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Arrangement of Voxel-based Housing Module as Community Spaces

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Abstract

Habitat 67 is an earliest example of a voxel shaped housing module, a ground-breaking architectural marvel located in Cité du Havre, Canada, stands as an early embodiment of a voxel-shaped housing module. Conceived by architect Moshe Safdie as part of his master's thesis at McGill University's School of Architecture, this innovative development was planned to seamlessly blend the advantages of suburban living—such as gardens, well ventilated air, privacy, and multi-levelled environments with the economic efficiency and density typical of modern urban apartment residence (Matthew, 1997). After its somewhat success, many architects around the world are playing with this idea with Habitat 2.0 being the latest example designed by Bjarke Ingels Group. The magnificent habitat 67 was designed before the technology era (more than 50 years ago, 1967) by Lego blocks and hand modeling. The architect himself admitted that he could have come up with an even more efficient design with today's software and computer's help. This thesis is a research through design project where the researcher tries to design an arrangement prototype of such a housing module in the most functional and sustainable way that fits in Kathmandu's geography and fulfills contextual needs. Due to the nature of pixelated buildings, there are more possibilities to play with it for maximum utilization of building science with the help of digital simulation and BIM software. Finally, such design will help to break the mundane housing blocks design culture in the architecture industry of Nepal. In this research, the main methodology is research through design where various iterations are created to design the housing prototype. It draws various inspiration from Newari courtyard and shapes. Although creating an interactive social space is a very hard and subjective task which needs a lot of individual effort as well as cultural aspect, this design tries to architecturally bridge the gap by creating interactive space through visual and connective open spaces in each floor by creating multi-level aangan (residence garden).

Keywords

Voxel arrangement, Modular housing, community space, prototype design, Newari courtyard

1. Introduction

A housing complex is a group of buildings that are designed for people to live in. The buildings are usually connected to each other and have common areas, such as parking lots or playgrounds. A housing complex, also known as a residential complex or housing development, is a large area of land that is planned and developed to accommodate multiple residential units. It is designed to provide housing options for a significant number of people or families within a cohesive community setting. Housing complexes can vary in size and architectural design, ranging from small-scale developments with a few buildings to expansive communities with numerous housing units and various amenities. Thus, housing complexes can be found in all parts of the world, and they come in a variety of sizes and styles. A community space is a physical place where people can gather to interact, socialize, and participate in activities. Community spaces can be found in a variety of settings, including parks, libraries, schools, and community centers. They can be indoors or outdoors, and they can be large or small.

Explaining Voxel:

The article "Why are most buildings rectangular?" underscores the efficiency and practicality of rectangular shapes in architecture, particularly when it comes to stacking and packing building blocks such as rooms, apartments, or modules. Steadman argues that the constraints of stacking and arranging rooms together and the flexibility offered by rectangular arrangements contribute to the prevalence of right angles in architectural plans. Rectangular shapes are indeed commonly employed in architecture for various practical reasons. The constraints of packing rooms together, and the flexibility of dimensioning allowed by rectangular arrangements, explain the predominance of the right angle in architectural plans [1].

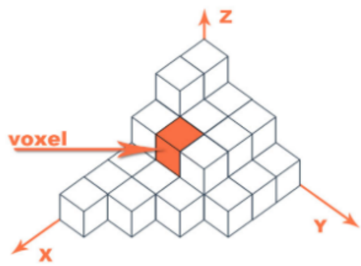

Figure 1: Illustration of voxel

"A geometrical demonstration comparing room shapes and room arrangements on square, triangular and hexagonal grids indicates that it is the superior flexibility of dimensioning allowed by rectangular packings that leads to their predominance." [1]

In the book "Computer Graphics: Principles and Practice" suggest that the word voxel originated by analogy to "pixel", with vo representing “volume" (instead of pixel’s “picture") and el representing element [2]. In the realm of computer graphics, a voxel, or a 3D pixel, represents a three-dimensional cube situated within a spatial grid, contributing to the construction of intricate 3D models. By envisioning each apartment block as a singular voxel module—a constituent of a 3D modular building—it becomes possible to simulate a design wherein the arrangement of multiple such blocks culminates in a functional housing complex. This approach incorporates fundamental building sciences such as wind direction, solar path, and ventilation. Voxel- based Housing complexes are designed to provide residents with a comprehensive living environment that combines housing, amenities, and community engagement. They aim to create a sense of community, offer convenient living arrangements, and enhance the overall quality of life for the residents within the complex. complex with proper use of building sciences like wind direction, solar path and ventilation.

