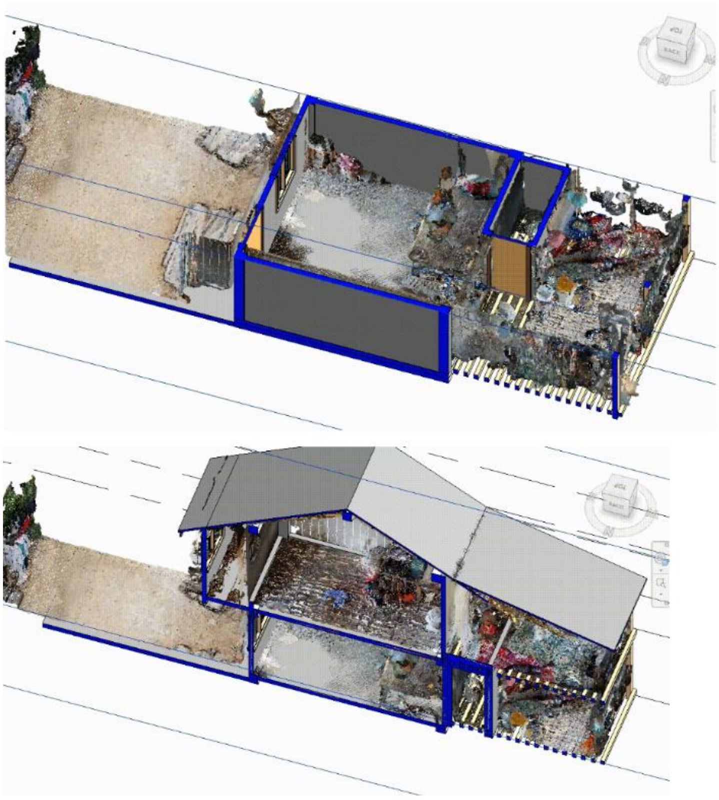

Fig. 11. Sectional view and plan view and indication of wall cross-section on AutoDesk Revit, demonstrating possibility of visual representation

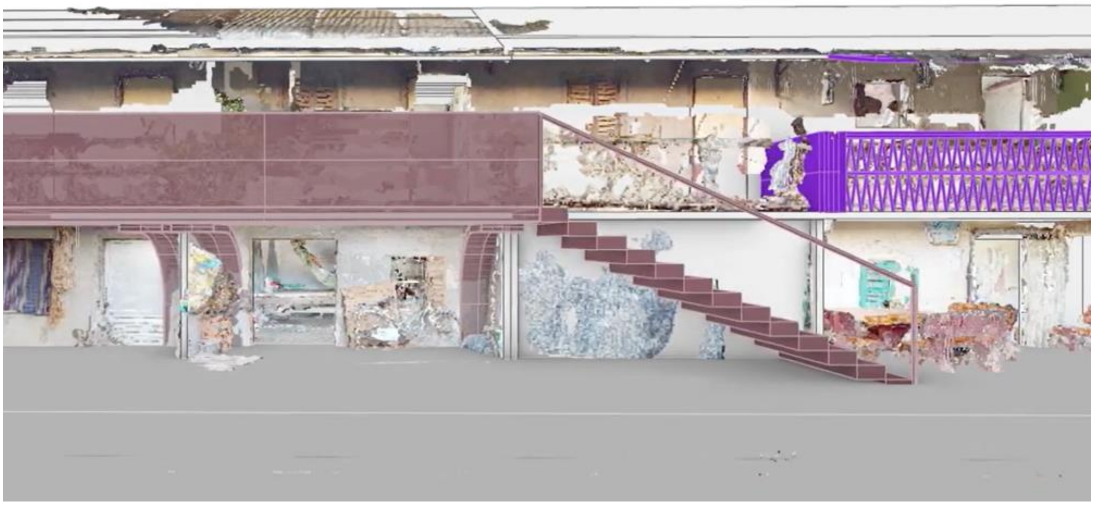

Fig. 12. Propositional expansions of façade elements in 3D onto existing housing façade, demonstrating representation of new structure/elements over existing structure and conditions in Rhinoceros 3D

4. Relevance of Information and Documentation Contained in Point Cloud Model

The research team not only evaluated the methods of sharing and viewing point cloud data but also scrutinized the pertinence of the information and data contained within these models. During discussions amongst researchers and practitioners, six primary considerations for housing development were identified, which spanned built environment, social, economic, and cultural aspects. These considerations, outlined in Table 2, were thoroughly addressed, analyzed, and visualized, with community discussions integral to the development process.

The relevance of the point cloud data was particularly scrutinized, resulting in the identification of additional sub-points by the researchers. These sub-points include both tangible physical elements and intangible aspects, such as household income and demographics.

