A STUDY ON THE ASSESSMENT METHOD OF TRANSFORMABILITY OF SKELETON-INFILL APARTMENT BUILDINGS

Through attempted case studies on three example buildings built between 1983-99

Keywords: Degree of Freedom of Transformation (DFT) Index, Transformability Profile (TP), Intended Transformability, Experienced Transformability, Substantial Transformability

1. Introduction

1.1 Purpose

The purpose of this paper is: 1) to propose the assessment method of transformability of SI apartment buildings, 2) to apply the method to analyze three apartments to prove its applicability, 3) to illustrate the research direction to develop substantial transformability assessment which is applicable to design.

1.2 Background

Transformability of apartment buildings for more sustainable environment has attracted interests of designers, as well as theoretical, and investigative researchers over the course of time.

First group of contributors to this theme were practicing designers who thought about it as a way of more appropriately satisfying the needs of residents and reducing waste. Most well-known proposals were those of Metabolists in Japan and Archigram group in Britain during late 50s and 60s. However, the proactive approach sometimes suffers too much assumptions and expectations which can turn out to be unrealistic\(^1\). The Authors noticed large mismatch between intended and realized transformability\(^2\) which awaked the curiosity for deeper research about the phenomenon.

Second group of contributors were theoretical researchers. Starting with Habraken in 1961\(^2\) (introduced terms “support” and “infill”, and residents’ involvement in design process)\(^3\), the most notable contributors were also Duffy (introduced 4S – four different paces of change of building “layers”\(^4\) and Brand (developed Duffy’s 4S to 6S or Shearing Layers of Change)\(^5\), then Schneider and Till (collected and organized strategies for flexibility, classifying it as “soft” and “hard”)\(^6\), Durmišević (introduced Design for Disassembly – technical decomposition of buildings in order to have its elements reusable, recyclable, repairable\(^7\)), and Kadowski (proposed quantification of skeleton’s capacity of change)\(^8\).

Third group of contributors were investigative researchers who conducted post-occupancy evaluations (POE) of apartment buildings through which each apartment’s state of actual transformations were recorded chronologically. Most notable among them were Uchida, Tsutsumi, Sawada, Hatsumi, Fukao, and...
Takada, Kobayashi, Minami, Takai, and others *3).

Following and based on these contributions the Authors thought it was a good time to advance to reliable, objective, and applicable assessment method of transformability of buildings.

1.3 Study Outline

The construction of the study is shown in Fig.1 (bottom up order). Combining the three contributions – designers' trials and studies, theoretical considerations, and POE, an assessment method and its protocol were proposed (chapter 2). To determine how much of designers' original intentions were experienced, the method was applied to three examples of SI apartment buildings (chapters 3 & 4). The ultimate focus of this study in the future, should be substantial transformability assessment which can be applicable in the design phase, and its main points were discussed in chapter 5.

Fig.1 Study Outline and Supporting Contributions

2. The Concept and Assessment Method of Transformability

The Authors thought there are two independent aspects of transformability, as follows:

a) What parts of building are to be transformed? This has been discussed in the past *6) and the most sophisticated concept is the one Brand developed, Shearing Layers of Change, which is a separation of building layers by the pace of their change *5) (Fig.2, left). We adapted this to be applicable to general construction of building parts of SI apartments (Fig.2, right).

Fig.2 Shearing Layers of Change *5) and Building Parts

b) How easily the transformation can be realized from the perspective of residents? This is very important for more efficient realization of intended transformations, but it has been rarely discussed systematically. It can be evaluated from psychological, economical, and/or other aspects, however, those are not always suitable in design phase. The involvement of certain parties in the transformation process is a good indication of transformation easiness as shown in upper part of Figure 3. There are nine values of DFT Index each corresponding to specific party involved in the transformation. Higher index means less time and resources consumed, therefore the transformation can occur more frequently, promptly, and affordably. This is very intuitive, so designers can have a clear mental image of transformation easiness even at the design phase. In order to have clear and objective criteria for each DFT Index value, the Authors developed DFT Index Determination Protocol (Fig.3, down). DFT Index is determined through a series of four questions based on the logical order of transformation process. Each transformation is first initiated by someone (Q1), then the decision to execute it is made (Q2), then it is executed by someone (Q3), and that is done in certain manner (Q4).