2. Need of Research

In the fast-paced, densely populated landscapes of urban areas, the demand for innovative and efficient housing solutions has never been more pressing. Prefabricated houses, or prefab houses, have emerged as a promising answer to the challenges posed by urbanization. This thesis explores the myriad advantages that modular houses bring to the urban setting, from rapid construction and efficient land use to reduced environmental impact, cost savings, and adaptability to unique design challenges. One of the standout features of such housing complexes is their rapid construction capability. This efficiency is complemented by the space optimization inherent in prefab design, making these houses ideal for smaller or irregularly shaped urban lots.

3. Importance of Research

This thesis topic explores the potential of voxels to create new and innovative forms of housing. By arranging voxels in different ways, you can create housing modules that are tailored to the specific needs of a community. For example, you could create modules that are designed for families, young professionals, or seniors. You could also create modules that are designed to promote social interaction or provide access to green space. Voxel-based housing modules are a sustainable way to build houses. The modules are made from recycled materials, and they can be easily disassembled and reused. Voxel-based housing modules are a scalable solution. They can be used to build small homes or large apartment buildings.

4. Problem Statement

In the modern context where most people are migrating towards the city, the living standard has risen in terms of services and opportunities, but things like social interaction, greenery have been in decline due to the arrangement of modern buildings in urban space. Some modern housing complexes feel impersonal and disconnected, as residents may not have much interaction with their neighbors. This can be a problem for people who want to feel a sense of community, as it can make them feel isolated and alone. Many modern housing complexes are built on small plots of land, which leaves little room for green space. This can be a problem for residents who want to enjoy the outdoors, as it can limit their opportunities for recreation and relaxation [3] .

5. Research Question

How can the rising trend of prefabricated modular housing be adapted to Kathmandu’s urban sprawl, seamlessly integrating the communal benefits of compact Newari settlement; the efficiency of apartment buildings, and the luxury of modern suburban residences into a cohesive housing complex?

6. Research Methodology

6.1 Research through Design

The methodologies are based on applied research where the research is done through an iterative design process. “Research through design" is closely aligned with practical design work, redefining the act of designing as a form of research. Designers/researchers using this approach actively create new products, experimenting with novel materials, processes, and more [4].

6.2 Research Method

- **Bottom-up Design Strategy**: A bottom-up approach is the piecing together of systems to give rise to more complex systems, thus making the original systems sub-systems of the emergent system.
- **Digital simulation**: BIM stands for Building Information Modeling and is a workflow process. It’s based around models used for optimizing the planning, design, construction, and management of building and infrastructure projects.

7. Limitations

The limitations of the project are given below:

- The space efficiency may not be as good as apartment and compact housing as well as the cost for this project may exceed normal modern housing construction due to the slow progress in prefab housing development.
- Challenges in structural load and building services management
- Research through Design (RtD) differs from researched art or design, as the latter prioritizes the creation of art, while the former emphasizes the pursuit of knowledge and understanding through the design process [4] .

8. Design Phase

In this research through design project, the voxel-based prototype has two phases of designing. First one is defining the individual module precisely which will be repeated throughout the design. And the other is its arrangement to create community space linking the modules as a housing unit.

8.1 Design Initiation

In the context of this research through design project, the creation of the voxel-based prototype involves two key phases, each contributing to the overall design concept. The first phase is dedicated to precisely defining the characteristics and specifications of the individual module. This module, once established, serves as the fundamental building block that will be replicated consistently throughout the entire design. The second phase centers around the arrangement of these individual modules to form a cohesive and functional housing unit. The emphasis is on the thoughtful placement and linking of these modules to generate communal spaces within the housing complex. This phase involves a meticulous consideration of spatial relationships, functionality, and aesthetic coherence to ensure that the ensemble of modules not only fulfills individual housing needs but also fosters a sense of community.