Points 1 to 4 pertain to physical and tangible elements, which are effectively captured and represented in both point cloud data and 360 images (photospheres) that are recorded simultaneously with 3D data capture. This dual-method approach allows for both the identification of issues and the quantification of elements, underscoring the utility of point cloud technology in understanding and evaluating physical properties.

Conversely, points 5 and 6, which focus on preliminary community understanding, present challenges. Demographic information, for instance, is nearly impossible to discern solely from point cloud or 360 images. While some assumptions can be made based on the presence of certain spaces or items (e.g., workshops, livestock), exact counts and deeper insights remain elusive and ambiguous in point cloud representations, highlighting a limitation in the accuracy of the data for certain types of analysis.

Table 2
6 primary points and sub points to evaluate the existing built environment and social and economic circumstance of informal settlement

Points of evaluation	Elements and information that must be available to evaluate built environment
1. Safety	i. Dead end ii. Dark spot (in day time) iii. Street light iv. Visibility v. Fire hazardous materials vi. Flood plain
2. Health and Hygiene	i. Toilet (water supply, common but in the community, not in community, public, open, ii. Bath (location, water, individual, open, iii. Solid waste collection iv. Common sewage (city sewage, Septic tank, open drain, closed v. Ventilation, natural light vi. Portable water supply common or individual (well or municipal, city, distance…) vii. General water supply (source, piped, common tap, well, bore well, surface water)
3. Housing	i. Number of rooms ii. Size and scale of rooms iii. Construction material (roof, wall, floor) 1. Roof (Gluvanised metal sheet/cement sheet/concrete/timber/bamboo…) 2. Wall (timber/Gluvanised metal sheet/brick with mortar/Mud unbaked brick/brick/concrete/bamboo…) 3. Floor (timber/bamboo/stone/tile…) iv. Lighting Source (electricity, Kerosene, Solar, other fuel, v. Source of cooking (PNG, LPG, Wood, coal, electricity, vi. Kitchen (inside, outside, no kitchen, vii. Hot water (Electricity, common with kitchen, piped, not piped viii. Leisure/communication (TV, Radio, Internet, Mobile service ix. Washing facility cooking/cloth (inside of house, common, none, x. Window, door fittings, (shutter and frame/jamb, glass, temporary, water tight…
4. Common space	i. Street pattern (regular, irregular, width, parking facility, side walk ii. Street condition (paved, concrete, asphalt, mud, on stilt, iii. Common ground (size, number per house, accessibility iv. Community facility (community space covered, uncovered, v. Landscape (number of trees
5. Demographic Pattern	i. Size of household (age distribution, number of members) ii. Head of household (male, female) iii. House hold income iv. Number and types of vehicle own by household v. Ownership of house (owned, tenement vi. Literacy rate, the last education (primary, high school, university, none
6. Social Economic Pattern	i. Domestic animals (chicken, rabbit, cow, goat in common space or in household space ii. Agricultural activity iii. Space for any other source of income (workshop for sewing, carpentry, welding iv. Shops in the community (number, size, types v. Proximity to institutions (School, hospital, post office, bank

5. Findings and Discussion

The evaluation of three methods for sharing and viewing 3D space as point cloud models has demonstrated their effectiveness in providing accessible data for various stakeholders. It is clear that point cloud data not only facilitates autonomous access to information but also contains adequate detail for professionals to utilize during the planning, conceptualizing, and developmental stages of housing projects. However, integrating point cloud methods into existing professional workflows requires significant time and effort to develop the necessary skills.

Nevertheless, table 3 indicates an example of housing development stages (vertically arranged from early stage to operation stage), actors (three major actors horizontally arranged) and possible use of 3D information and documentation (in right most column). Much emphasis is given in the table is stage I, planning stage which include any operation precede construction activities, including design), so that discussion is about effectiveness of 3D information and documentation for horizontal networking, which is dependent on sharing of knowledge and information, and decision-making process in early stage, rather than design and construction stage, which is obviously benefitted from advancement of 3D information and documentation.

This means that visualization or visually represented information, which include traditional 2D drawing on paper, physical model and 3D documentation, must be understood as tools for communication, instead of representation of concrete idea. It's communicative capacity across different actors must be used to inform decision making process, especially for those otherwise having less access to information and knowledge, like urban poor community.

