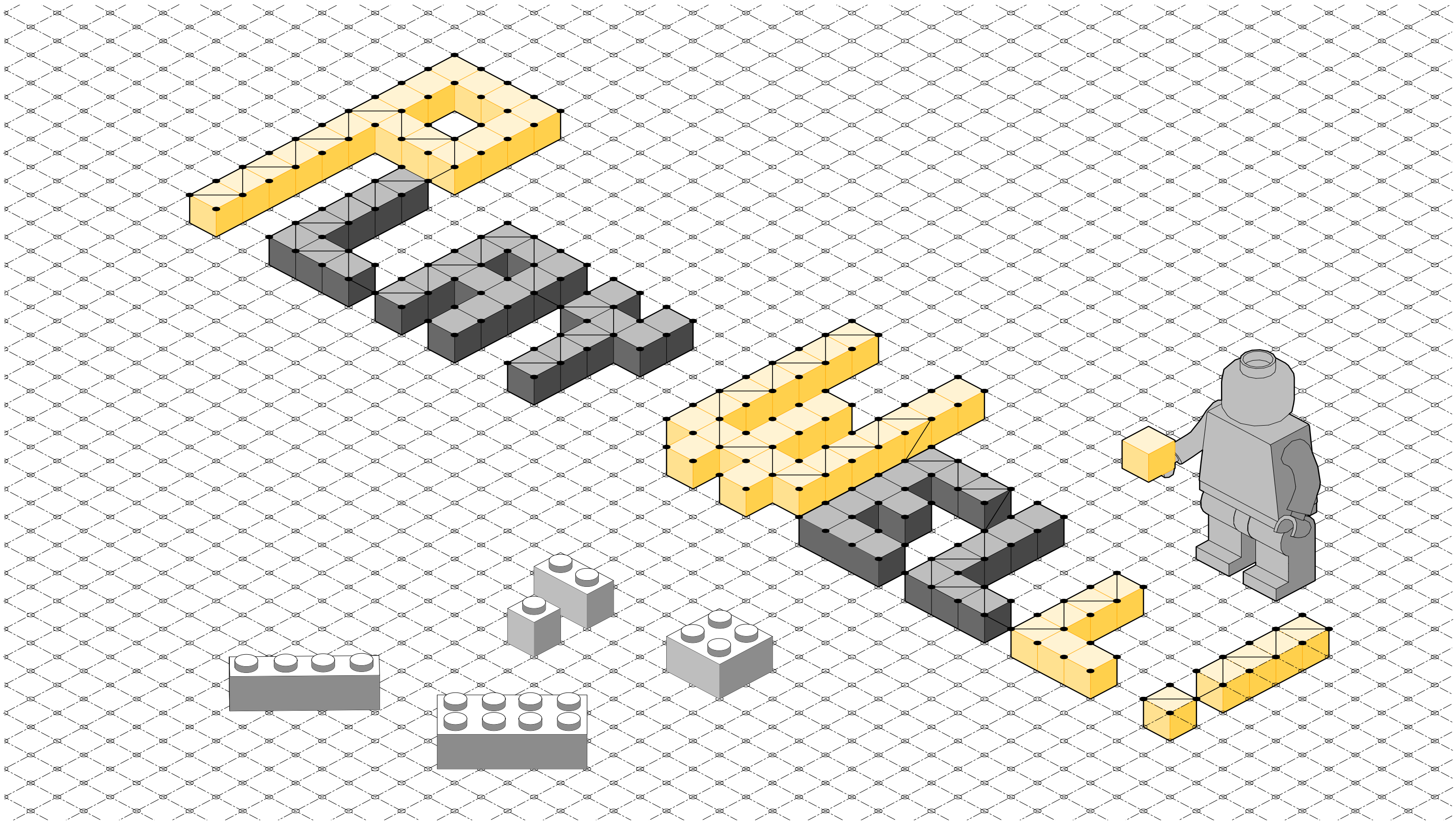
aE GRADUATION STUDIO | AR3AE100

P2 - PLAY WELL RESEARCH | MODULARITY & PREFABRICATION



LEGO - LEG GODT(DAN.) - PLAY WELL !

AN EXPLORATION OF COMPUTATIONALLY DRIVEN, GAMIFIED, MASS-CUSTOMIZATION AND PARTICIPATION ENABLING HOUSING DESIGN PROCESS - FOR HOUSING AFFORDABILITY, PERFORMANCE, AND FIT FOR PURPOSE DESIGN. REDEFINITION OF FRAMEWORK FOR 21ST CENTURY HOUSING DESIGN: FROM MACHINE FOR LIVING TO **A SYSTEM FOR LIVING.**

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Modularization, discretization, mass-customization, participation, democratization, affordable housing, generative design, architectural configuration, space-syntax, voxelization.

PLAY WELL!

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ABSTRACT:

This article explores the steps taken in development of a discretized dimension and construction system called Play-Well. In point 00. it briefly analyzes the history of modular design starting form an early 20th century and progressing to contemporary examples. It indicates the lessons learned form historical examples of system design. A list of 7 principles is defining the foundations of Play-Well setup is presented. Point 01. proceeds to showcase the manual steps taken in order to form a system of spatial and dimension relationships. The result of that process is constitution elements catalogue and proportions between these elements. Point 02. guides through the process of automation of implementation of a system on any input volume. Here the outcome is a versatile script, capable of automatically creating and applying building units. Last segment puts forward a method of translating the system elements (one of the outputs of Point 02.) into a fabrication and assembly manuals, along with the suggestions of system integration with other building techniques. The conclusion discusses potential further steps in the implementation of Play-Well, with a cursory description of the strategies that might be taken in design and algorithm enrichment.

00 : HISTORY, BACKGROUND & DIMENSIONS SYSTEMS.

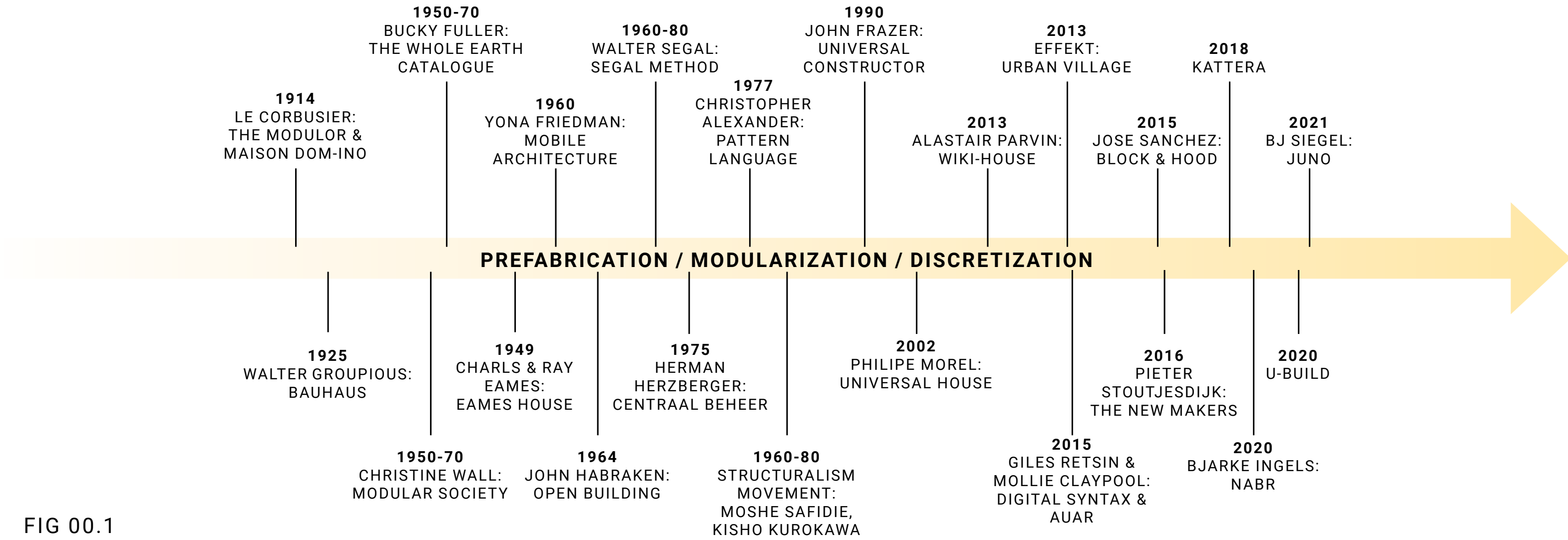


FIG 00.1

Understanding the patterns of development of the field is essential for creating visions of its future. A lineage of a modular design has been created to order the findings and try to extract a tendency from them. [Fig 00.1] The history of modularization and prefabrication in architecture can be traced back to early 20th century. With the advent of new construction methods and a significant increase in demand for workers housing, members of Bauhaus were tasked with developing solutions for working-class housing. Such challenge required a tremendous amount of thought to be put towards the standardization of building design. This resulted in a highly unified, unitized housing solutions, that for all their merit lacked in taking the personal needs and preferences into account. In the 1960s Yona Friedman tried to take the challenges that modernists approach posed and put forward a rule based design strategy that could take individual needs into account. Due to the lack of technical advancement at that point in history the wider adoption of his proposal was impeded, yet the ideas survived to inform later generations. In the early 1970s Walter Segal undertook an effort to create a building system that utilized only off-the-shelf, standardized products. He tried to combine them only using dry methods, in order to achieve a construction technique that did not require specialized equipment and could be thought to communities that were willing to self-build their habitats. In many ways Segal was a precursor to what we have seen developed in the present - Wiki-house, Auar, U-build. Alstar Parvins Wiki-house is one of the most important contemporary moves towards the democratization of architecture and there has been many projects developed as offsprings of his way of thinking. His idea of mass customization pushes the modular from universal design for the masses to an adaptable framework

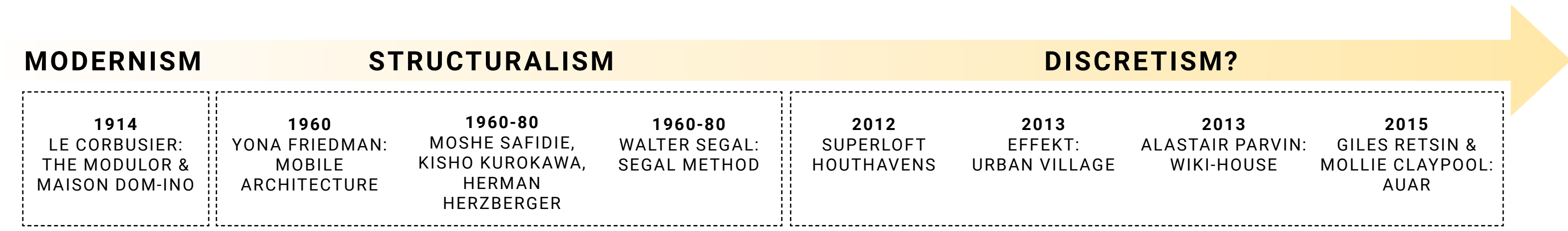


FIG 00.2

that gives the possibility of mass production, but with a promise of easy adaptability to the needs of the inhabitants. More recently, moves towards the productization of architectural design, such as Nabr and Juno, have been made. They foreshadow the future of the housing industry. These companies are effectively trying to shift the housing design towards mass customization at an industrial scale. Allowing for grater personalization of mass-produced housing. These steps in the progression of modular design development can be divided into three distinct yet interrelated eras.[Fig 00.2] Modernism - focusing on one-fit-all solutions, Structuralism - embracing the standard unit and creating complex forms with it, and finally, Discretism - which operates in different scales but essentially suggest catalogues of customizable solutions that can be implemented depending on the needs of a particular situation.

