Innovative Mid-rise Timber
Timber Tectonics Meets Spatial Force Flow

Spring 2021
ARCH 705-001
(Mondays), Wednesdays, and Fridays 8:00 am – 12:00 pm

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cross-laminated timber Pavilion
Image courtesy kawasum kobayashi kenji photograph office

1 Brief

For thousands of years, wood has been an important building material for its abundance, strength, and sustainable nature (Ahmed and Arocho, 2020). Engineered mass timber such as glue-laminated, cross-laminated timber, I-Joist, etc., include a range of products manufactured by binding or fixing the strands, fibers, veneers, or boards of wood by applying adhesives to form composite materials. These products were developed to utilize material more efficiently with respect to the inherent variability (anisotropic properties) of wood systems (Mallo and Espinoza, 2014). The main objective of these engineered products was to maximize durability, strength, and a high level of consistency in the material properties (Council, 2010).

Problem Statement and Objectives

In Europe, Australia, and Canada, timber products have been used in various building types, including residential, commercial, educational, and industrial, but in the US, such applications have remained quite limited. The main objective of this studio is to investigate the potential of using mass timber in the construction of mid-rise buildings through developing novel structural and architectural concepts. The outcome of the studio is aimed to increase the perception, motivation, and awareness among the industry practitioners to adopt engineered timber as an important material in the US construction sector as suggested by Mallo and Espinoza (2015).

Designing mid-rise, mass-timber buildings requires utilizing specific structures. In fact, the studio will concentrate on the development of non-conventional architectural structures that can respond to the needs of such buildings and programs more succinct than the conventional solutions (See the following additional readings by Jeska and Pascha (2014); Lennartz and Jacob-Freitag (2015); Weinand (2016)). Therefore, the main research objectives of the studio can be summarized as follows:

- formal explorations of efficient structural typologies suitable for mid-rise buildings;
- material computing research including tectonic studies on the design of structural forms using various construction detailing and prefabrication techniques;
- programmatic studies of the buildings and realizing the relationships among program, materials, detailing and structure; and,
- and finally the architectural design of the building to manifest the research.

2 Design Research Approach

The studio will be divided into multiple modules to design a mid-rise building as a technology hub and incubator space for startups and their laboratories.

Workshop On Parametric 3D Graphic statics The studio will include an intense 3D graphic statics workshop introducing constrained 2D graphic statics to lay the foundation for describing geometrically constrained structural forms and their force diagrams in 3D. The workshop will present the equivalent methods in 3D and students will develop constrained spatial structures with compression and tension combined systems. Relevant readings will be suggested from Akbarzadeh et al. (2014, 2015a,b); Akbarzadeh (2016); Schumacher (2016); Harris and Li (2012).

Structural Module Development The students will develop parametric structural modules as building components and explore variety of equilibrium states by manipulating the force diagram. The parametric studies will be translated into physical scale models to test the space-making potential of the studies. Relevant readings will be suggested from Engel and Rapson (2007); da Sousa Cruz (2016); Moussavi (2018).

Material Computation The structural forms developed in the previous step will be translated into construction materials. Algorithms will be developed to populate the structural forms with discrete/continuous elements. Innovative construction systems such as prefabrication and smart assembly of the parts will be developed and tested in smaller scales to manifest the research. Following references will be introduced to students including Block et al. (2017); Gramazio et al. (2014); da Sousa Cruz (2016); Meijs and Knaack (2009); Hauschild and Karzel (2011); Tichelmann and Pfau (2008).

Structurally-Informed Massing Strategies The programmatic studies from previous exercise will be used to develop a massing strategy for the terminal incorporating the programmatic studies. This massing strategy will also follow the geometry of the structural modules that were developed earlier The relevant readings will be introduced including (Kerez et al., 2009; Morgan and Sobek, 2004; Conzett and Mostafavi, 2006).

