A STRUCTURAL PLANNING MODELER OF INFORMAL SHAPE BUILDING DESIGN

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Abstract. This study aims to implement a design tool that can help architects predict space configuration along with structural member location in complex shape buildings. Architects can use the tool to confirm spatial allocations and configurations as they apply structural members to building shape. The modeler is based on the object hierarchy of structural members in order to grab and to edit them conveniently.

1. Background

In recent building design architects attempt to elaborate irregular shapes or arbitrary forms which resemble sculptural objects. These efforts are made by a group of architects who foresee possibilities of virtuality of the computer technology within a physical environment. Building models of this trend have following characteristics; 1) building envelopes cannot be formulated by mathematical equations, 2) distinctions of structural elements diminish since they are not composed by axial grids, and 3) building envelopes are primarily decided by building skeletons.

Formerly architects used their knowledge and intuition for space allocation and structural plan of regular shape buildings. As design proceeds architects collaborate with structural engineers about detailed structural design for the initial plan. However, recent computer-nurtured design models of complex shapes cause complicated structural member design for the support of exterior shape. Thus, internal spaces may become...
unreasonable or unusable. Architects have difficulties in forecasting where these space configurations might occur.

2. Building shape and spatial configuration

If building design is affected by computer technology that result in irregular shapes or arbitrary forms, the problems arising in designing this kind of buildings should be resolved by the computer. One of the most crucial problems in designing an irregular shape building would be to keep a balance with the structural efficiency. The structural systems must resist against the gravity force in such a way that columns stand vertically and support beams and slabs. To be an economical construction method the structural system has to be based on the three dimensional grid. However, buildings of irregular shape supported by regular grid structural system may generate uncertain, mostly undesirable spaces. Spaces on a top floor and outermost places of each floor in an arbitrary form building with a formal grid structural system might have too short a ceiling height for normal occupancy and/or columns might locate in an abrupt position inside a space. The aim of this study is to implement a design tool that can help architects predict space configuration along with structural member location in complex shape buildings. This tool can generate basic structural member, locate them and modify them as designers assess their design in terms of spatial feasibility and efficient space configuration. By doing so, dead space can be reduced and simplify structural member composition (Figure 1).

![Figure 1. Section & Plan of dead space](image)

3. Functional modules of a modeler

To achieve the study goal, following modules are developed; 1) a structural member design model, 2) a collaboration model between an architect and a structural engineer, and 3) a data import model to reuse previously created building models. A proposed design modeler imports sectional line drawing data and plan drawing data of each floor from a three-dimensional wireframe
model. Entire data of a three dimensional model are not considered to be necessary to exploit structural member placement. However, regularly spaced sectional lines are adopted with floor plans. The modeling proceeds as follows: Firstly, sectional line drawing and plan drawing of a designed building model will be imported so that the building model can be compared with a structural grid on a plane projection. Secondly, the grid will be modified in order to perform spatial configuration in terms of certainty and usability of spaces. Thirdly, after the satisfactory spatial configuration from plane projections with structural grid, the entire building model in a three dimensional wire frame will be imported to compare with the structural grid visually for a final check.

4. Realization of irregular shaped buildings

Historically it was believed that buildings with formal regular shape present aesthetic beauty based on Euclidean grid. This belief combined with simplicity and consistency of axial grid structure has been a dominant architectural design paradigm. Early computer aided design systems were set to support traditional design methods in this paradigm. Recently, new attempts to use computer graphics and three-dimensional modeling technology as design methods are introduced, and are accepted enthusiastically among experimental architects. Enhanced computing power and elaborate modeling algorithms for arbitrary shapes make building design of previously regarded as impossible to be realized (Figure 2). A number of this kind of design proposals is increasing as a new trend. The design of irregular shaped buildings using computers requires an additional step compared to the design of regular shaped buildings to meet structural and spatial coherence. While in the design of regular shaped building spaces and the structural system have coincident axial grids, the irregular shaped buildings are based on the multiple axis to which building surface angles are normal. This is because it is difficult to distinguish between walls and ceilings and/or between walls and floors in irregular shaped buildings. In these types of buildings, a structural system based on three axial grids must be assessed for application and spatial configuration according to the structural system must be assessed vigorously. In order to do this, a structural planning modeler is needed, which can undertake this assessment in addition to the conventional processes of computer modeler. And using this modeler at an early design stage will be a critical factor in saving time and reducing workload.
5. Concepts of the model design

The modeler suggested in this study is developed under following concepts:
1) Because of the complexity of irregular shapes it is not feasible to check the structural system from all angles to which building envelopes can face.
2) Therefore, a main sectional plane is checked and modified against the structural grid so that the outermost spaces are configured to be usable under the vertical structural grid. Columns are then placed by the structural grid on a ground level, which propagate to remaining floors.
3) Next a perpendicularly cross sectional plane to the main sectional plane is checked in the same manner (Figure 3).
4) From the two cross-sectional planes structural grids expand horizontally to cover the boundary of a building. The modeler then shows a plan drawing of each level/floor with column locations, and designers modify the structural members by moving the grid in a way which suggests optimal spatial configuration.
5) Designers decide to divide a number of vertical levels or floors on a mass model. Spaces of each floor are checked against the horizontal grid of the structural system and modified for the spatial configuration of the entire building.
6) Finally the three dimensional wire frame model data of a building is imported to be checked against the modified structural grid for the comprehensive spatial configuration.

6. An object-based system for collaboration

The modeler is based on the object hierarchy of structural members in order to grab and to edit them conveniently. An object-based modeler makes
structural members traceable which is critical in the design process. The modeler also utilizes Web technology to share a program and data between participants. Collaboration using Internet or Intranet can help design works at an early design stage to be fast and smooth. The system configuration of the modeler is shown in figure 4.

![Figure 4. System Diagram](image)

Java language and event handling mechanism is adopted for efficient computer communication in terms of computing load on client and server data handling. The hierarchical organization of objects of the modeler is illustrated in Figure 5.

![Figure 5. Object-Tree View](image)

7. The modeling process and system interfaces

Structural members are generated from frames of axial grid, and then these members will be modified with possible building envelope changes. After designers are satisfied with preliminary structural design, they will collaborate with structural engineers for a feedback. Figure 6 shows the
process of the modeling for structural grids of informal shaped building. The structural grid is generated in an array of X axis and Y axis by the number of floors and column intervals. Such structural elements as columns, beams and slabs are all attached to the grids. Since the modeler is object-based, it is possible to manipulate the generation and modification of these structural elements by simply editing the grids. At the top of the window are tools for modeling structural elements, and at the bottom is a communication window between participants for the real time communication. Right side window shows the geometries of structural grid which is pointed and activated, while left side window indicates the hierarchical organization of objects of the modeler.

![System process diagram](image)

**Figure 6. System process**

8. Conclusion

The modeler proposed here is to help the design of irregular shaped buildings to be check against the structural system at an early design stage. Its purpose is to reduce the design conflicts and errors in spatial configuration by collaboration between architects and structural engineers from the early phase of planning and design. Also the designer can identify ill formed spaces against the structural system easily and promptly, and modify the structural grid to satisfy the spatial configuration. The outcomes
of this study are 1) architects can use the tool to confirm spatial allocations and configurations as they apply structural members to building shape. 2) Data integration can be achieved as data import and export are possible to popular modeling software. And 3) Unnecessary structural members can be minimized since building’s supporting members are planned in accordance with spatial assessment. In future, there will come an attempt to develop a structural system which can trace and support the shape of buildings without considering natural gravity as primary barrier to build a structure. Then the structural modeler will enter a new dimension in planning and developing a structural framework.

References

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