As a reference for the Play-Well framework, a series of modular systems, dimension relationships and space organization strategies have been studied.[Fig 00.3] The analysis of those provided invaluable inspiration for informing the Play-Well strategy: Tatami mat - space-filling unit, tartan grid - gross zone for structure and utilities, modulor - design based on ergonomics and human dimensions, Neufert - standardization of spaces, Lego - universal joinery method, Wiki House - ease of construction and building with disassembly/circularity in mind, U-Build - discretization as means of facilitating participation.

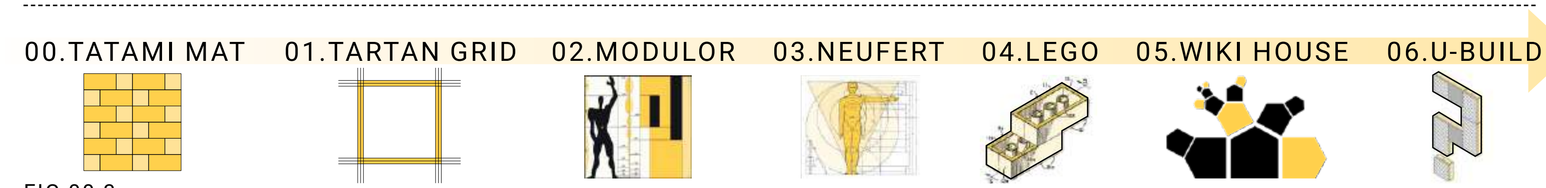


FIG 00.3

01 : PLAY-WELL: MODULAR CONSTRUCTION SYSTEM.

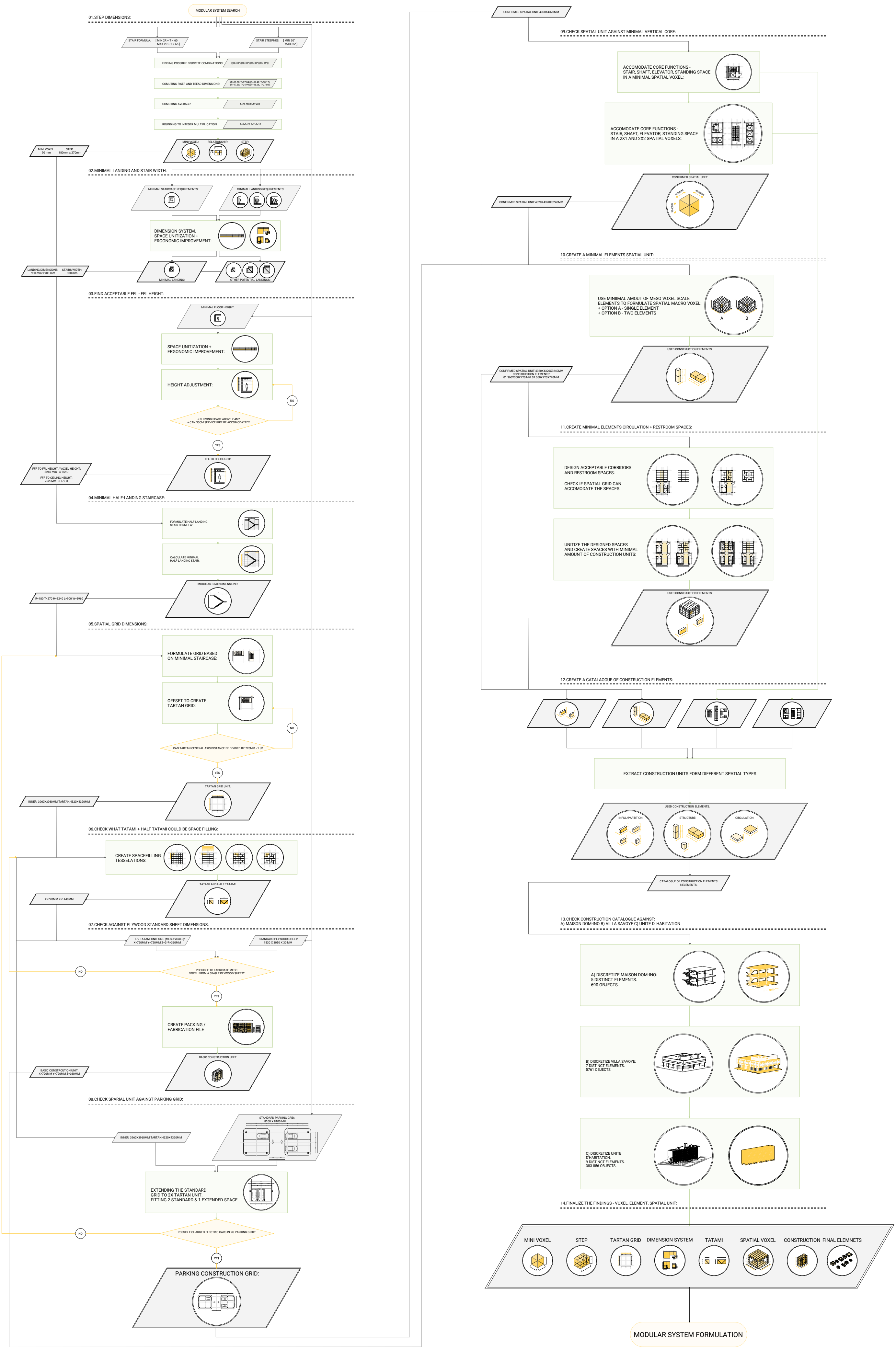


FIG 01.1

01 : PLAY-WELL: MODULAR CONSTRUCTION SYSTEM.

In the 3rd decade of the XXI st century we are faced with similar challenges as the modernists were at the beginning of the XX th, namely the need to provide a dignified housing that answers ever growing demand. Yet, we are also under an unprecedented pressure when it comes to addressing the environmental issues. The housing crisis that is haunting cities of the developed countries demands creation of methods that put people at the center of the equation. In her book 'System for living' Agata Twardoch calls for new housing solutions that can ensure the affordability and accessibility of housing stock. Play-Well system is a proposed answer to that call. It aspires to increase of affordability, productivity, process participation, lower the construction time and cost, create a universal system, design for disassembly - circularity, work with low-emission techniques - sustainability. Play-Well means to take the best form many of the endeavors currently in development - NABR, U-Build, Urban Village to name a few, and inform its ways based on those projects. It allows thinking both in building units and singular elements, which enables grater flexibility. Play-Well system wants to capitalize on this move towards discretization of architecture. It is an endeavor in creating a construction method that with a minimal amount of elements can achieve a great versatility of possible built forms. Through its simplicity it aims to democratize the housing design. The further segment of the article describes the moves taken is creating the system. All the detailed drawing of the steps taken in the development of the system, along with diagrams of the results are available in appendix A. The following description of the process is meant to be read in conjunction with that imagery.

STEP 00 - STEP DIMENSIONS**:**
Preliminary question when it comes to finding the system of spatial relationships is the question of the staircase step. The inputs of step 00 are the stair formula [min 2R+T = 60cm, max 2R+T = 65cm] and a stair steepens angle [min 30', max 35']. With 4 combinations of those, 4 possible riser and tread dimensions are computed. From those average is taken, resulting in tread of 27.52cm and riser of 17.489cm. The result is rounded to the nearest numbers that are a multiplication of the same integer forming a step of **27 x 18cm**. That integer is a basis of the entire system and a so called **9x9x9cm mini voxel.**

STEP 01 - MINIMAL LANDING AND STAIR WIDTH**:**
According to Neufert a minimal landing and a single passage stair with should not be lower than 80cm. This dimension however is not a multiplication of a minimal voxel size and is adjusted to 90cm - 9cm x 10 - resulting in a **step of 90 x 27 x 18cm.** Minimal landing is assumed at **90 x 90cm.**

STEP 02 - ACCEPTABLE FFL - FFL HEIGHT**:**
Another boundary condition of the system is a minimal acceptable floor-finish-level to floor-finish-level distance. A minimal 240cm of floor-to-ceiling height is assumed for a comfortable living environment. On top of that 35cm of service layer and 35cm of structural floor is considered. Coming up to a total of 310cm of FFL-FFL distance. This distance is than rounded up to the an even multiplication of a spatial voxel Z dimension resulting in **H = 324cm FFL-FFL**. The need for such rounding comes from an idea of simpler division into construction elements on the later stages of the process.

STEP 03 - MINIMAL HALF LANDING STAIR:
Having the input parameters form the previous steps, it is now possible to formulate a minimal half landing stair and find the minimal in-construction width of a space-defining macro voxel - such voxel will serve as a basis of spatial division of a future massing. Half landing stair is defined by a formula [H = R (N + 2), W = 2L + (N/2 x T)]. With a know H=324cm and R=18cm it is possible to calculate the N - number of steps (excluding landings) which are needed to rise the distance: N = 16. With the N defined the next step is to calculate the width of the entire staircase (including the landing space) which comes to a: **W=396cm.**

STEP 04 - SPATIAL GRID DIMENSIONS:
With the inner grid distance set at 396cm the proceeding step adds a zone of structural provision offsetting the grid by 4x9cm on each side. This results in a tartan grid of **432cm** (hearth to hearth) and a 36cm structural layer.

STEP 05 - SPACE-FILLING TATAMI + HALF TATAMI COMBINATIONS:
After establishing a spatial grid dimensions we check what even integers divide the space into segments that are a even multiplication of 9cm. These divisions come down to 432 : 8 = 54cm, **432 : 6 = 72cm**, 432 : 4 = 108cm. The middle one of them is taken as a proverbial half-tatami - space filling meso voxel size and a reference size of 72cm = 1U.

STEP 06 - CHECK HALF TATAMI FABRICABILITY AGAINST STANDARD PLYWOOD SHEET DIMENSIONS:
A block of 1U x 1U x 1/2U (Z dimensions defined by 2*R or a height of a structural floor layer) is converted into a fabrication stencil for CNC milling out of structural plywood. Elements of the block are laid flat and packed to cover a minimal area on a market-available 153x305x3cm plywood sheet to check if it is possible to cut out a main construction element out of a **single sheet of material.**

STEP 07 - CHECK THE SPATIAL GRID AGAINST STANDARD PARKING GRID:
Standard parking grid in contemporary buildings is assumed to be 810cm x 810cm - which accommodates 3 standard (250cmx500cm) parking spaces in between structure. With the advent of an electric car however, those spaces will need to increase in size to allow for charging stations to be placed in the proximity of a spot. That is why an extension to 2x432cm works perfectly to address the future needs, allowing for 3 electric cars to be charged in between the structural elements.