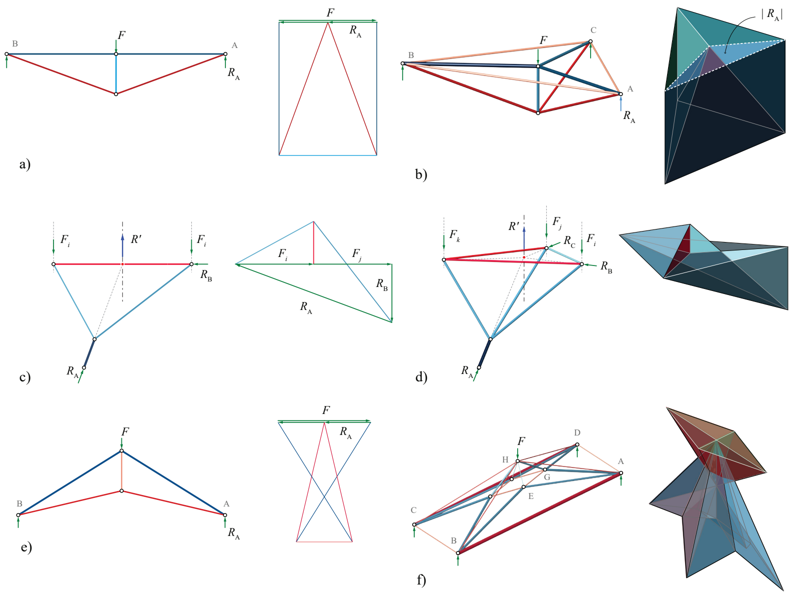

Figure 1: a) 2D form and force diagram generated using 2DGS; b) similar structural system and its polyhedral force diagram in 3D; c) 2D branching system and its force equilibrium; d) similar branching system in 3D and its force equilibrium; e) a 2D truss system and its force diagram; and f) a similar 3D truss and its polyhedral force diagram.

3 A Short Introduction to *LaTex*

LaTeX is a typesetting system designed for the production of technical and scientific documentation. LaTeX is available as free software and provides standard features necessary for the communication of scientific documents. In this concise tutorial, you will be introduced to some of the basic commands in the LaTeX environment, which allows you to document your work and the explanation around it quite rigorously. The following sections will introduce you to the sections and subsections in a document, the inclusion of Figures in the text, and referencing the figures, bibliography, and reference management in the text.

3.1 Writing in LaTex

Often you can copy and paste your text from any text editor into the LeTex environment. To emphasize a word or sentence in the text, you can use the `\textit{}` command and put your words in between the curly brackets. For instance, the edges of the form diagrams should be *perpendicular* to the faces of the force diagram. In this example, the word 'perpendicular' has been written as
`\textit{perpendicular}` in the text. To write a text in its bold format, use `\textbt{}` for the word. For example, **word** has been written as
`\textbt{word}` in this text. You should note that any number or math symbol in the text should be started and ended by `$` sign. For instance, the term e_i in the text should be written as `$e_i$` in the text.

3.2 Including Sections and Subsections

Often in a text, we may need to organize the information into sections and subsections to facilitate the flow of the text. Use the `\section{}` command to divide your text into modules. Once the `\section{}` command is used, you can divide the section into *subsections* and *subsubsections* and *paragraphs* by using the `\subsection{}`, `\subsubsection{}`, and `\paragraph{}`. Note that
the `\subsection{}` and `\subsubsection{}` commands may not be used without having a section, but the `\paragraph{}` command can be used with no prior division.

3.3 Including Figures in the text

The inclusion of Figures in the text is quite simple and is achieved by using the `\begin{figure}` and `\end{figure}` command. For instance, Figure 2 is included in the text using the following command lines:

```
\begin{figure}
```

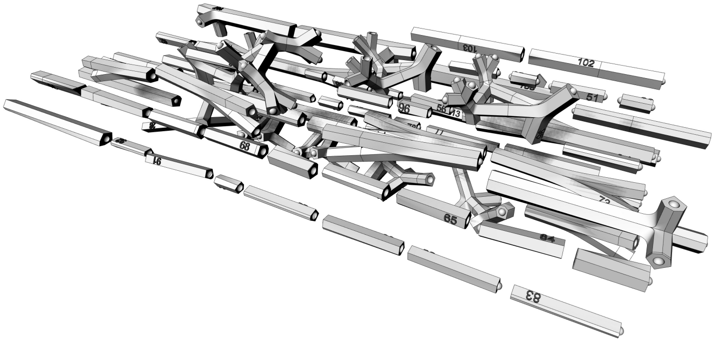

Figure 2: This is the stack of the parts for the assembly of your structure

```
    \centering
    \includegraphics[width = \textwidth]{figs/stack.jpg}
    \caption{This is the caption text.}
    \label{fig:stack}
\end{figure}
```

There are multiple items in this command to which you need to pay attention. Always the command starts with `\begin{figure}` and ends with `\end{figure}`. The `\includegraphics[]{}` is used to specify the size of your figure and the location of the file, which will be used for this figure. The size of the figure can be specified in the `[]`. You may always use the size of your text for your figures; for instance, `[width = \textwidth]` forces the figures to be fit within the boundaries of your text. For more options on the size of the figures, you can always search online. Once you specified the figure's size, you can put the address of the figure in the `{}` and compile your document.