Table 3
Housing development: its key stages arranged vertically (I,II,III) and actors arranged horizontally (A,B,C), and use of 3D information and documentation (right most column in red text)

						Actors that operate (Who is involved in the process)			
						A	B	C	
						The Users (popular sectors)	**The Suppliers** (the private commercial sectors)	**The Regulators** (Public sector or government)	
						urban poor communities network leaders community saving group	contractor, architect, survyer, engineer, planner, community architects, community contractor (vendors, professionals, technicians)	munincipality, academics, NGOs, funding bodies	**relevance of 3D information and documentation in the process**
Division of stages according to decision-making process and operation	I	Planning (any operation that precede construction	1	Idetify stakeholders / beneficiaries		target urban poor community	N/A	NGO	
			2	Organise network meetings	**Horizontal networking** learning from other communities, increase their skills, and sense of what is possible	target urban poor community, possibility of includeing communities from multiple locations	Community architects	NGOs, Munincipalites, Academics	Community Architect (or NGO) to present past project. It could be simple point cound model (or VR) of before and after will clearly present what is possible development/updradation.
			3	Organise meetings with each urban poor community		target urban poor community	N/A	NGOs	
			4	Establish a joint **commitee**	To oversee implemantation across the city. Aiming to integrate urban poor housing into the city's overall development	urban poor communities network leaders	Proffessionals	Munincipality, local academics, NGOs	
			5	Joint committee organises meetings		Urban poor communities network leaders	Proffessionals	NGOs	
			6	Conduct a survey of all communities in the city	gathering information for each community (the number of households and family members, housing security status, land ownership, infrastructure problems, community organizations, savings activities, existing development initiatives) This citywide survey is an opportunity for people to meet with and learn about each other as well.	Urban poor communities network leaders	Proffessionals	NGOs, Academics	Mapping and integrating information gathered on to pointcould model could be one of supporting tools. Some of problem related to infrastructures, housing condition could be presented better with pointcloud model / VR.
			7	Use information from the survey to develop a citywide housing development plan		N/A	Proffessionals	NGOs, Munincipalites, Academics, Local Academics	
			8		mobilizing people's collective resources and strengthening community groups and building collective financial management skills	target urban poor community Community saving group	N/A	NGOs, funding bodies	
			9	Select communities which should be upgraded first	The selection criteria should include a collective assessment of the urgency of need and the community's willingness to try and learn	target urban poor community	Community architect	NGOs	Demostrating phase /incremental development in pointcould and BIM modeling
			10	Develop detailed housing plans for communities in the first group to undertake projects. Subseaquently, finance has been approved, followed by construction immediately.	These early projects in a city serve as learning centers for other communities in the city, as they prepare their housing projects for later phases.	target urban poor community, community saving group	Proffessionals, Community architects, community contractor	NGOs	BIM modeling in pointcloud to develop design and simultaneously present estimate
	II	II. Construction (building operations)	11	Measurements, consolidating data for scaled map	actual measure their houses, existing lots and community boundary	Target urban poor community	Community architects	NGOs	Detailed pointcloud will help measurements and plotting
			12	Preparation of bill of quantity, estimate	finnding resources available within budget and organise/facilitate logistics and procurment of materials.	Target urban poor community	Community architects community contractors	NGOs	BIM modeling to present estimate
			13	Prepareation of construction schedule, payment shedule	phasein construction and facilitate community contractor for arranging workforces	Target urban poor community community saving group	Community architects community contractors	NGOs	BIM modeling to organise schedule of construction
			14	Organise technical traning for construction	efficient construction technique, safety measure and site managements	Target urban poor community	Community architects community contractors	NGOs, local academics, academics	photogrammetry for documentation of construction process for training material
	III	III. Management and maintenance / dissemination	15	Documentation of construction process, preparation of as built drawing, mapping	allowing technical information and knowledge to transfer to following phase. As built drawing allowing further upgradation and maintainance.	Target urban poor community Network leaders	Community architects community contractors	NGOs, local academics, academics	simple 3 dimensional documentation of construction process will act as as built drawing
			16	Expansion/scale-up plan based on the first phase	After the first phase of project is well underway, the upgrading process can extend to as many other communities.	urban poor community	community architects Professionals	NGOs	Pointcloud model and BIM will inform exptention
			17	Integrate all these housing projects into a citywide thinking and a citywide development.	This includes coordinating with public and private landowners to provide secure tenure or alternative land for resettlement and coordinating with utilities to improve access to basic services on a citywide scale	urban poor community	Professionals	NGOs	Documentation for material used for disseminating pilot project
			18	Build layers of overlapping issue-based and area-based networks around issues of mutual interest or mutual benefit	a common land ownership, shared construction, cooperative enterprises, community welfare and collective maintenance of public resources	urban poor community		NGOs	

6. Conclusion and Future Research

According to Chawanad Luansang, Projects implemented through the Asian Coalition for Community Action (ACCA) and a network of community architects across Asia have shown that community architects play a crucial role in translating community ideas into practical visual representations like drawings and models[5]. These initiatives underscore the importance of integrating technological advancements into traditional architectural workflows. Such integration can empower communities, fostering their participation in the social and economic development processes.

Future research should explore further technological integration, aiming to streamline these processes and reduce the learning curve for professionals. Additionally, examining the direct impact of these technological tools on community empowerment and participation could provide deeper insights into the transformative potential of advanced visualization methods in community-driven housing projects.

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