STEP 08 - CHECK THE SPATIAL GRID AGAINST VERTICAL CIRCULATION AND ESCAPE CORES:
The 432 x 432cm unit is furthermore tested for its potential to fit the minimal elements required for a vertical circulation core. It is proven that the unit can fit in a comfortable 230 x 230cm elevator shaft, 230 x 70cm service zone, and a previously defined

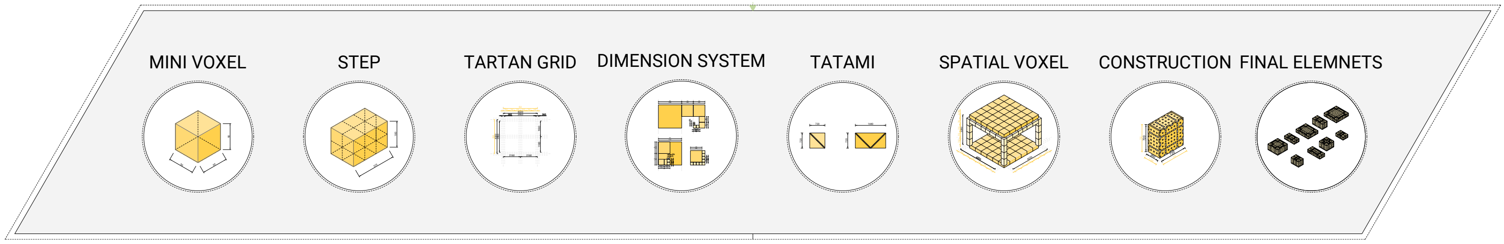


FIG 01.2

minimal half-run landing staircase. The 2x1 and 2x2 spatial unit cores are also tested to see the capabilities of applicability to different building typologies. 2x1 core is capable of fitting 2 elevator shafts and a generous U-staircase, whereas 2x2 core can accommodate 3 elevator shafts and 2 criss cross staircases - ideal for a use case scenario in a taller building.

STEP 09 - CREATE A MINIMAL ELEMENT SPATIAL UNIT:
With a spatial (macro) voxel confirmed at 432 x 432 x 324cm step 09 proceeds to divide it into constriction elements. The structural floor is formulated based on the meso voxel and is a 6x6 grid. When 36cm of a structural floor is subtracted form 324cm we are left with 288cm which is divisible by 4 and results in 72cm - 1U height of a column element. The X&Y dimensions of the column are defined by the size of the tartan grid structural zone and the final element dimensions are 1/2U x 1/2U x 1U. The final minimal elements spatial unit consists out of **1U x 1U x1/2U and 1/2U x 1/2U x 1U elements.**

STEP 10 - CREATE A MINIMAL ELEMENT CIRCULATION + RESTROOM SPACES:
This spatial unit is later on divided into the zones of restrooms and horizontal building circulation to check if it can accommodate a corridor with entrances to the future flats on either of its sides. It is confirm to be generous enough, discretized and blocks constituting partition walls are extracted to be added to the list of construction elements.

STEP 11 - CATALOGUE OF CONSTRUCTION ELEMENTS:
9 Construction elements are extracted from the discretized versions of various building systems - infill/partition walls, structure, circulation. It is assumed that with those elements any potential variation can be formed.

STEP 12 - CHECK CONSTRUCTION CATALOGUE AGAINST THE CLASSICS OF MODERNISM:
As one of the final steps in the system development the formulated construction elements and grids have been checked against the classics of modern architecture in order to confirm the validity of the findings and the assumption of the step 11 has been confirmed. [Fig 01.3]

STEP 13 - FINALIZE THE FINDINGS, EXTRACT THE PARAMETERS:
The final results of the system: mini voxel, step proportions, tartan grid size, spatial voxel, constitution elements catalogue and proportions between elements (dimensions system). [Fig 01.2] These parameters are extracted and utilized as a basis of a script that automates the generation of building units and systems (i.e. circulation, partitions, facade).

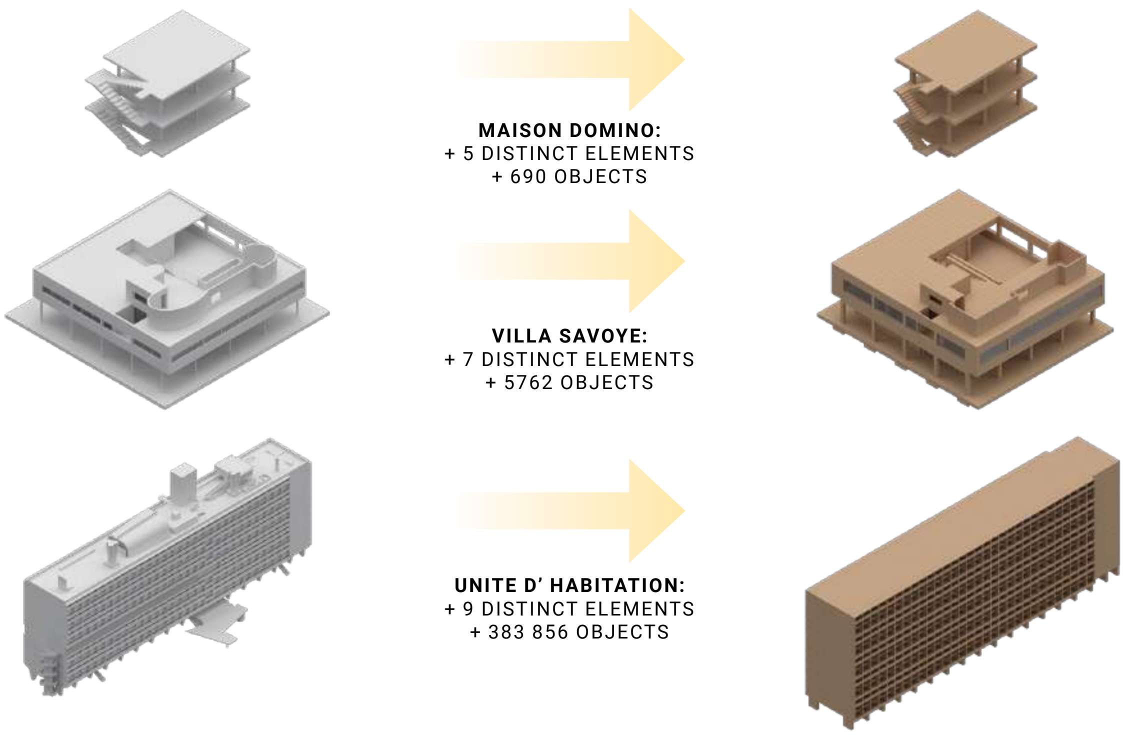


FIG 01.3

02 : SYSTEM IMPLEMENTATION & AUTOMATION.

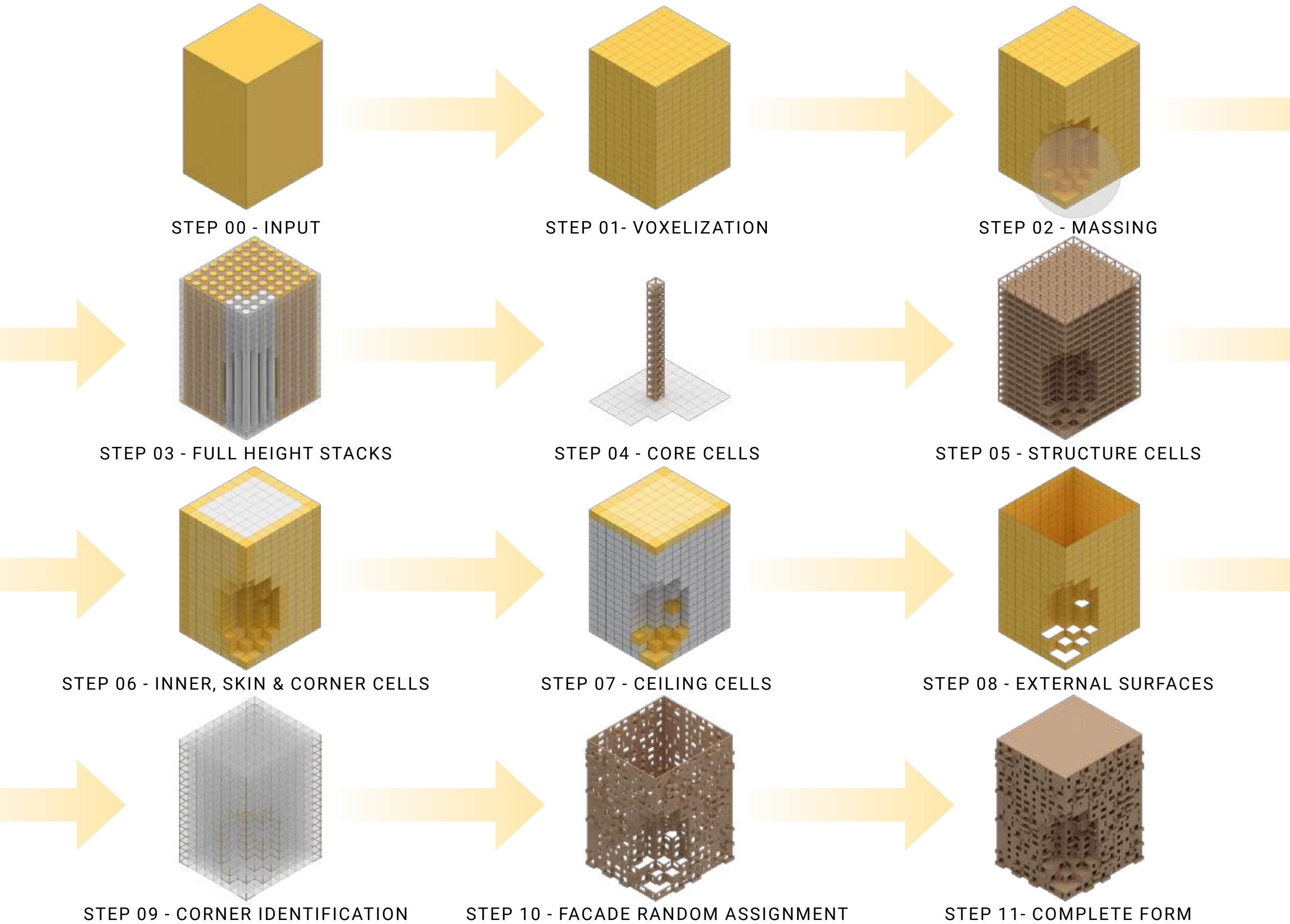


FIG 02.1

After developing analogue understanding of the parameters that define a construction system, an automated way of implementation has been developed. The analogue part of study is much more than just a singular result. The results of that initial research formulate a set of interrelated parameters that can inform a parametric script. The development begun with the assumptions of base proportions taken from the initial research and followed to automatically generate the geometry of the building system. Script also allows further testing with different input values and on different building cases - the model is capable of implementation of the construction system on any given starting volume. This part of the study not only increases the usability and versatility of the system, allows for the flexibility in terms of adjustment of input parameters, but is also a way of further validating of the analogue research, as through turning the system into a universally applicable program a number of special cases has been found and dealt with without increasing the overall amount of building blocks necessary to create the buildings.