The second most crucial element in the Figures is the `\label{}` of your figure. This is quite important since it allows us to call the figure from any point in the text by simply referring to its label. This obviates the need to constantly change the numbering of the figures in static typesetting environments such as Microsoft Word and prevent mistakes in enumerating the figures that often happen in documentations. To call a figure in the text, you can use `\ref{}` command and put the label of the figure in the `{}`, for instance, Figure 2 has been written as `\ref{fig:stack}` in the text.

Note that you should not include any empty *spacebar* in the name of your figures. Otherwise, you won't be able to load your figures in the document. For instance, the name `my fig.jpg` is not allowed since there is an empty space in the name. You may use $underscore$ to separate words in the name of your figures, e,g, the example can be fixed by renaming the figure to `my_fig.jpg`. Also, put your figures **always** inside the folder under your name in the document and keep the naming and the entire space tidy.

4 Assignment 1

The first assignment is designed to help you develop a better understanding of the relationship between form and the force diagrams in three dimensions. It will emphasize the geometric articulation of the structural configurations by designing their topological force diagram. This research should result in a variety of different spatial structural forms that can be used as the basis for architectural spaces of your building.

The first assignment is to find spatial funicular structural modules using subdivision/aggregation of polyhedral cells. For this exercise, each person is responsible for generating ten (10) various compression-only spatial structural forms from the following categories:

- compression-only shells (with synclastic curvature);
- folded plate systems with creases (origami patterns);
- anticlastic shells;
- branching systems;
- funnel-shape geometries;

Develop a step by step exploration by designing the geometry of the force diagram to produce the intended structural geometry and show how you can create various features on the initial configuration including:

- opening features in plan;
- the formation of creases; and
- curved creases and force flow in plan and elevation;

Deliverable

The following items are due Fri January 22nd at 8:00 am (EDT).

Precedent studies You may start your work by going trough various precedent buildings and designs to choose your structural system. Choose a structural geometry from the above categories and try to model that using the form and force diagrams of 3D graphic statics. Please see Engel and Rapson (2007),

Drawings The form and force diagrams and their clear drawings should be presented on letter-sized papers in a format of a pamphlet in each session.

The format of the drawing should be exactly as same as the Figures 3 and 4. Later, you will be invited to contribute to a document in an online platform. Each individual will be responsible for his/her chapter of the document. The format of the drawings, line weights, naming and coloring convention for the form and the force diagrams should follow the provided example.

On the left column, the 2D version of the form and force is provided as an exercise to move to the 3D example. Please note that this example only includes a compression-only shell. You may choose another structural typology. Please visit the Studio Book 2018 and Studio Book 2019 to get some inspiration of the structural typologies you may choose or explore.

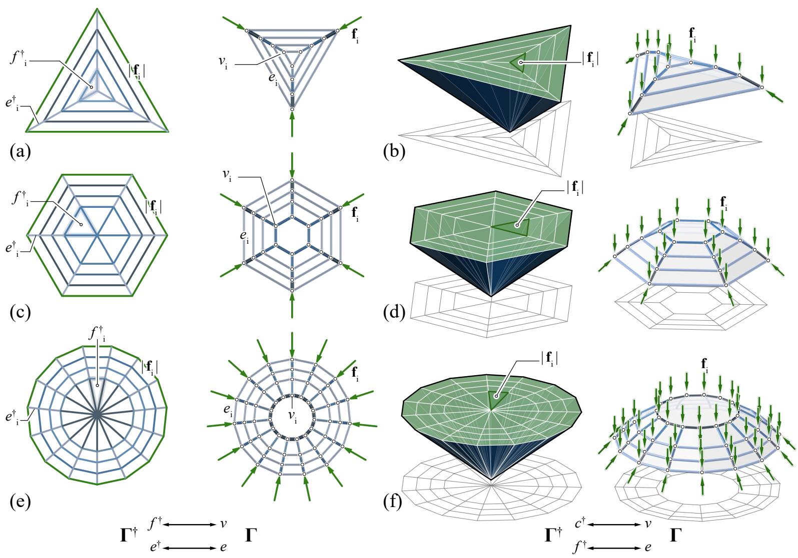

Figure 3: (a), (c), (e) Subdividing the global force polygon with convex faces corresponds to a compression/tension-only networks in 2D; (b), (d), (f) extruding the 2D networks to a point results in 3D force diagrams reciprocal to compression-only polyhedral shells.