8.1.1 Defining module (First Phase)

This section dives deeper into the requirement of voxel-based apartment modules in terms of size, scale, proportion, interior zoning, interlockings mechanism and material. In the context of Kathmandu, this prototype design is validated with the help of pre-existing centuries old traditional houses built organically over the years with tried and tested methods [5].

- Scale and proportion: The proportional relationship between the individual floor height; typically ranging from 2300 to 2500 (Jigyasa Subedi, 2021), and the width of traditional residences consistently maintains a ratio of approximately 1:3 from section reference [6]. This implies that the width of each floor is three times that of its height. To adapt this traditional proportion to a modern context, where the standard floor height is considered to be 9 feet (2.7 meters), the width of the modern module is calculated to be 8.1 meters, adhering to the established ratio. With the height and width of the voxel now determined as 2.7 meters by 8.1 meters, the remaining dimension for the cuboid voxel is its length.

  Drawing inspiration from Habitat 67's pragmatic structural approach, the length of the module can be set as double the width. This echoes the design principle observed in Habitat 67, where the construction system revolves around large precast concrete, three-dimensional modular units. These box-like elements, as detailed by Moshe Safdie in 1966 [7], measure 17 feet 6 inches by 38 feet 6 inches by 10 feet high, showcasing a harmonious 1:2 ratio between length and width. This structural approach not only ensures stability but also aligns with modern design principles, emphasizing efficiency and functionality. Thus, the final proportion of the length: width: height will be 6:3:1 i.e. 16 m × 8 m × 2.7m as shown in the figure below.

- Interlocking Mechanism of the modules: From the above discussion, we can make the pixelated plan version of the given cuboid of the housing module. The plan will be of dimension 8m × 16m. Which can be further segregated equally into 8 parts of 4 m × 4 m square shape. The main structural component may run through the center of the grid which is show in Figure 2

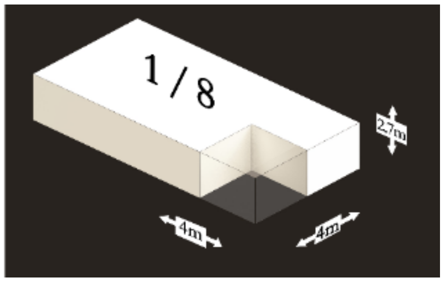

Figure 2: Illustration of placement of porch/ vertical circulation through mass and void

  Now, those 8 parts can be interpreted as pixels. Thus, the plan contains 8 square pixels each side of 4m length. These pixels can be visualized as adaptable zoning where the interior can be customized as per user need and requirements because each square has the area of nearly 14 sqm (excluding partition and external wall) which is enough for any room; whether it's Living room or Master bedroom or Kitchen plus dining.

  After segregating the module into such eight equal parts, we can draw inspiration from literature reviews for stacking / packing of these plans and modules for functional purpose. Looking into the Habitat 67 stacking method, the block where one is stacked over the other is mostly 50 percentage of its area, which means at least half of the block is stacked over the other one. Although all of this permutation of overlapping is theoretically possible, only few of them are pragmatic when it comes to functionality. Especially with vertical circulation and space efficiency, careful consideration must be taken while choosing the stacking method.

- Interior Zoning: The figure just above is an example of interior planning and partition walls within the module. The given planning is done in accordance with the Vastu sastra but as the stacking and interlocking goes in all directions, the possibility to integrate the essence of Vastu sastra seems impossible. But the idea of giving porch in the entrance which reduces apartment area from 128 sq. m to 114 sq. meters is quite intriguing since with the help of rotation and reflection can shift the void (porch) in all four corners as shown below:

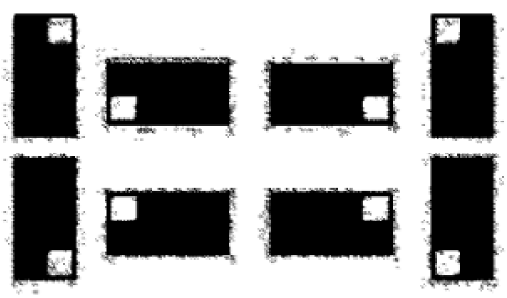

Figure 3: Rotation and reflection method for planning

Xiaojuan Hui explores the application of pixelation in the internal spatial arrangement of architecture where the possibilities and effects of pixelate techniques in organizing internal spaces, provides insights into innovative design approaches. Hui examines how pixelation can be utilized to create unique and functional architectural configurations, considering factors such as layout, aesthetics, and spatial efficiency. Applying this theory to understand the pixelate's potential in shaping architectural interiors, we can use the corner space as vertical circulation in all directions since the plan can be rotated and mirrored. Thus, giving access in all directions both horizontally and vertically.

Figure 4: one corner pixel is left as porch or staircase

Now, by utilizing the porch space as vertical circulation zoning as shown in figure 4 , we can play with the module in a vertical dimension where the entry of the upper floor is decided by the placement of the module porch as well as the staircase position of the module leading towards it. It gives an interesting form to play with. But the challenge of stacking these modules in accordance with the staircase will remain a difficult problem to overcome. The minimum size for a modular unit, allowing for pre-finishing, was determined to be around 600 sq. ft., resulting in components weighing approximately 80 tons when using concrete. Although this weight posed a challenge, especially for future applications aiming for greater economies, Habitat '67 justified the use of concrete as the most economical material within the existing technological landscape. It showcased the material's strengths while also revealing its limitations when applied to three-dimensional building systems.

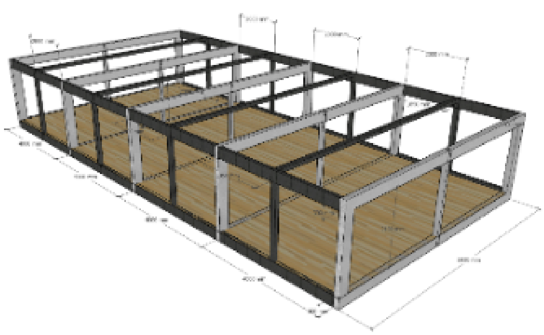

Figure 5: Skeleton System Structure of the module

The module may follow the 4x4 grid as previously shown as well as a secondary structure support at the center @ 2 m distance from each main grid may be also integrated for structural support. As shown in figure 4. Thus, the module is based on a steel skeletal system for its strength and flexibility.

Figure 6: Section of the module

The partition wall will run through the grids of the structure of the module shown in the figure 5 but the flexibility of the light weight partition wall is considered during the design of structural steel components. The section also hints toward the arrangement and positioning of openings guided by the frame of the structure.

8.1.2 Arrangement of Module (Second Phase)

While designing the module was part to whole method, the arrangement is a bigger picture of designing whole to part. In this section, the modules are considered voxels where they are synchronized in such a way, the housing unit acts as one single unit of the architectural and structural system. In the first method the proportion of Newari houses was taken, whereas in this section we will dive into the dimensions of the courtyard of Kathmandu.

In the layout of the Nabahal court's dwelling blocks, several distinctive planning features are evident beyond the central axis. One noteworthy characteristic is the uniform width of the corner blocks, a trait shared by all four courts to be analyzed subsequently. The width of these corner dwellings falls within the range of approximately 310-330 cm, with an average width of 320 cm [8]. Pant's research sheds light on the relationship between the courtyard and the buildings, particularly in terms of proportions. For instance, analyzing the layout of Nabahal nani plots reveals a clear sequence that allows for the derivation of an equation governing the division pattern of the quadrangle. Through his research, Pant establishes the relationship between courtyards and building proportions. For instance, analyzing the layout of Nabahal nani plots, a clear sequence allows the derivation of an equation governing the division pattern of the quadrangle. The equation is expressed as $n(y + c) + c = w$, where w is the width of the open courtyard, c is the corner frontage (320 cm), and y is the width of the plot with the longer frontage facing the courtyard [8].