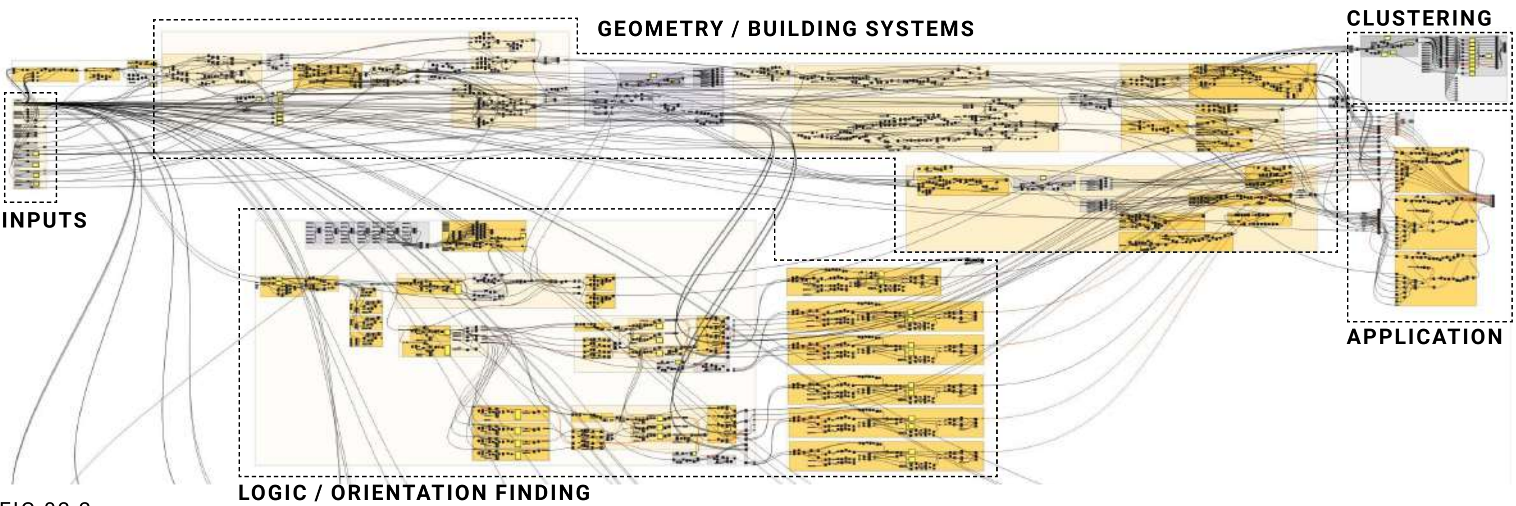
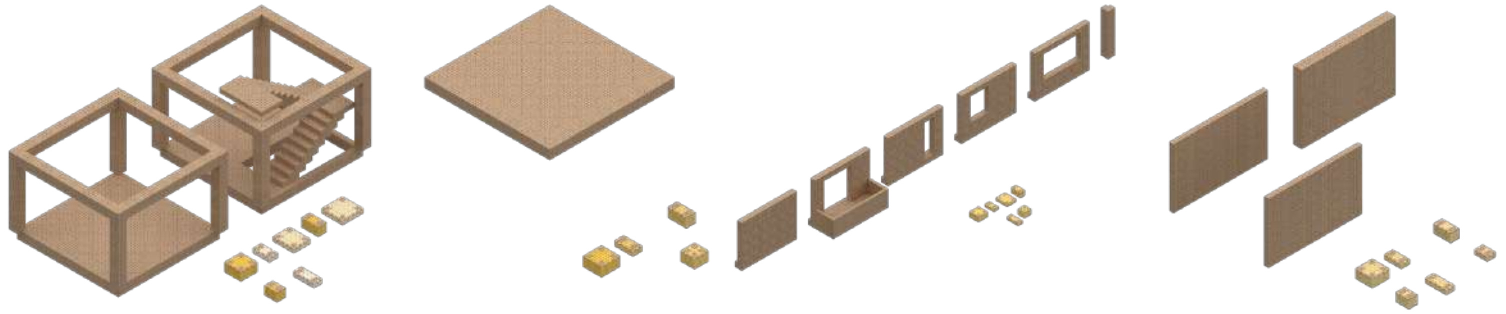


FIG 02.2

02 : SYSTEM IMPLEMENTATION & AUTOMATION.



STRUCTURE + CIRCULATION ROOF FACADE + BALCONIES WALLS + PARTITIONS

FIG 02.3

The program description will focus on the logic and orientation part of the script as it is the most crucial part of the script's added value.[Fig 02.2] The respective zoom-ins of the grasshopper code for selected steps are available in appendix B.

STEP 00 - INPUT:
The selection of any input volume to be preprocessed for analysis. For the visuals diagrammatically depicting the result of each step of the script please refer to Fig 02.1.

STEP 01 - VOXELIZATION:
The volume is processed by scaling it to the dimensions that are integer multiplications of a spatial voxel unit dimensions in the respective directions (432 x 432 x 324cm). The adjusted volume is divided into the cells that correspond with the spatial voxels.

STEP 02 - MASSING:
At this stage a more elaborate massing is created using a rudimentary attractor script, this creates a variety in the volume and allows for testing the later logics on a geometry that provides a higher number of potential special cases of voxel types.

STEP 03 - FULL HEIGHT STACKS:
In order to pre-filter potential cells for the core, a checking algorithm is created that selects only the base voxels that have a full height stack of cells above them. For each base cell a cylinder extending to the top of the building mass, with a center of the base at the respective voxels center and a radius of 1/2 of its width is created. Later, the script checks the number of all the voxels centers that can be found within that cylinder. If the number is lower than the building height expressed in units the base voxel gets discarded. The others are considered for a potential core position.

STEP 04 - CORE CELLS SELECTION:
The final core position is determined using an evolutionary solver Galapagos. Number sliders indicating a core position in the list of pre-selected base cells are used as the genotype and a number of cells within a 30m radius (acceptable approximation of an allowed escape travel distance) of such cell is used to define a fitness function. The amount of indicator sliders that define the genotype and the number of cores is determined by the overall dimensions of the initial input volume. After the most optimal cells are selected, a staircase unit (prepared in the geometry part of the script) is oriented to them.

STEP 05 - STRUCTURE CELLS SELECTION:
The standard unit is reoriented to all the cells that are not defined as core, formulating the structure of the building.

STEP 06 - INNER, SKIN & CORNER CELLS SELECTION:
A layer of information is added to the system by formulating an algorithm that determines the type of the cell on the basis of the amount of its horizontal face-sharing neighbors. This number is found by creating a oblate rotational ellipsoid with a longer semi axis equal to the 3/2 of the cell width at the center of each voxel and checking how many other centers are within that ellipsoid. The result divides the cells into 4 distinct groups: 4 - inner cell, 3 - skin cell, 2 - corner cell, 1 - lonely cell.

STEP 07 - CEILING CELLS:
Additional information regarding each cell is added by finding out the number of vertical face-sharing neighbors. It uses similar logic to the step 06, changing the ellipsoid to be elongated in Z dimension. The result divides the cells into 3 distinct groups: 2 - inner cell, 1(top) - floor cell, 1 (bottom) - roof cell.

STEP 08 - EXTERNAL SURFACES:
In order to find the position and orientation of the facade surfaces each of the cells in their respective types is exploded into its constituting surfaces and the number of other cells surfaces in an immediate proximity is checked. This allows to distinguish the external surfaces. Each one of them is evaluated, its centroid, normal and U,V orientation found.

STEP 09 - CORNER IDENTIFICATION:
The corner conditions are found by evaluating the external surfaces of the corner and lonely cells, the coinciding edges of those surfaces are selected as they form the corner edges of the building. Starting point of each edge is found and along with the

normals of the surfaces used to define the orientation plane of the respective corner.

STEP 10 - FACADE TYPE RANDOM ASSIGNMENT:
Having found both facade surfaces and corners with their orientation defining vectors the script proceeds to orienting the pre-scripted geometries [Fig 02.3] to their respective positions. As of this moment the code selects the type of the facade finish on a randomized basis, however this feature is planned to be extended and rationalized.

STEP 11 - COMPLETE BUILDING FORM:
The building form is completed using the roof elements to cap the cells that requite such operation. The finished building form is an information rich model that can be utilized to evaluate the cost, time and feasibility of construction.

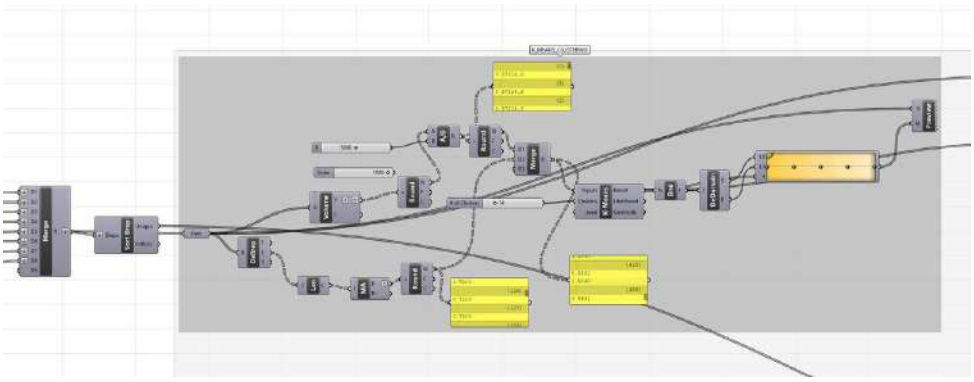


FIG 02.4

The script has been tested on several distinct volumes with special case characteristics to check the universal applicability of the logic.[Fig 02.5] For each one of the starting volumes a number of used elements is generated and using a k-means clustering machine learning algorithm (form a Lunchbox Grasshopper plug-in) a list of distinct elements necessary for construction is assembled. The distinct volumes are selected based on their volume and a sum of the lengths of their edges parameters.[Fig 02.4]

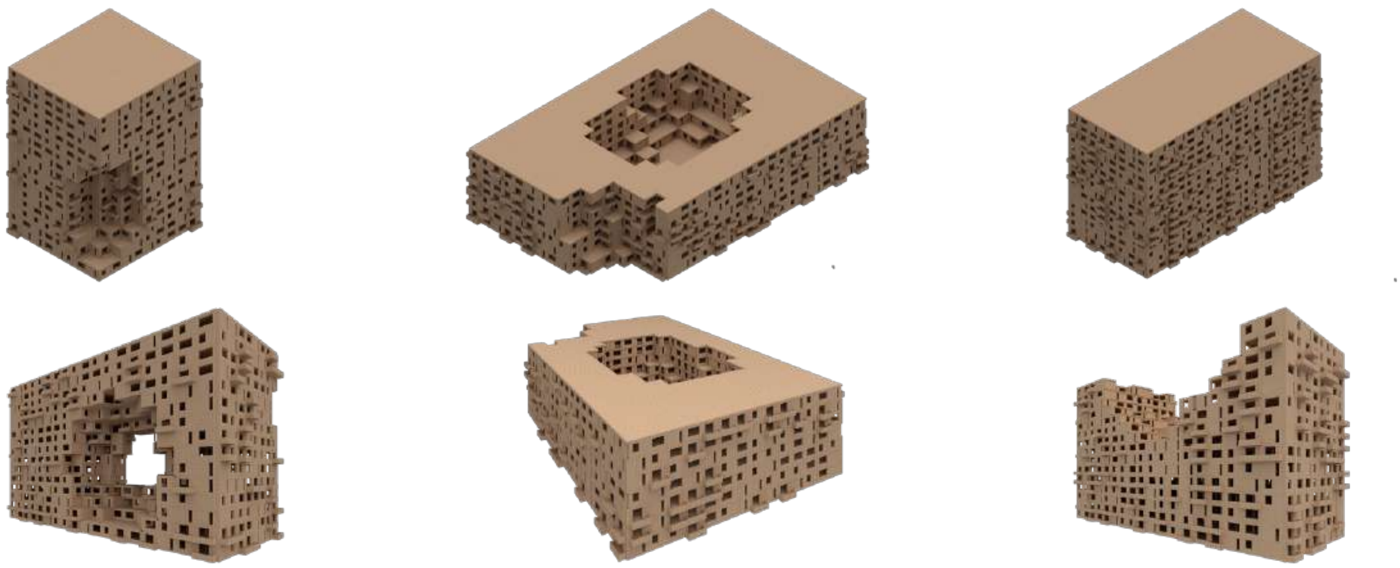


FIG 02.5

The final results of both parts of the study together formulate the refined construction system. With 9 distinct construction elements the script creates generic solutions for structure and circulation units, roof structure, facade and balconies, and structural and partition walls. [Fig 02.3] Each one of the categories is given a distinct color that is also attributed to all building elements belonging to that category. This would simplify the construction process as each building block becomes instantly recognizable as a part of a certain category. All the elements dimensions are a product of multiplication of 18cm = 1/4 U by an integer and thus form an integrated whole of interchangeable pieces.