3D model The 3D model of both form and force should be included in the related folder and submitted accordingly.

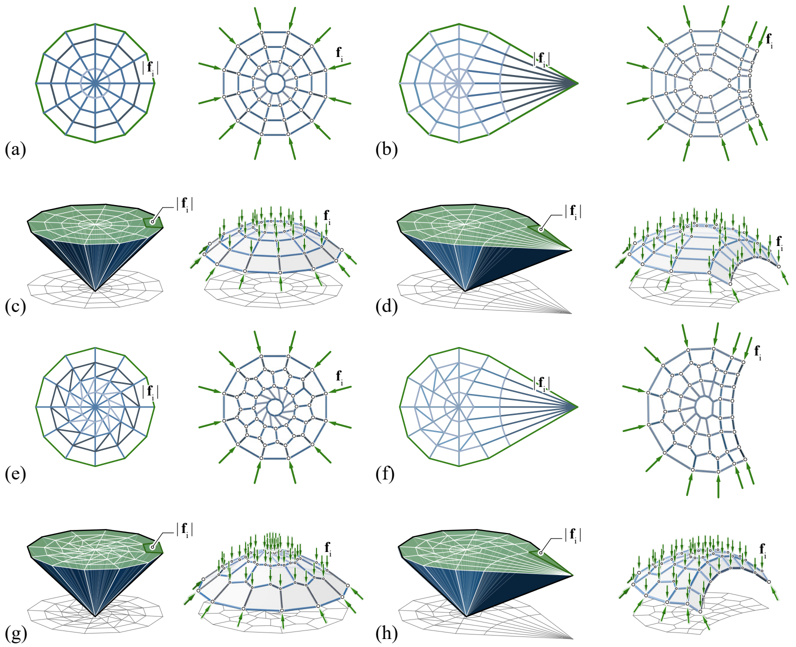

Figure 4: (a), (c), (e), (f): A subdivided global force polygon and its reciprocal compression-only form with an opening on the side; (b), (d), (g), (h) the 3D equivalent of the same network extruded to a point below the network and their reciprocal forms with openings on the side.

5 Assignment 2

This exercise intends to develop systems that can serve as wall/column ceiling and floor. It is essential to create a system representing the flow of force from a horizontal surface to a vertical element and back to a horizontal surface for architectural design purposes. Describe your investigation by highlighting such qualities in the geometry.

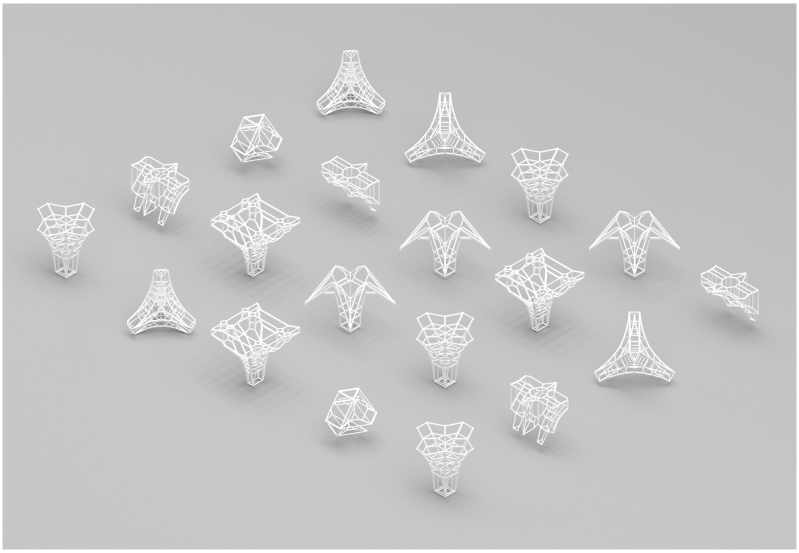

Figure 5: A sample matrix showing various elements placed on a horizontal plane.

