Comparative Studies on the Regional Differences of Modularity Design Tendency Between the United States and Japan

Ying-Chang Yu¹, Tomonari Yashiro², Satoshi Yoshida³ and Zhi Qiu*⁴

¹ Assistant Professor, Department of Architecture, Tamkang University, Taiwan
² Professor, Institute of Industrial Science, the University of Tokyo, Japan
³ Professor, Master Program of Innovation for Design and Engineering, Advanced Institute of Industrial Technology, Japan
⁴ Lecturer, College of Civil Engineering and Architecture, Zhejiang University, China

Abstract
A standard architectural project comprises multiple interfaces among individual modules of information, components, systems, or players. Each society possesses its own history and background that derives a unique pattern of modules and interfaces. In 2005, Prof. Tomonari Yashiro and Prof. Satoshi Yoshida identified the antagonistic concept of design tendency between modularity and integration. Players from different countries tend to manage projects on different levels of modularity or integration, and create unique work system structures for each. The effects of the difference between modularity and integration were identified, but the mechanism was not demonstrated in visualized or quantified models.

This research identifies the United States as the most oriented to modularity and Japan as the country most oriented to integration. The Two countries were the focus of analyses to demonstrate the effect of using the task structure matrix (TSM). The TSM analysis model is a method to visualize and quantify the module pattern and relationship by recording the dependencies of all the elements. This research sought to verify the different pattern of regional modularity between the United States and Japan, as well as offer a quantified understanding to help transnational project players identify the critical paths that are potentially omitted from a project.

Keywords: modularity; integration; task dependency; design structure matrix; design information

1. Introduction
Globalization has been widely infiltrating every aspect of our lives, and even the building construction industry is not immune to this trend. When multiple professional players engage in a transnational project with different construction knowledge and backgrounds, the project usually leads to unpredicted failure caused by inappropriate management of conflict among the players. Although a large amount of research has been dedicated to differences among cultures, little is known about how the mechanism of differing local design philosophies and convention could affect the outcome of architectural collaborations.

2. Theory and Literature Review
In 2005, in the report titled "Study of the Shift of Construction Technology and Organizational Configuration Based on the Development of Architectural Elements", the authors, Prof. Tomonari Yashiro and Prof. Satoshi Yoshida noted the antagonistic differences in design methods between modularity and integration. They also observed how the different orientations of integration and modularity would shape the final outcome of artifacts among different cultures. However, this observation was seeking a further quantitative study for verification.

To model the process of project execution affected by concepts of modularity or integration, this research adapted the approach used in "Design Rules, Vol. 1: The Power of Modularity" by Prof. Carliss Y. Baldwin and Prof. Kim B. Clark. This book presented a methodology for modularity in response to a dynamic economic and commercial world. "Design Structure Matrix" method was presented as an efficient analytical tool to describe the abstract concept of modularity in a scientific format.

3. Hypothesis and Research Methods
3.1 Definition
A Task is an action element that can be accumulated to provide a service or form an artifact. It can be information, a process for execution, or a component.
The dependency among task elements is the link to maintaining the task function, and is the primary target for improving design and project management.

3.2 Hypothesis

Designs in countries oriented towards high modularity tend to have less dependency among tasks than those in countries oriented towards high integration levels.

3.3 Analysis Modeling Tool

The research aims to develop a scientific model that can visualize and quantify the disparity in dependency between the modularity oriented United States, and the integration oriented Japan, to identify possible causes of transnational project failure.

3.3.1 Task Structure Matrix Based on DSM

Donald V. Steward conceived the Dependency Structure Matrix (DSM), also called Design Structure Matrix, Incidence Matrix, or Design precedence matrix, in 1967 while designing a nuclear power plant. It was systematically introduced to the public in his 1981 book, "Systems Analysis and Management: Structure, Strategy and Design". The basic idea of DSM is to break each element of the target artifact down into a list and recreate the dependency network among elements for project analysis. Similarly, TSM uses operational tasks instead of elements to assess the target construction approach.

3.3.2 The Basic Principle of Making TSM

Taking production of a concrete block as an example of TSM modeling, a designer would collect a systematic set of information to complete the design process, such as manufacturing processes, the feature of the specimen, and the designer's intention. The first step is to list all the affective factors of this target job as parameters during the design process, and collect corresponding data associated with the parameter.