These final catalogues of elements and categorized building units have been utilized to manually create designs for 3 distinct flat sizes. [Fig 02.6]. A 30m2 studio constructed using 432 elements, 60m2 1-bedroom flat made with 774 elements, and 90m2 3-bedroom flat made with 1312 elements. All flats have been designed using 8 distinct elements types as they do not include vertical circulation.

An extended catalogue of unitized flats and standard building spaces will be proposed at the later stage of development to further improve the potential of automatic generation of design options depending on the needs of the future inhabitants.

02 : SYSTEM IMPLEMENTATION & AUTOMATION.

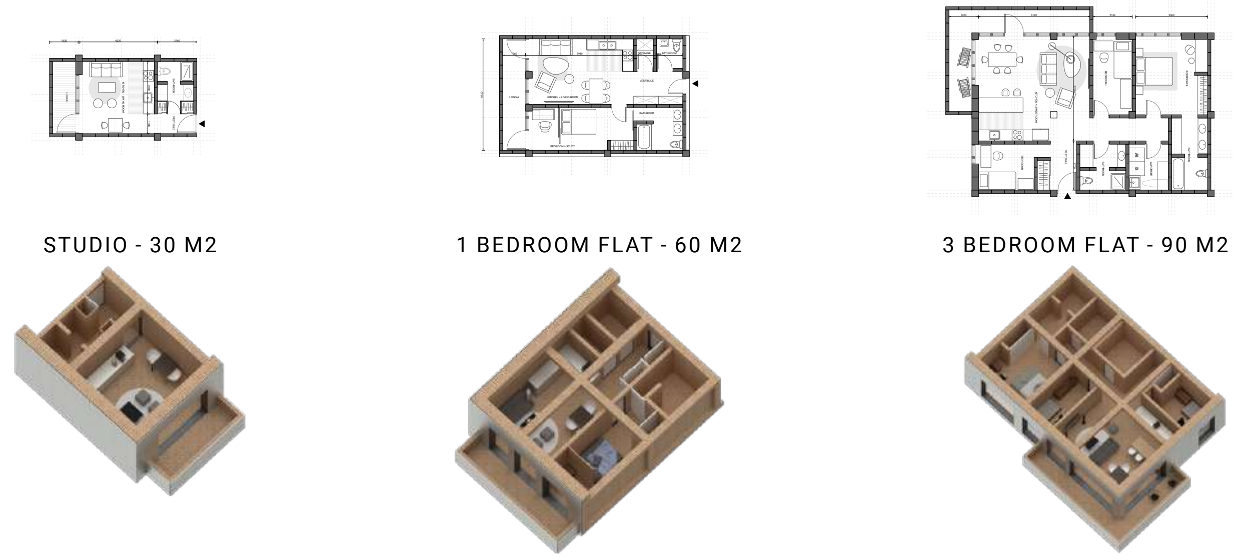


FIG 02.6

03 : FABRICATION & CONSTRUCTIBILITY.

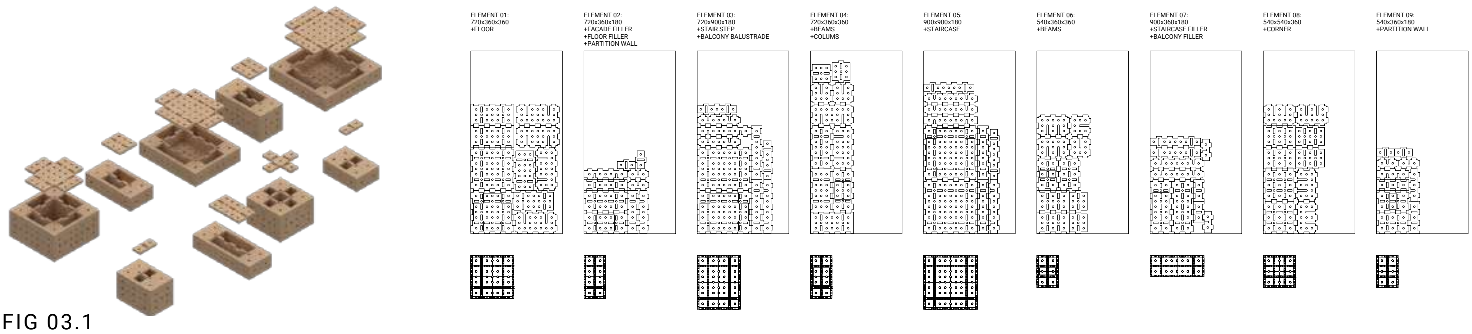


FIG 03.1

In order to ensure the full constructibility of the proposed 9 element system and an automated creation of a fabrication files, another part of the script has been developed. It transforms any given input volume into a schematic for CNC cutting. [Fig 03.1] The outputs of the k-means clustering from a system automation part of the program [Fig.02.2] (distinct volumes used in the system) are used as input boxes for the fabrication script. The code transforms each surface of the input volume into a piece of interlocking puzzle, that in the end forms a construction element. At a fist stage the script reorients the volume with its largest surface facing upward (surface normal matching z axis) in order to ensure that all the volumes are converted into fabricable units according to the same rules and reference.[Fig.03.2] Then, the program proceeds to extract the box surfaces in facing pairs, while also adding inner support elements. Largest surfaces and inner support ones are converted into a puzzle-like interlocking patterns. Failsafe part of the code ensures symmetry of the cut-prepared pieces. Second to last segment of the logic is a series of boolean operations, which ensure that when coming together, elements interlock perfectly to form a cuboid. It also creates the wholes at a 9cm grid (excluding the places of interlock) that provides the possibility of connecting the cuboids together to form larger structures. A final piece of the script is a packing algorithm (from OpenNest Grasshopper plugin) that allows for material saving orientation of the desired geometries in a sheet of material. Final output is a 2d CNC-ready file.

This script has been developed in parallel with a method of joinery that informs the addition of the whole-cutting part of the code. The proposal is to use tensioning rods in different lengths in conjunction with capping screw pieces. [Fig 03.3]

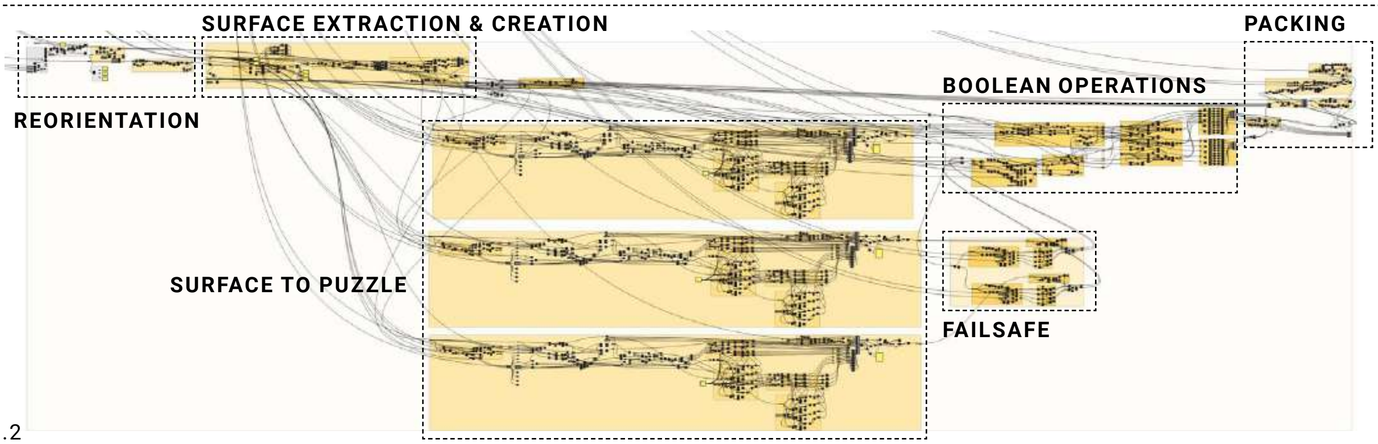
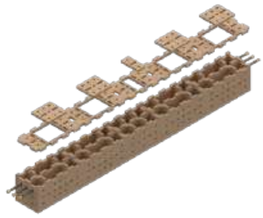


FIG 03.2

FABRICATION & CONSTRUCTIBILITY.

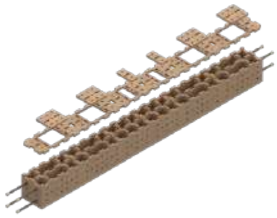
STRUCTURAL FLOOR JOINERY



COLUMN JOINERY

STAIRCASE JOINERY

COLUMN-BEAM-FLOOR CORNER JOINERY

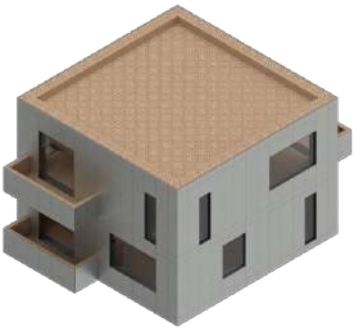


STRUCTURAL BEAM JOINERY

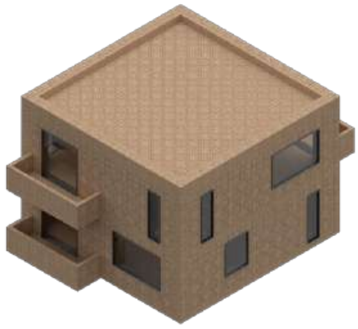
PARTITION WALL JOINERY

FIG 03.3

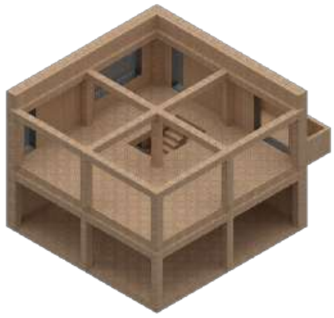
This joinery method allows for easy demountability and potential reusablity of building blocks. It is a dry method that does not requite any adhesives. The largest piece of the box is always divided into an inner an outer segments, in order to provide the possibility of accessing the connecting rods after first mounting is complete. Such solution facilitates the possibility of self adaptation of the proposed flat designs by the future inhabitants as all the partition walls and other non-structural elements are easily repositioned if needed. Each element has the same base grid of connection points, which ensures compatibility when replacing or repositioning parts of the building. The fact that after assembly the boxes are hollow, except for structural support elements, provides a possibility of infilling them with various types of either acoustic or thermal insulation solutions. These would require a close collaboration with manufacturers as the systems would have to be unitized to match the dimensions of the system.