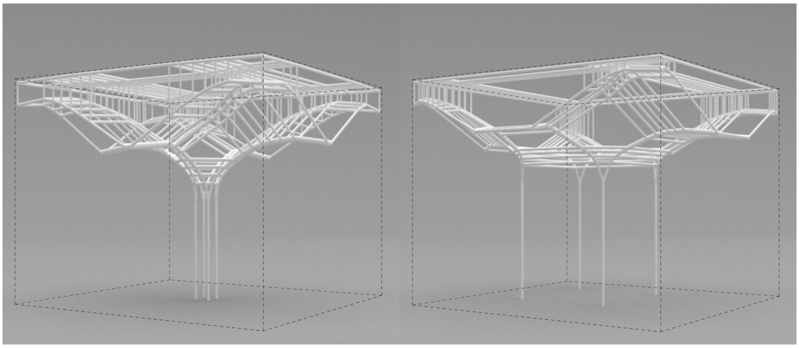

Figure 6: A sample example of a single funicular with various geometric degrees of freedom.

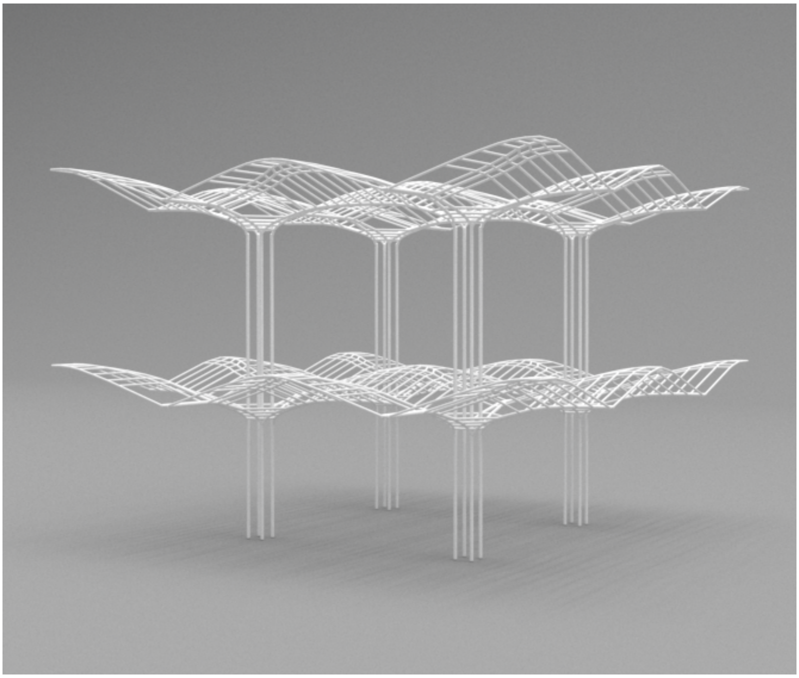

Figure 7: A sample example of a two-floor system.

deliverable

The following items are due on Wednesday, Jan 27th EDT:

- present your studies in a matrix of various geometries and their relationship, showing the development process rendered in the given format with the same light settings and background (See Figure 5).
- The investigation of a single structural module and its various geometric degrees of freedom should be rendered in the scene and format shared with you (See Figure 6).
- use the geometric degrees of freedom to highlight various design features in your module, including openings in the plan as well as elevation;
- show the module's spatial design quality by aggregating them to create a two-floor system similar to the example shared with you (See Figure 7). Note that your system might have a completely different vertical element and may not consists of columns to support the floor structure.

6 Assignment 3

This assignment aims to continue the research in structural morphology and investigate its use in developing a versatile architectural space. We will also start to gain more knowledge related to timber construction by reviewing the existing literature.

Deliverable

The following materials are due on **Wednesday, Feb. 3rd.**

The structural module study Each group should present their developments on the spatial funicular geometry by presenting ten different investigations on the structural geometry and ten aggregated modules in the form of multi-level units rendered in the same setting as exercise 2. The form and force geometry related to the presented modules should be submitted in a $.3dm$ file format together with the rendering images.

Learning about Wood Construction The next session will read the book *"Timber Construction Manual"* by Herzog et al. (2012) in the studio. Each group should prepare a presentation and describe the book's content for the rest of the studio. In this regard, we will divide the book into multiple segments divided among the studio teams.

Deliverable

Each team should prepare a PowerPoint presentation on the assigned content from the book and submit it before the class. Besides, both members of the team should present the content to the studio in a 15-minute presentation.