In this example, producing a concrete block would involve the ten different types of information or actions listed below in "Fig.1.". Each information or action was labeled as "Task" for manufacturing parameters such as "molding", specimen features such as "treatment", and design intents such as "dimension", or "precision" and so on.

![Fig.1. Task List of Making a Simple Concrete Block](image)

Table 1. Task Description of Making a Concrete Block

<table>
<thead>
<tr>
<th>Task #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The concrete dimension defines the strength of the block and the size of molding.</td>
</tr>
<tr>
<td>2</td>
<td>The material of the block controls the strength and appearance of the block, and decides the method of pouring and curing time.</td>
</tr>
</tbody>
</table>

3. The strength requirement determines the material of the block, and the method of pouring and curing time.
4. The precision requirement defines the appearance of the block, and gives guidance to the molding method and calibration of molding.
5. The quality requirement controls the quality standard and the surface treatment method.
6. The molding method determines the precision of the final product, and what kind of calibration methods can be used.
7. The calibrating procedure affects the molding method, and determines the beginning of the process.
8. The pouring process will affect the final surface treatment, and determines the beginning of concrete curving.
10. Surface treatment as finish of the work.

The second step is to locate the dependency among tasks. The correlations of each task are listed in "Fig.2.". If the existence of lower tasks depends on the higher tasks as shown in the left side of the matrix, then the authors label it at the lower left corner, and if the dependency is in reverse, they label it on the upper right corner. In the case that both tasks are interdependent to each other, they were labeled on both sides.

![Fig.2. Example of TSM](image)

Dependency mark on one side suggests a hierarchical relationship between two tasks (One dominates the other). Dependency marks on both sides show these two tasks are interdependent (Coexistence).

![Fig.3. Principle of Task Markin](image)

3.3.3 The Basic Pattern from TSM

The TSM may be applied to almost all artifacts to analyze the design dependency mechanism. Depending on the nature of different artifacts, the Task Structure Matrix reveals some corresponding preset patterns.

The first type of pattern is the modularized block pattern, as shown in "Fig.4.a". Modularized blocks, also called object-oriented design, are commonly seen...
in the electronics or information technology industries. In such patterns, each block contains sufficient self-support information, and requires very limited information from other blocks.

Fig. 4.a, Highly Modularized Interface; b, Sequential Tasks without Clear Module and Interface

The second pattern is the linear sequential task as shown in "Fig.4.b". The linear sequential layout of tasks indicates that every task depends on another task and acts as a unit of transmission linkage. This pattern is commonly seen in factory assembly lines or construction projects.

Fig. 5.c. Integrated Orientation; d. Mixture Module with Integrated Correlation

The third pattern is the integrated module block as shown in "Fig.5.c". In such pattern, there are modules existing in the matrix with intensive interdependency among module blocks. This occurs in customized product markets, such as laptop computers, or high-end vehicles.

The fourth pattern is the mixture pattern shown in "Fig.5.d". In this pattern, there are a few modularized blocks in the system that depend on an assembly process to hold all the pieces together. This is the most typical pattern in the building construction industry.

On the basis of the abovementioned observation, it is imperative to match the structure of the design team with the project task pattern. Otherwise, a critical task dependency may be ignored or omitted, which leads to project failure.

4. General Observation on Modularity Tendencies between the United States and Japan

To compare the hypothesis in section 0 with the methodology in section 0, this research assessed four different types of construction methods utilized in the United States and Japan, 1) precast concrete assembly, 2) parapet construction method, 3) roof expansion joint, and 4) window construction.

These targets for observation were selected to demonstrate four different levels of system mechanisms, 1) intra-organization integration, 2) collaborative integration, 3) function integration, and 4) integration of multiple entities.

4.1 Modularity Analysis of Intra-Organization Construction Method

Case selection: Examples of precast concrete details (Fig.6.) were selected to identify the effects of organizational behavior on building construction methods where the interfaces and related components are all provided by the same entity.

United States: This detail was selected from the Architectural Graphic Standard (AGS) issued by the American Institute of Architects (AIA) which provides a privilege of authority as a guideline to the building construction industry as the minimum standard datum.