TEST HOUSE - FINISH



TEST HOUSE - RAW STATE



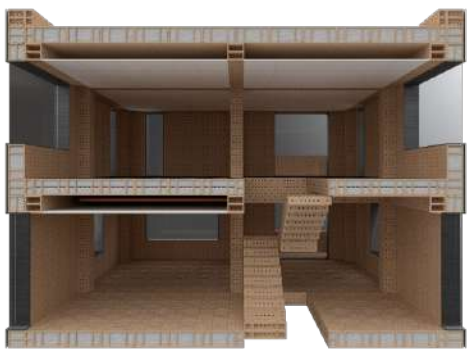
TEST HOUSE - STRUCTURE/INTERIOR

FIG 03.4

To prove the constructibility of the system and its potential for integration with other building systems, the developed elements, their construction technique and detailing have been tested against a mock-up house unit. It is a two floor, 8 cell unit of approximately 150 m2 area. The Fig 03.4 shows how the house could be structurally sound, fitted with window and balcony frames, and finished with and external cladding. Initial solutions of integration of the system with other building elements such as facade finish, window elements, ceiling finish, and building services have been proposed. [Fig 03.5]

This is a preliminary trial and the details have not yet been considered in-depth, however the system exhibits an interesting potential for easy integration with other unitized solutions and interior finish elements that could be temporarily fixed to the structure, which at this stage have remained unexplored.

SECTION 01 - SERVICES INTEGRATION



SECTION 02 - VERTICAL CIRCULATION

FIG 03.5

04 : FURTHER STEPS.

The final method has been proved to work on a variety of input building volumes and tested against special case scenarios. The results have also been used in a case study house to show the potential of multi-system integration. The future use of the scrip however is planed to be expanded.

The targeted use of the developed method is planned to work in conjunction with spatial and environmental analysis scripts. Those will enable a more informed formulation of a starting voxelized geometry and the division of cells into specific program types. Hence, requiring more conditions, such as addition of partitions between different program cells, to be added to the system in order to facilitate a full automation.

Step 2 of the process described in point 2 of the article can be significantly improved using the environmental analysis input. At this stage the massing is developed by using an attractor method to remove some arbitrarily selected voxels in order to check if the developed script can deal with geometric complexity, however the planned method will create the input voxelized geometry based on a list of pre-selected factors. (Please also refer to appendix C for mode in-depth diagrams) These factors to include have been prepared in diagrammatic terms and will be implemented in the workflow on the further stages of the development. [Fig 04.1].

In the current version of the script the cells are divided into 4 distinct types based on the amount of face-sharing neighbors in the horizontal plane: 1- lonely, 2 - corner, 3 - facade, 4 - inner. This information can be enriched by an introduction of programmatic division - attribution of additional numerical value to the cells based on the preferred location of each program type; this will be developed based on the bubble diagrams, spatial relationship matrix, and environmental factors [Fig 04.1], which will inform the Cellular Agent Based Model that will be capable of generative program allocation.

Step 10 can also benefit form an extra layer of information being added to each cell, as having an understanding of a program type of a cell would facilitate a creation of conditional logic for the selection of facade type that is to be applied to cells external faces.

The construction detailing and system integration presented in point 3 will be further explored and improved based on consultation with industry specialists, a series of exemplary integration details and diagrams will be produces. An extended catalogue of unitized flats and standard spaces will be proposed and added to the script to improve the potential of automatic generation of design options that are attuned to the needs of the potential inhabitants. This catalogue could be integrated with BIM software to allow for a drag-and-drop participatory design.

The final results of the projects and an entire development process will be posted on-line on the play-well.io website.

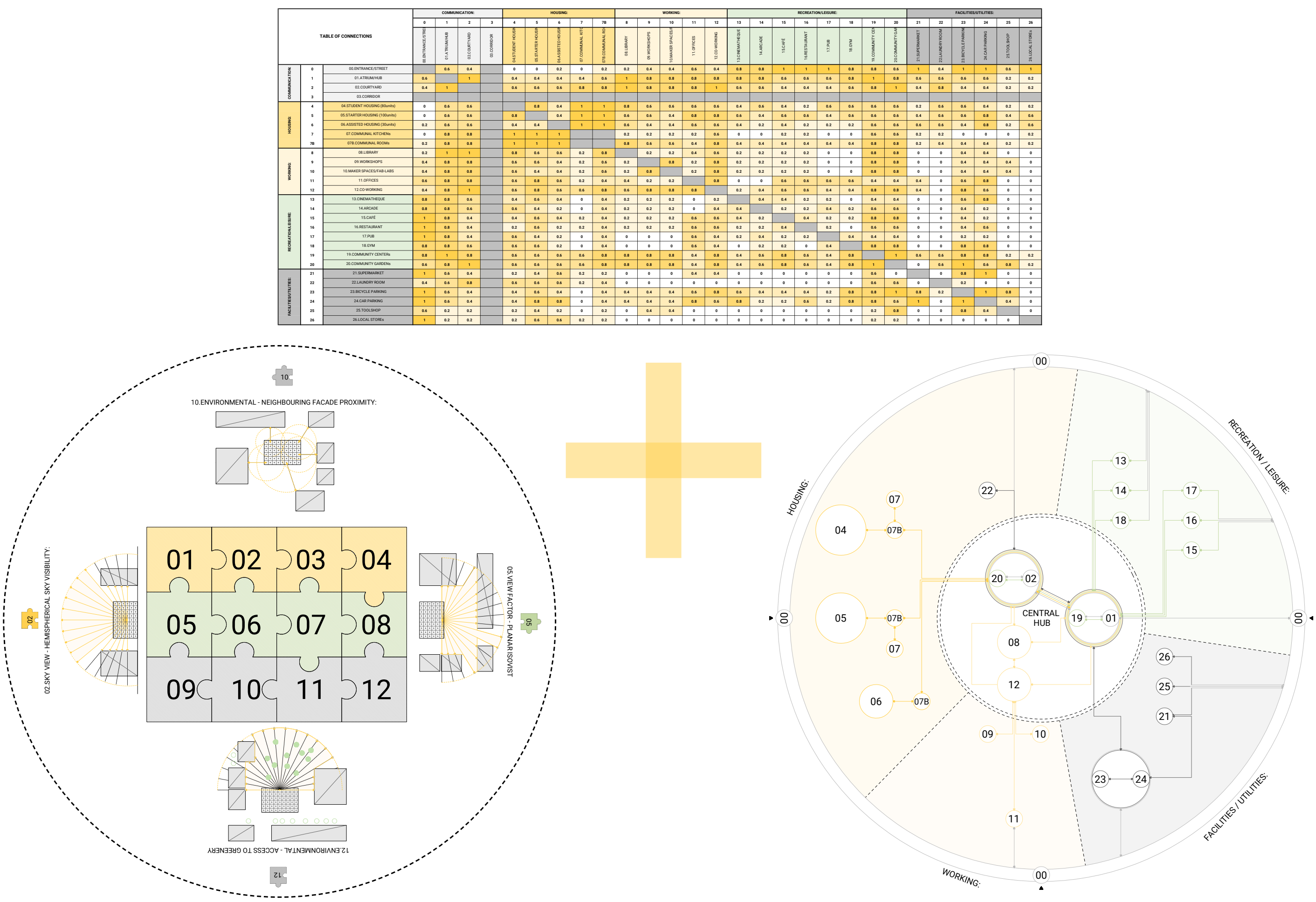
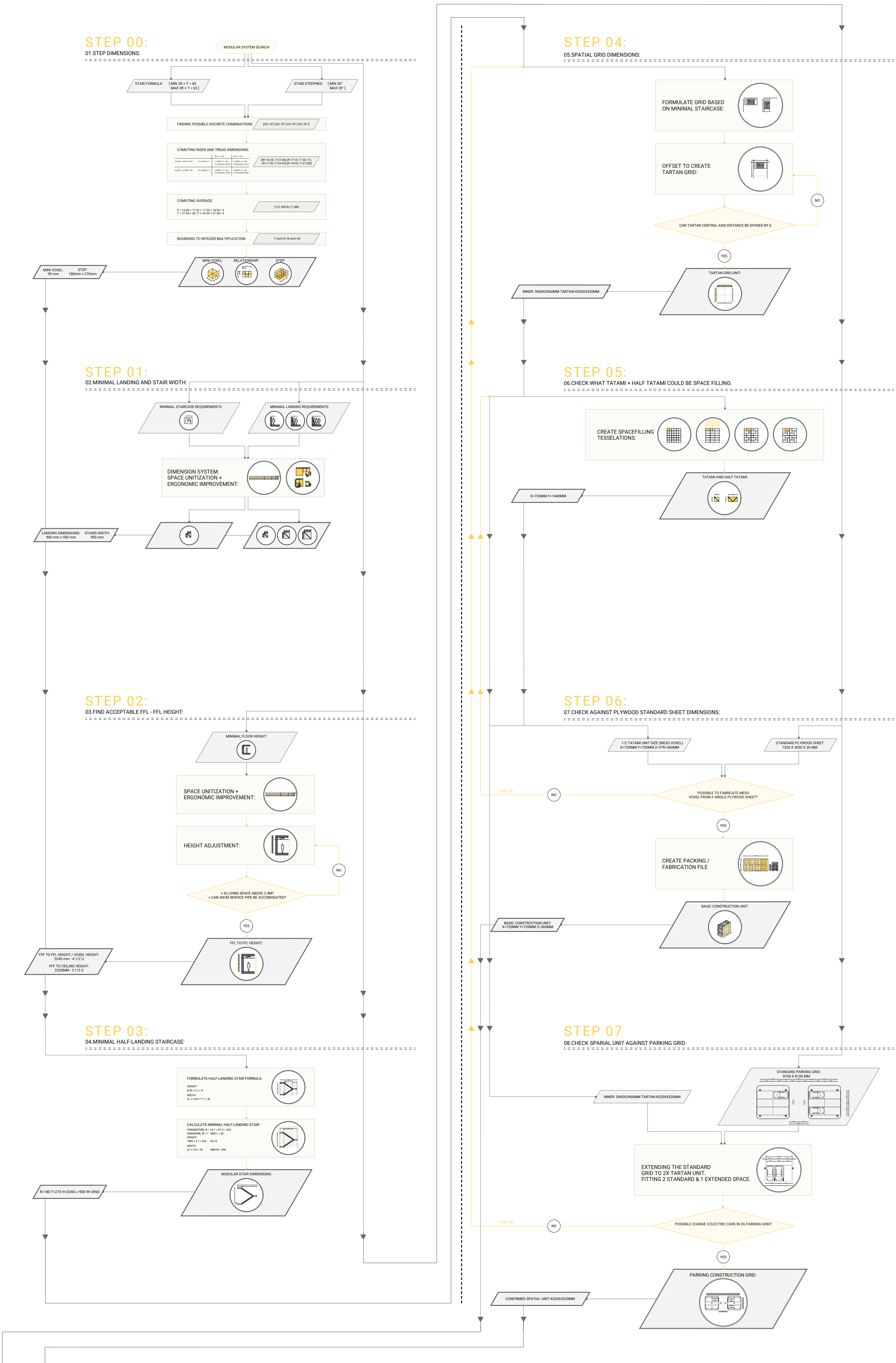
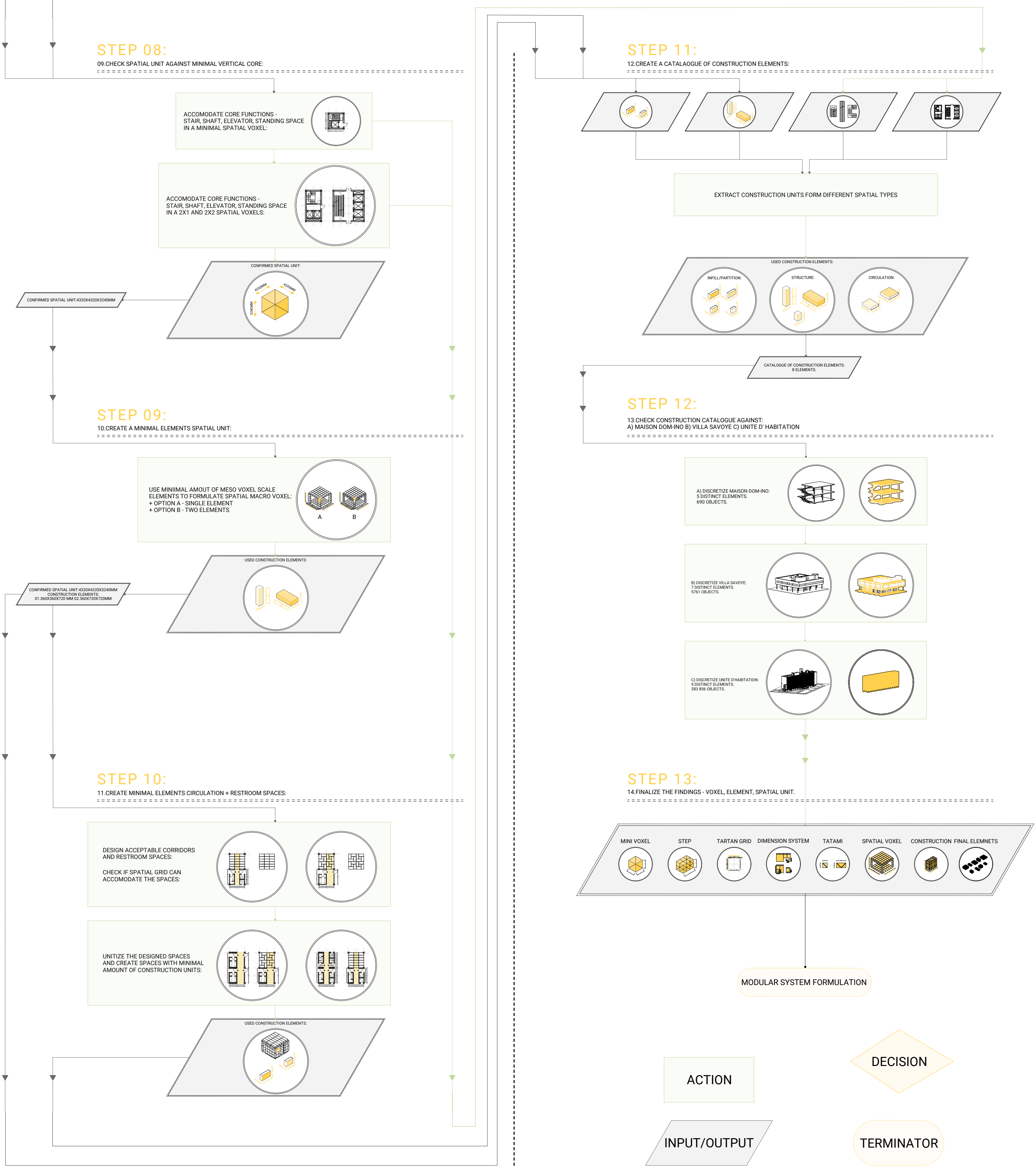