- Explanation of the courtyard division pattern: Before designating the courtyard for the voxel-based housing module, one must put constraints and parameters around the scale and proportion of the courtyard similar to the first design method.
  From Mohan Pants research, we can understand that bahal's were the inspiration for Newari courtyard designs. And the researcher design is also intended to follow the tradition thus the parameter for defining courtyard size lies in measurement in Rajju (1 r = 60 feet = 19.2 meters). For the voxel-based design, 3 rajju which is 57.6 meters is too much since it exceeds the expansion joint limit of 45 meters according to national code. Thus 2 rajju (38.4 meters) seem to be perfect for our design since it is not only just below maximum

allowable expansion joint limit but also within the human scale of creating cozy public squares / courtyard. As per Gehl (1987), the audible range extends up to 30 m. Within this range, it becomes possible to discern the voices of market vendors. In streets and squares broader than 30 m, visibility allows the identification of individuals, although understanding their speech becomes challenging.

Applying this concept to our design, a size of 2 rajju (38.4 meters) appears to align well. This dimension not only falls just below the maximum allowable expansion joint limit but also adheres to the human scale, creating cozy public squares or courtyards. According to Gehl (1987), the hearing range extends up to 30 meters. Within this range, voices of market vendors can be detected. In spaces wider than 30 meters, it becomes possible to see and recognize individuals, but deciphering their speech becomes challenging. Therefore, the chosen size of 2 rajju (38.4 meters) exceeds the limit for audio perception, providing privacy, and falls within the range for visual recognition, fostering a sense of community.

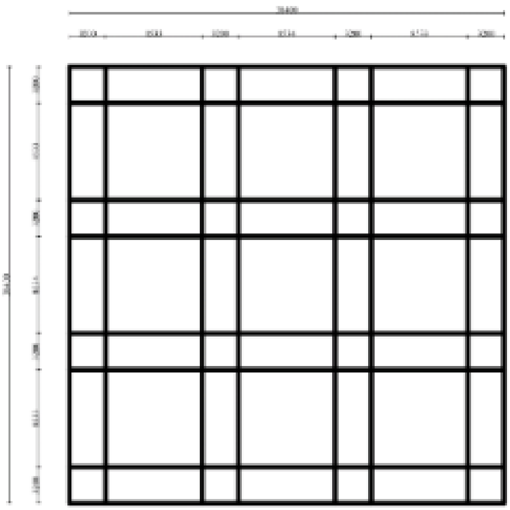

Figure 7: Dimension and Division of courtyard

In this design, the courtyard size is 38.4 m × 38.4 m where, c is 3200 mm and y are 8533 mm. There are three columns of y vertically thus n is equal to 3. The n is always in odd numbers due to the shape configuration and this might also be the reason that the traditional houses in Kathmandu have an odd number of openings and creating symmetry.

- Arrangement of modules in accordance to the courtyard grind: As discussed in the Mohan Pant's paper where the courtyard lead in swastika shaped planning configuration, the joining of modules in horizontal manner where the walls of the voxels collide makes where 2 are east-west arranged and 2 are north-south arranged in each direction making the number of modules 16 in the ground floor that surrounds the courtyard. But there are multiple ways to arrange it. Then another module on the first floor is stacked according to need.

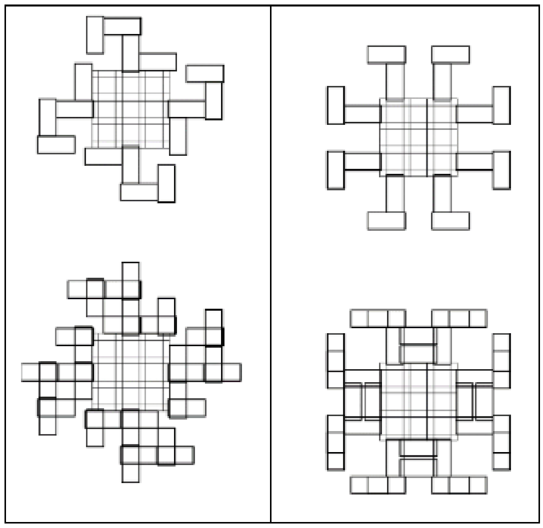

Figure 8: Module arrangement in mandala and swastika

A mandala is a geometric, circular, or square-shaped design that holds spiritual and ritual significance in various cultures, particularly in Hinduism and Buddhism. The term “mandala" is Sanskrit for “circle," and these intricate patterns often radiate outward from a central point. Mandalas are used as spiritual symbols, tools for meditation, and representations of the universe. The design typically consists of repetitive patterns, geometric shapes, and symbols that convey a sense of balance, unity, and harmony. Mandalas are found in various forms, from traditional religious art to contemporary therapeutic practices where creating or coloring mandalas is considered a meditative and calming activity.