Japan: This detail was selected from the "Manual of Pre-fab PC for Construction and Design" by the Kajima Company.

4.1.1 Observation on Precast Concrete Assembly

Fig. 7 shows the design of a precast concrete floor to bearing wall connection in the United States in accordance with the "AGS". The connections
between slab and bearing wall require less predefined engagement. The embedded connection is a typical standard product, and no special welding skill is required.

Fig. 8 shows a similar detail used in Japan. This connection contains more hardware and cut-outs on components, which also involves onsite grout injection. The detail requires higher precision overhead onsite welding. The embedded rod fabrication relies greatly on the attributes of other components.

Fig. 8. TSM of Typical Slab Connection in Japan

On the basis of TSM analysis, the authors identified the following points,
1. The quantity of total tasks in the US (the modularity oriented country) tends to be less than in Japan.
2. The quantity of hierarchical dependent tasks in the US is relatively less than in Japan.
3. The quantity of interdependent tasks in the US is somewhat less than in Japan.
4. The number of internal tasks required to produce a single component in the US is less than in Japan.
5. The assembly system transition process in the US is generally simpler than in Japan.

According to the judgment criterion identified in section 0, a TSM which tends to have less hierarchical dependent tasks, interdependent tasks, and internal task leads the user toward a modularity oriented approach. In this case, American intra-organization tends to be more modular-oriented, while Japanese organizations tend to be more oriented toward integration.

4.2 Modularity Analysis of Collaborative Integration

The second example for analysis is the parapet area, which is a location most vulnerable to water infiltration in building construction.

This comparative analysis was conducted to discuss the differing collaborative behaviors among parties in the United States and Japan. The representative cases selected for the US and Japan are shown in "Fig.9."

The detail for parapet construction in Japan shown in Fig. 9 was selected from "Building Construction Standard Detail", which was released by the Ministry of Land, Infrastructure, Transport and Tourism (Maintenance Division, Government Buildings Department). Japan has a typical system of civil law system. The regulations and public guidelines established by government authorities establish strict standards for every user.

The corresponding details in the United States are based on the standard in the AGS as shown in "Fig.9.". The typical approach by American architects to overcome water infiltration issues at the parapet is to disregard the wall as part of the waterproofing solution. They consider the waterproofing system to be an attachment to the structure.

4.2.1 Observations on Design and Construction Methods for Parapets

The corresponding TSM indicates practices similar to intra-organization behavior. The construction method used in the United States requires only 15 tasks to complete, and the dependent task connections among systems occur only at the wall to roof and waterproofing-to-wall. The installation of waterproofing reveals a linear sequential pattern, which indicates that the process tends to a low interdependent pattern as shown in "Fig.10."

The Japanese standards for parapet design show a fold back from the top to cover the inner waterproofing system as the first line of defense against water infiltration. This is a very common approach in Japanese building construction, but not in the United States.

The TSM pattern for the parapet design in Japan reveals a high tendency toward interdependence, which indicates that the design of the parapet is taking a highly integrated approach. The base concrete parapet requires a significant amount of interdependent
Fig. 10. TSM for Typical Parapet Detail in the United States

information from other components to be poured on time, such as the recess space for the waterproofing material, or the extension of rebar to receive and hold the inner concrete in place as shown in "Fig. 11.".

The different levels of interdependence among components caused by disparate construction approaches can be explained by the tendency toward modularity of designers from different social backgrounds. Japanese are more willing to surrender benefits to provide a more competitive, highly integrated, and better quality product. American contractors work only according to the specification in the contract. These two different tendencies also magnify the difference in construction quality between the US and Japan.

4.3 Modularity Analysis of Function Integration

In this section, a slab-wall expansion joint is the basis for discussion of the comparative tendencies of function integration between the United States and Japan. Expansion joints are commonly used in buildings to absorb heat-induced expansion or seismic movements and to avoid leakage or alleviate concentrated stress.

The authors' research selected a typical roofing area expansion joint detail used in Japan from the "Architectural Waterproofing Handbook" provided by the Building Waterproof System Handbook Committee. For parapets in Japan, architects generally create a lateral cantilever from a vertical member to provide a solid base to cover the joint and waterproof system as shown in "Fig. 12.".