FIG 04.1

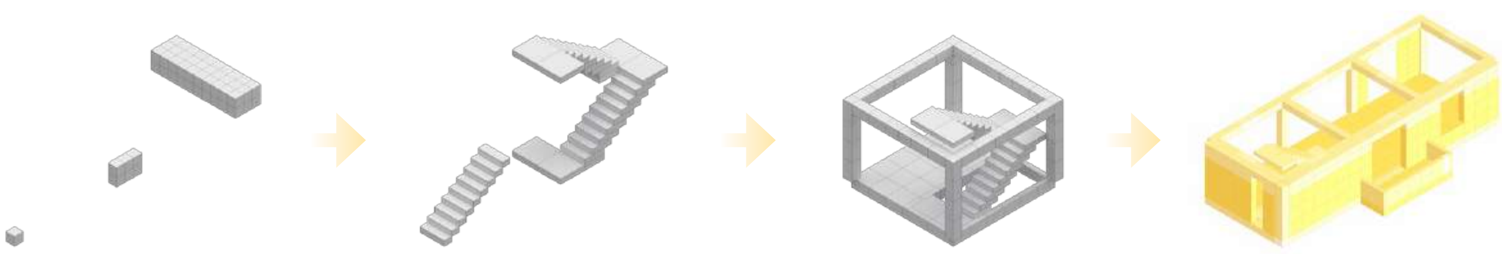
APPENDIX A - SYSTEM CREATION STEPS:



APPENDIX A - SYSTEM CREATION STEPS:



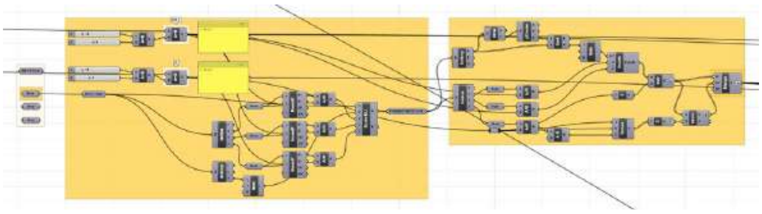
RELATIONSHIPS:



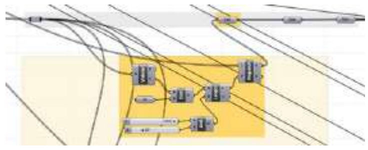
MINI VOXEL - STEP   STEP - LANDING - STAIRCASE   STAIRCASE - SPATIAL UNIT   ALL-SYSTEMS

APPENDIX B - SYSTEM AUTOMATION STEPS:

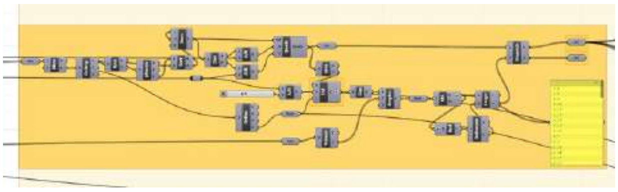
STEP 01 - VOXELIZATION:



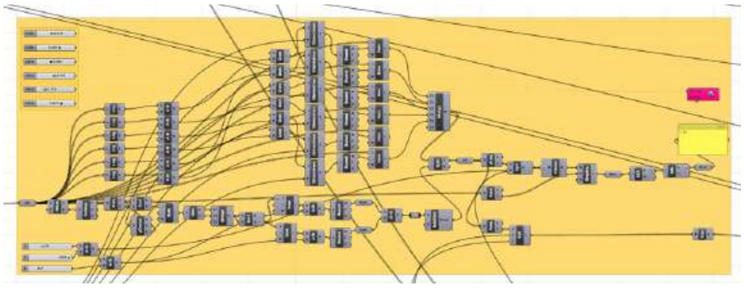
STEP 02 - MASSING:



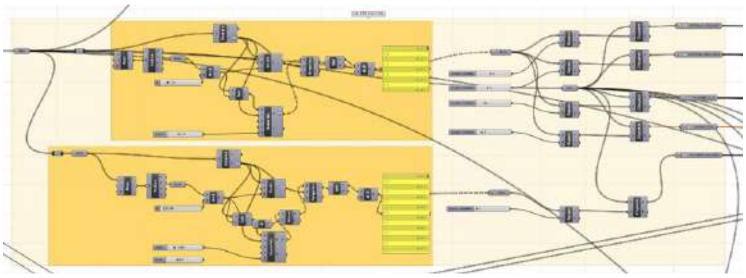
STEP 03 - FULL HEIGHT STACKS:



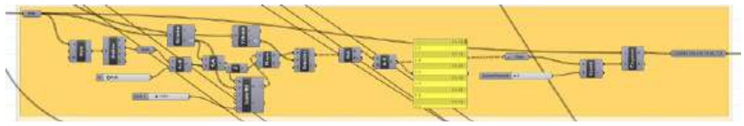
STEP 04 - CORE CELLS - OPTIMIZED POSITION:



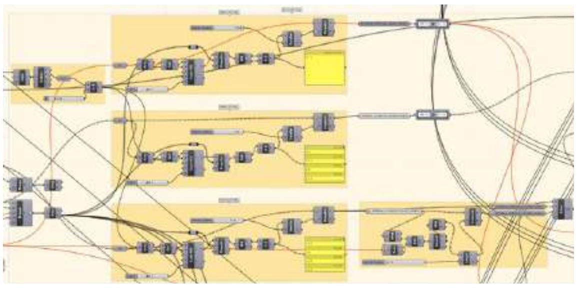
STEP 06 - INNER, SKIN & CORNER CELLS:



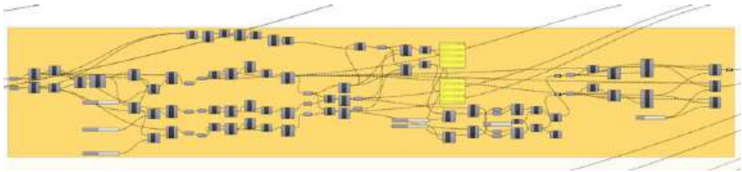
STEP 07 - CEILING CELLS SELECTION:



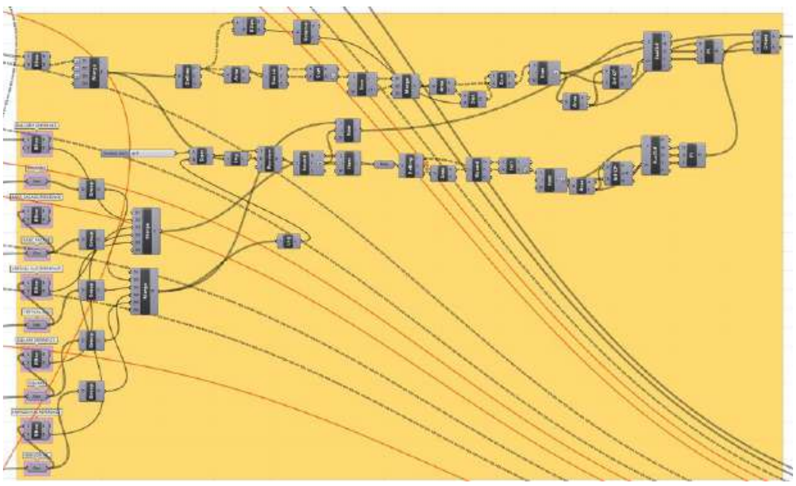
STEP 08 - EXTERNAL SURFACES:



STEP 09 - CORNER IDENRIFICATION:



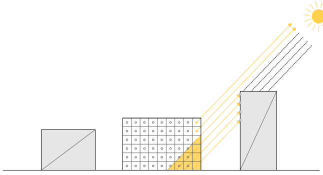
STEP 10 - FACADE RANDOM ASSIGNMENT AND ORIENTATION:



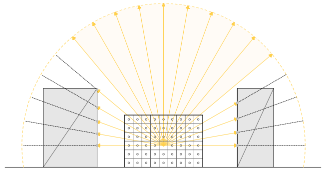
APPENDIX C - ENVIRONMENTAL & SPATIAL EVALUATION:

ENVIRONMENTAL FACTORS:

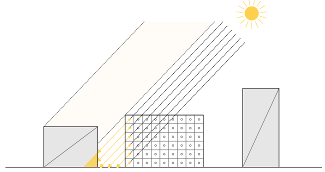
01.DIRECT SUNLIGHT - SOLAR VISIBILITY:



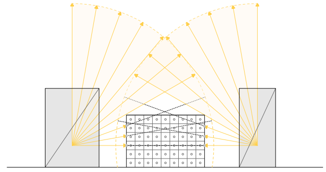
02.SKY VIEW - HEMISPHERICAL SKY VISIBILITY:



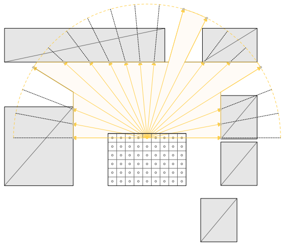
03.DIRECT SUNLIGHT - SOLAR OBSCURITY:



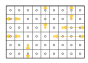
04.SKY VIEW - HEMISPHERICAL SKY OBSCURITY



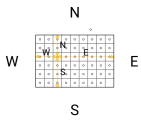
05.VIEW FACTOR - PLANAR ISOVIST



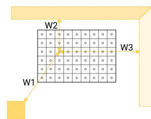
06.VIEW FACTOR/DAYLIGHT - FACADE PROXIMITY



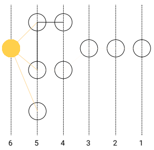
07.DAYLIGHT/ENVIRONMENTAL - N-E-S-W PROXIMITY:



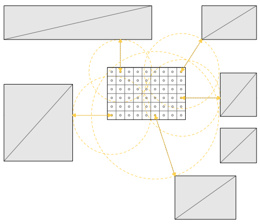
08.COMFORT - NOISE PROXIMITY:



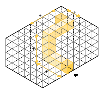
09.ENVIRONMENTAL - PRIVACY:



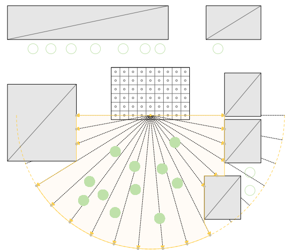
10.ENVIRONMENTAL - NEIGHBOURING FACADE PROXIMITY:



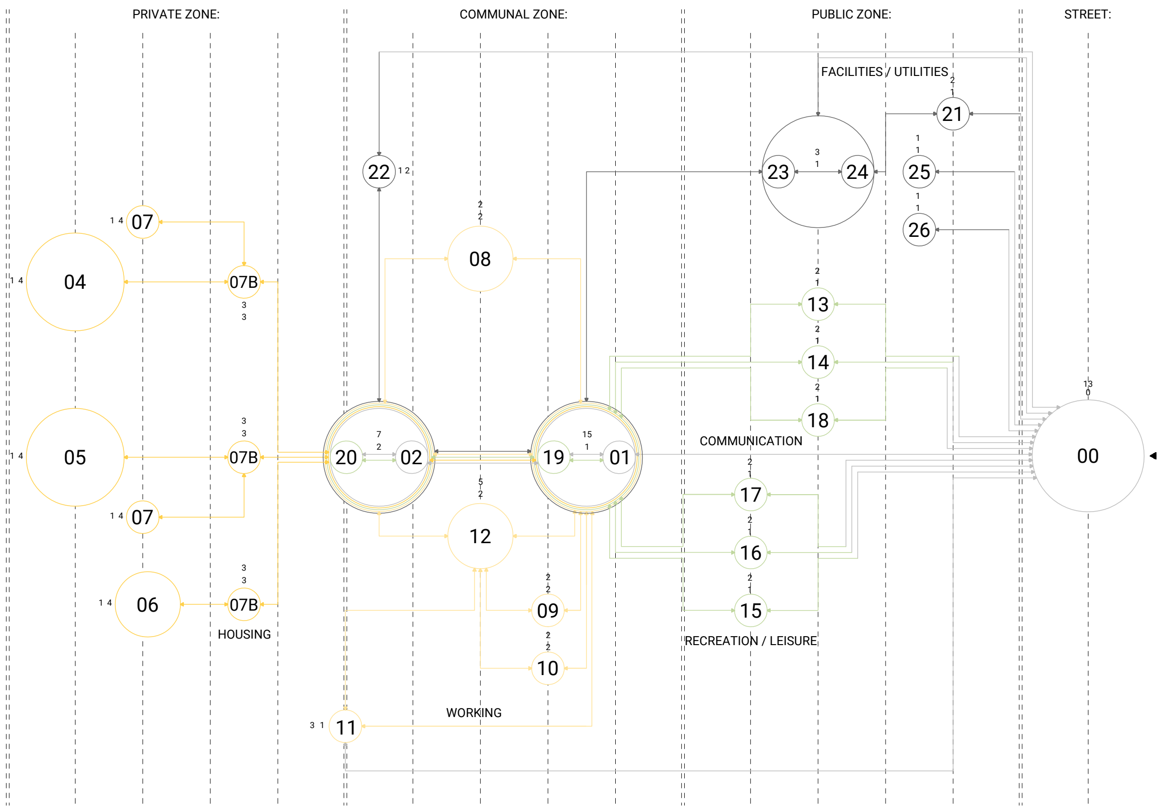
11.ENVIRONMENTAL - ACCESS TO ENTRANCE/STREET:



12.ENVIRONMENTAL - ACCESS TO GREENERY



SPATIAL FACTORS:



COMMUNICATION:	HOUSING:	WORKING:	RECREATION / LEISURE:	FACILITIES / UTILITIES:
00.ENTRANCE 01.ATRIUM/HUB 02.COURTYARD 03.CORRIDOR	04.STUDENT HOUSING (80units) 05.STARTER HOUSING (100units) 06.ASSISTED HOUSING (30units) 07.COMMUNAL KITCHENs 07B.COMMUNAL ROOMs	08.LIBRARY 09.WORKSHOPS 10.MAKER SPACES/FAB-LABS 11.OFFICES 12.CO-WORKING	13.CINEMATHEQUE 14.ARCADE 15.CAFÉ 16.RESTAURANT 17.PUB 18.GYM 19.COMMUNITY CENTERs 20.COMMUNITY GARDENs	21.SUPERMARKET 22.LAUNDRY ROOM/TRASH 23.BICYCLE PARKING 24.CAR PARKING 25.TOOLSHOP 26.LOCAL STOREs

BIBLIOGRAPHY / REFERENCES:

01.Avi Friedman, A. S., Basem Eid Mohamed. (2013). *A Computer-Based System For Mass Customization Of Prefabricated Housing.* Open House International.

02.Chiappone-Piriou, E. (2019). Et Alia: A Projective History of the Architectural Discrete. *Architectural Design*.

03. Claypool, M. (2019). Our Automated Future: A Discrete Framework for Production of Housing. *Architectural Design,* 89.

04.Claypool, M. (2019). Discrete Automation. *eFlux*.

05.Claypool, M. (2020). Architecture Goes Digital: The Discrete. In *The Architecture Machine.* Birkhauser.

06.Claypool, M. (2020). Towards Discrete Automation. In *Fabricate 2020: Making Resilient Architecture.* UCLPress.

07. Friedman, Y. (1971). *Toward a Scientific Architecture.* MIT Press.

08. Gershenfeld, N. (2015). Macrofabrication with Digital Materials: Robotic Assembly.
Architectural Design, 85.

09.Habraken, J. (1999). *Supports: An Alternative to Mass Housing* (2nd ed.). Urban International Press.

10.Hertzberger, H. (2016). *Architecture and Structuralism: The Ordering of Space.* Nai010 publishers.

11.Koehler, D. (2019). Mereological Thinking: Figuring Realities within Urban Form. *Architectural Design,* 89.

12.Koh, I. (2019). Discrete Sampling: There Is No Object Nor Field ... Just Statistical Digital Patterns. *Architectural Design,* 89.

13.Meuser, P. (2020). *Prefabricated Housing, Construction and Design Manual* (2nd ed.). Dom Publishers.

14. Morel, P. (2019). The Origins of Discretism, Thinking Unthinkable Architecture. *Architectural Design,* 89.

15.Morel, P. (2009). Universal House. *EZCT Architecture & Design.*

16.Neufert, E. (2018). *Architects' Data* (4th ed.). John Wiley and Sons Ltd.

17.Parvin, A. (2019). WikiHouse Manufacturing Guide. In: Open Systems Lab.

18.Parvin, A. (2019). The DfMA Housing Manual. In: Open Systems Lab.

19.Ratti, C. (2015). *Open Source Architecture.* Thames & Hudson Ltd.

20.Retsin, G. (2019). *Discrete: Reappraising the Digital in Architecture*. Wiley.

21.Retsin, G. (2019). Discrete Architecture in the Age of Automation. *Architectural Design,* 89.

22.Retsin, G. (2019). Bits and Pieces: Digital Assemblies, From Craft to Automation.
Architectural Design, 89.

23.Sanchez, J. (2020). *Architecture for the Commons: Participatory Systems in the Age of Platforms.* Routledge.

24.Shervin Azadi, P. N. (2020). Collective Intelligence in Generative Design: A Human-Centric Approach Towards Scientific Design. *BouT Rumoer,* 76.

25.Shervin Azadi, P. N. (2020). *GoDesign: A modular generative design framework for mass-customization and optimization in architectural design.* eCAADe 39.

26.Simon, H. (1996). *The Sciences of the Artificial.* MIT Press.

27. Tian Tian Lo, M. A. S. (2015). *ModRule: A User-Centric Mass Housing Design Platform.* CAADRIA.

28. Tian Tian Lo, M. A. S. (2018). Redefining Supports: Extending Mass Customization with Digital Tool to Push the Limit of Collaborative Residential Design Process In *Design Computing and Cognition.* Springer.

29. Twardoch, A. (2019). *System for Living. Perspectives of developments in affordable housing.* Fundacja Nowej Kultury Bec Zmiana.

30. Twardoch, A. (2014). Social and cooperative housing as the future of affordable housing in the context of coherent city development.