Mandalas in architecture can be seen in the layout of buildings, temples, and urban planning. For example, some traditional Hindu and Buddhist temples are designed with mandala-like floor plans, where the central sanctum represents a sacred focal point, and various structures or elements are arranged in symmetrical patterns around it. In modern architecture, the concept of a mandala may be adapted and integrated into designs to achieve a sense of balance and tranquility.

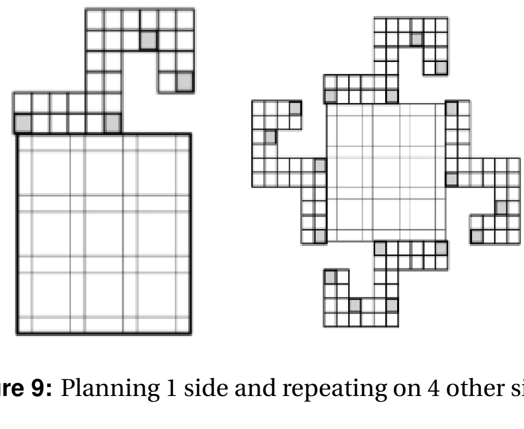

Figure 9: Planning 1 side and repeating on 4 other sides

After the creation of a grid for the courtyard, the grid for voxel planning is laid out. The three external lines outside of the courtyard in the figure 52 is the guideline for voxel modules. Each line is placed at 8 meters offset from each other and the courtyard. The 8 meter is derived from the width of the individual module. Thus, the farthest guideline from the edge of the courtyard is 24 meters. In the initial phase, the designer should only be on the one side of the courtyard (either East, West, North or south. In this case, only the Northern side is designed first and when the ground floor plan is completed then the first floor plan is overlapped on the same side. This method is kept on repeating until all the floor plans are completed then the design is repeated / rotated throughout the plan in all other three sides as shown in the figure 9. In the above design, gray solid hatching represents the staircase position thus in this planning the entrance for each apartment is provided from the respective hatched portion which is its porch.

- Floor Plan Arrangements: In the realm of modular construction for housing design, the use of repeated design components offers several advantages. The efficiency in manufacturing is enhanced, as the same design elements can be replicated, leading to economies of scale and reduced production costs. Consistency in aesthetics is achieved, ensuring a cohesive and visually appealing look for the entire building. Precision and quality control benefit from the standardization of design, facilitated by advanced manufacturing technologies.The swastika is sometimes incorporated into mandala designs, including the Vastu Purusha Mandala mentioned earlier. It is used as a part of the overall sacred geometry to bring balance and auspiciousness to the architectural space.