In the United States, architects follow the same principle used in parapet design (Fig. 12.). The typical expansion joint on the roof would not be considered a part of the structure, and the installation of the expansion joint would be an additional step in the construction process.

4.3.1 Observations on Expansion Joint Construction

In the United States and Japan, design of expansion joints at roof or terrace areas reflect two opposite approaches to following the same principle. The expansion joint detail in the United States tends to be detached from element to element as shown in "Fig. 13.". The concrete supplier only needs to deliver the product on time and within tolerance. The waterproofing contractor would only need to cover
the gap with an independent expansion joint device. There is almost no interdependent flow of information between the processes for the two components.

The design of expansion joints in the United States shows that the function of each component is relatively simple. For example, the function of the concrete wall is to receive the metal flashing.

Fig. 13 TSM of Typical Roof to Wall Detail in the United States

The Japanese design tends to contain more hardware and multiple lines of defense to control water infiltration. This, in turn, requires more preparation of the base concrete, such as grooving, notching, or laying embedment in advance. As a result, more processes for integration are engaged during construction. Analysis of similar designs in Japan reveals that each component tends to have multiple functions as shown in "Fig. 14." For example, in the Japanese design the same structure covers the gap, receives the metal flashing, holds the stiffener, and provides a recess to accommodate sealant.

4.4 Modularity Analysis of Integration with Multiple Entities

A typical construction project is carried out by multiple players with varying types of components and functions. In a building system, the window is an interface between the interior space and exterior environment. Due to its special characteristics, numerous interior components would meet or engage with the exterior components in this area and create multiple points of communication among players. The intensity of communication would depend on the extent of modularity, as mentioned in section 0.

In general, there are multiple systems in contact with each other in the window area. When comparing processes in the United States and Japan, consciousness of modularity would greatly affect the complexity of the window design, and verify the modularity or the degree of integration in construction methods.

Fig. 14 TSM of Typical Roof to Wall Detail in Japan

Comparatively, the typical window detail used in Japan shows that more methods of transition are applied among window frame to structure, as well as to exterior surface treatment and the interior drywall system as shown in "Fig. 15.". For example, Japanese architects tend to use more steel rods to connect the window frame to the structural wall. A sloped concrete sill with grout infill is commonly used in this application. Clearly, this method involves more interdependent communication during construction.

Fig. 15 Typical Window Detail in the US and Japan

The design of building window areas in the United States takes an opposite approach as shown in "Fig. 15.". This approach minimizes the interconnection among components, and only a very few connecting
devices are applied to assemble all the components in the window area.

4.4.1 Observations on Multiplayer Construction of Windows

Based on the selected detail and corresponding TSM, the window consists of a larger amount of tasks and blocks in both the American and Japanese examples. Based on the comparative analysis as shown in "Fig.16.", the dependent tasks of window construction design in the United States occurs mostly between design and components (X1-X9/Y10-Y24); very few tasks will interfere with other components, and most modules are carried out in a linear sequence. In other words, each task group could be performed free of, or with minimum constrains from other task groups. The designer provides only enough information for other parties to follow up. It consists of 34 identified tasks with a total of 69 dependency links among tasks, and only 33 dependency links among blocks (~48% of total dependency links).

The TSM for window construction in Japan reveals the opposite as shown in "Fig.17.". With the exception of the dependent tasks between design and construction components, multiple interdependent blocks appear on the TSM among structure, window, and exterior finish. This suggests a highly indivisible integration and verifies that the organizational tendency is closer to integrated design.

On the corresponding TSM for window construction in Japan, the dependencies are distributed among groups. No clear pattern can be observed on the matrix. Each task group has multiple constraints of dependency with other task groups.

A total of 46 active tasks are identified in total with 150 dependency links among tasks, and 89 dependency links among blocks.

Based on the results of the abovementioned analysis, dependency links for window construction in Japan represent 217% dependency of the dependency link for the same process in the US (150:69). The critical dependency in Japanese window construction (external dependency among blocks) is also 270% of the US (89:33).
The relationship between task quantity and project outcome still need further study, but it is clear that a project player originally designated to a particular task structure pattern may not perform equally in an opposite modularity tendency project environment.

The organization may not be arranged to deal with an unfamiliar amount of tasks and task dependencies in different interface areas.

References