- group 1: page 8-36
- group 2: page 38-46
- group 3: page 47-68
- group 4: page 68-75
- group 5: page 76-105
- group 6: page 105-139

7 Assignment 4

This exercise aims to materialize the structural forms developed using the principle of the equilibrium of polyhedral frames. Each team should take their relevant polyhedral frame and show multiple materialization strategies to contain the structural system's thrust lines. The materialization should be based on an existing timber construction strategy or an advanced

Deliverable

The following items are due Monday, Feb. 22nd:

- Present an updated matrix of the structural module showing the changes and subdivision in each step, transforming the primitive system into a high-resolution geometry.
- Each group should choose a part of an aggregated configuration and use four different timber construction strategies to materialize your developed polyhedral geometry.
- Assign wood material to the geometry and render all configurations with the same angle and the same bounding box. Explain the advantages and disadvantages of each system concerning the architectural use of space.
- With your materialization strategy, show how your proposed system can work as a beam and column to transfer the forces to the ground. Use precedents from the Timber Manual Construction Book to support your ideas.

8 Assignment 5

The following items are due on Monday March 1st:

- material computation on a chosen structural module (each individual should present 4 different studies);
- 1:25 scale of the section model of your building including:
  1. material computation;
  2. the structure and its vertical and horizontal elements as the architecture;
  3. the connection to the circulation;
  4. mechanical equipment;
  5. connection to the facade;
- an elevation rendering of your structure;
- a sectional drawing of your system sc:1/25.
- side renderings of your section geometry.

The following items are due on Monday, March 1st: material computation on a chosen structural module (each individual should present 4 different studies); 1:25 scale of the section model of your building including: material computation, the footprint should be bounded to 50x50 cm there is no limitation on the height of system; the structure and its vertical and horizontal elements as the architecture; the connection to the circulation; mechanical equipment; connection to the facade; an elevation rendering of your structure; Side renderings of your section geometry. include all modules and matrices of modules you have explored since the beginning of the semester on the Miro board.

9 Assignment 5 (mid Review)

The mid-review will be held on Friday, March 5th 8:00-11:00am. Each group will have 15 minutes for a presentation, followed by 15 minutes of discussion with the reviewers. Prior to the review, we will have a rehearsal session on Wednesday, March 3rd , and all the materials should be ready by then. For the digital presentations, each group should have:

- 15-minute PowerPoint slides; and
- 2 panels on Miro (Please see the Miro Board for more details.)

The contents of the presentations should cover all but not limited to the following items:

1. Matrix drawing/rendering of various structural modules. The research and development process should be clearly illustrated from this matrix.
2. Drawings/renderings of the aggregations of the structural modules. For each of the aggregation studies, each group should have a perspective drawing, a side drawing, a plan drawing, and an axon drawing that with one module highlighted (Please see template).
3. Materialization strategies. Present the related precedents and show the techniques of materialization/fabrication in addressing the needs of a structure with vertical and horizontal elements.
4. Take a chunk of the aggregation and show different strategies for materialization. For each of the strategy, the tectonics, geometrical parameters, and assembly logic should be clearly demonstrated. Change the parameters and show different alternatives for each strategy. Each group may have one or more strategies.
5. For your materialization strategies, show how the loads are transferred from top to the ground. For example, you may distinguish the tensile elements from the compressive elements in your system. Alternatively, you may use Fusion 360 and do a simple Finite Element Analysis to show how the structure performs under the design load.
6. Sectional model. Each group should take a bounding box (12.5m × 12.5m × 12.5m) and build a sectional model with 3-4 floors using their modules, aggregation strategies, and materialization strategies. The sectional model should include the elevation, and it show also show how your structural system can accommodate programs of different scales. A physical model is not required since most students don't have access to the digital fabrication facilities, but instead, each group should have nice renderings of the model with an adequate level of

details. The model will be rendered at 1:25 scale (50cm × 50cm × 50cm) with line-overlay. Please see the templates for more details.

7. site specifications:
   (a) the foot print/figure ground of the building cannot exceed 1200 sqm.
   (b) the total size of the project is 12,000 square meters.
   (c) the building is aimed for a tech center for research and development and should include the following programs: office space 60 percent including working area, presentation and meeting rooms, 20 percent circulation, cafe, auditorium, gym, self-service/restaurant, classrooms, enclosed office spaces, and playrooms.

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