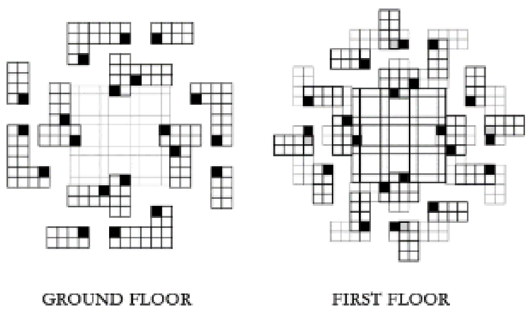

Figure 10: Ground and first Floor Plan

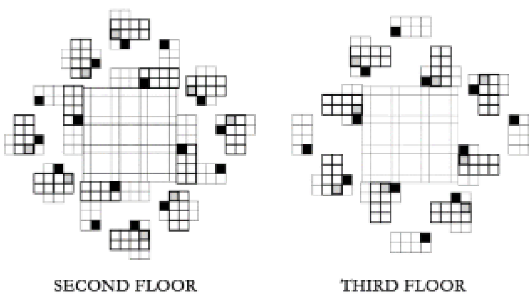

Figure 11: Second and third Floor Plan

The design is as shown in the figure 10 and 11, the Dark Hatch is the porch as discussed earlier. It grows from the central Y part of the courtyard and porch are all aligned such that it faces the courtyard. From previous interlocking and stacking methods such as Lego, various possibilities in design can be achieved through this voxel arrangement method. The possibilities are endless but for the sake of this thesis a prototype is crated as shown above figures in plan.

- Placement of openings: The placement of openings in the voxel-based prototype is a crucial aspect that requires careful consideration, especially given the precast nature of the modules. Strategic placement of openings contributes significantly to the functionality, aesthetics, and adaptability of the design. To optimize this, a key approach is to maximize the number of openings and maintain a consistent sill level. The initial structure guides the placement of the opening where the sill and lintel height will be the same for rotation and mirroring purposes where the change is indistinguishable. The door and windows should be interchangeable by making most opening doors like and later adding sill to make it window if necessary. By leaving the openings versatile, without a fixed sill level, the design introduces a high degree of flexibility. This means that a particular opening could serve as a door or a window interchangeably. All together there are 56 modules thus housing 50 families. Only four storeys are the stacking of this design, since anything above 5/6 story apartment might be a better solution for space efficiency. Reduction of floor module from 20, 16, 12, to 8 in Gf, ff, sf, top floor simultaneously which is the similar (not same) ratio of tiered temple.
- Aesthetic of the prototype: Newari residential architecture, found primarily in the Kathmandu Valley of Nepal, is known for its distinctive and aesthetically rich features. The Newar people, an indigenous community of the region, have a unique architectural tradition that reflects their cultural, religious, and social values. Some of the key aesthetic properties of Newari residential architecture include: Wood Carvings, Pagoda-style Roofs, Brickwork, Courtyards, Traditional Windows and Doors

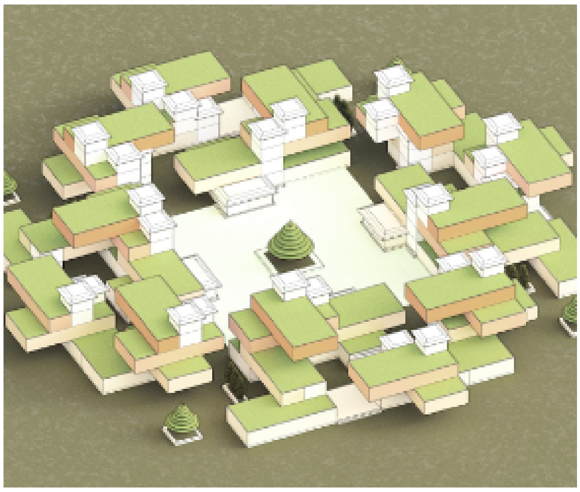

Figure 12: Aerial view of the prototype render

9. Findings and Discussion

In this design method, the vertical indoor spaces (from ground floor to roof kitchen) are converted into horizontal planes where all necessary spaces are created in one module of 114 sq. meters. And the horizontal compact planning of each house along the streets of traditional Newari settlement is converted to compact vertical stacking of mass and void of modules. In short, although it is directly inspired from traditional ideas but diverges to a new realm that was not conventionally possible centuries ago. Let us replace the courtyard of 2 rajju squares we created and replace it with the typical courtyard planning with similar facilities. One key difference in creating is that the modules rarely need an internal staircase as in vertical planning thus a lot of space is conserved in saving the staircase area. But the new approach of stacking needs another vertical circulation through outdoor staircases and lifts. As shown in the figure below four storeys of similar housing units will be about 60 in numbers where each housing unit has its own street / courtyard facing elevation. The garden / outdoor space is only available for ground floor area. Whereas in the voxel-based design each housing unit has its own gardens since all the programs lie in the same floor. The roof of one floor becomes the garden for the above unit. If we look at the voxel-based design within a similar area, the housing unit is also about 60 so the density is more or less same for storey. As the high-rise increases, the density factor will be beneficial in the traditional pattern but all other aspects must be compromised.

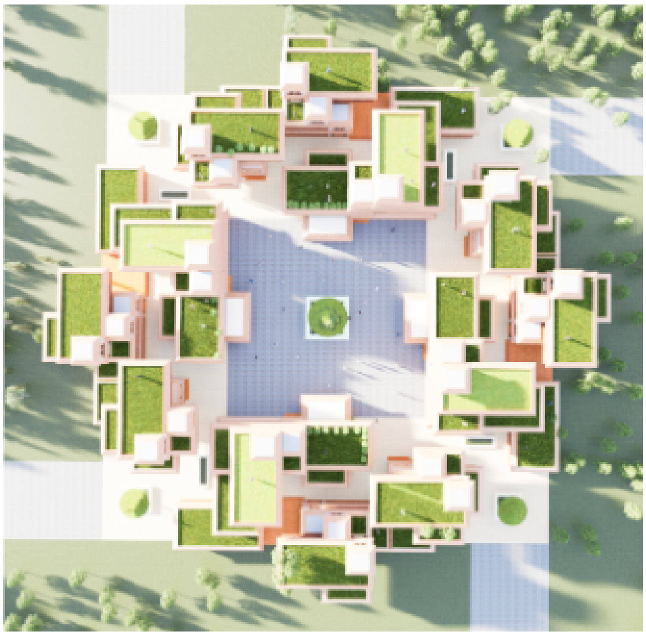

Figure 13: A Rooftop Garden and Courtyard as a Community space

The creation of a roof top garden for each module / apartment creates an additional green area to the site giving more than 100 percentage of green area which is more than the area of the site due to the summation of additional roof tops in these arrangements. Common staircase and walkways link the modular units, providing residents with shared pathways. These spaces facilitate casual encounters and interactions among neighbors, contributing to a sense of community within the building. Shared amenities such as communal laundry facilities and recreational spaces. These common areas serve as additional focal points for community interaction and engagement. These spaces can be personalized by residents, but they also contribute to the overall sense of community by providing areas for outdoor gatherings and socializing.

10. Conclusion

The prototype of voxel modules features central courtyards within the building complex. These courtyards serve as communal spaces where residents can gather, socialize, and engage in shared activities. The design encourages a sense of community by providing residents with a common area to connect with their neighbors. While the building maintains a modular and systematic approach, there is variety in the layouts of individual units.

Figure 14: Courtyard view of the Prototype render

10.1 Modular Apartment Design:

Ensuring that the design of each apartment module is consistent. This makes the construction process more efficient and allows for easy replication. Emphasizing good natural light and ventilation in each module becomes very easy as it is the iteration of the same block with practicable arrangements.

10.2 Rooftop Garden Design:

The rooftop gardens are planned to be easily accessible to all residents. This promotes community interaction and a sense of shared space.

10.3 Community Spaces:

Designated central gathering areas within the complex which could be a courtyard, a communal room, or any shared indoor space integrating recreational facilities.

10.4 Aesthetic Harmony:

Newari architecture, native to the Kathmandu Valley, carries distinctive features like intricately carved windows, pagoda-style roofs, and courtyards.

10.5 Respect for Scale and Proportions:

Voxel designs can be tailored to respect the scale and proportions of traditional residences. This ensures that the new structures do not overpower the existing architectural character of the city.

10.6 Scalability and Incremental Growth:

Voxel-based housing allows for phased development, accommodating incremental growth in the city. This aligns with historical patterns of urban expansion seen in tradition-rich cities.

10.7 Development of parameters:

When conducting research through design on the arrangement of voxel-based housing modules as community spaces, there are several parameters you can explore and learn from. This type of research involves a combination of architectural design, urban planning, and community dynamics. Here are some key parameters to consider:

- Spatial Configuration and Layout
- Community Interaction and Connectivity
- Sustainability and Environment
- Privacy and Personalization
- Cultural and Social Diversity
- Amenities and Services
- Aesthetics and Identity

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