Fig.3 DFT Index Determination Protocol & Corresponding Parties

To assess the transformability of the SI apartment buildings, we need to combine a) and b) in a consistent assessment system as shown in Fig.4. Building Parts' Parameters were placed vertically, and DFT Index was plotted horizontally. Connected values represent the Transformability Profile (TP).
Transformability has a slightly different notion depending on the role that one has in the transformation process. We can recognize designer and resident as the main parties, each having a profound influence to transformation process just not at the same time. On the other hand, any building has certain transformability that depends only on its physical characteristics. Therefore, we can draw at least three different TPs, as follows:

1) Intended TP – Represents the designers’ predictions about future transformations.

2) Experienced TP – Shows the actually experienced transformations at a designated moment after completion. For this TP, there is a possibility that the transformation never took place. In this case the DFT value should be “N/A” (Not Available).

3) Substantial TP – Ideally represents the maximum potential of transformation based on objective physical characteristics of building.

Logically, Intended and Experienced TPs cannot exceed Substantial TP. Intended and Experienced TPs can be compared in order to assess how the designers’ predictions correspond to reality. Substantial TP is ideal, a theoretical hypothesis, but it will be needed for extending the assessment toward design phase. Intended and Experienced TPs can help derive Substantial TP.

3. DFT Indexing and TP Evaluation of the Examples

The three examples of SI apartment buildings were chosen to present the proposed methodology in respect to wide variety of SI apartment buildings. Specific information and data of the exampled buildings are shown in Fig.5.
3.1 Intended TP Evaluation

Two types of materials created by designers were analyzed:

i) Explicitly stated intentions in written form (promotion pamphlets, books, papers, schemes, and explanations), and

ii) Observations from technical materials (drawings and specifications), where i) is more direct than ii). The evaluation of Intended TPs of three examples is shown in Fig.6. DFT Indexing for intended transformability is explained on case of FCY.

Designers of FCY showed many of their intentions explicitly through promotion pamphlet. Those are marked by ○, □, ◊, ◆, and ◊ in Fig.6. Statements ○, ◊, and ◆ indicate that many Building Parts are to be changed every 30 years, residents of all the units having to do it at the same time. Since the society has the final decision on Q1 and Q2 (see Fig.3) it can be concluded that DFT Index for intended transformability is shown in Fig.6. DFT Indexing for intended transformability is explained on case of FCY.

Evaluation of Intended TPs of three examples is shown in Fig.6. DFT Indexing for intended transformability is explained on case of FCY.

3.2 Experienced TP Evaluation

Experienced TP is evaluated using the records of actually realized transformations gathered through POE investigations. A series of Experienced TPs could be made and the accumulation of the transformation experience could be observed.

Evaluation of DFT Index for experienced transformability is shown in Fig.7 on three apartment units of TM3, which were carefully investigated for 30 years already, first by Hatsumi in 1995, then by Minami et al. in 2006 and 2014.

Unit 1 transformed in 1990 when the special movable partition (A in Fig.7) was moved to a new position (B transforming at the same time the sizes of two rooms, but not the number of rooms. It was moved in designated way, therefore: DFT Index for storage displacement=6). Storage and movable furniture were relocated to a new position, however this was done freely, therefore: DFT Index for movable furniture=7. The accumulated TP expanded accordingly. In 2013 another partition provided by architect was removed: B*, thus the living room became larger and the number of rooms changed: DFT Index for movable furniture=7. The tatami floor was replaced by flooring which is a transformation of surfaces so the TP expanded even more. This change was done by skilled professionals, therefore: DFT Index for movable furniture=4.

Example

<table>
<thead>
<tr>
<th>BUILDING PARTS (DF) &amp; DFT PARAMETER</th>
<th>ANALYSIS OF INTENTIONS REGARDING TRANSFORMABILITY</th>
<th>OBSERVED IN TECHNICAL MATERIALS</th>
<th>SOURCE</th>
<th>INTENDED TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURFACES</td>
<td>Building selection</td>
<td>Conventional construction methods which were not specified.</td>
<td>Page 14, 15</td>
<td>○</td>
</tr>
<tr>
<td>FURNITURE</td>
<td>Movable displacement</td>
<td>Not designated, may be freely chosen and moved.</td>
<td>Page 16</td>
<td>○</td>
</tr>
<tr>
<td>PLAN</td>
<td>Area</td>
<td>Not predicted.</td>
<td>Page 17</td>
<td>○</td>
</tr>
<tr>
<td>UTILITIES</td>
<td>1. Movable partitions and movable storage developed and provided</td>
<td>Only few elements are marked according to Better living standardization for easy exchange and maintenance.</td>
<td>Page 18</td>
<td>○</td>
</tr>
<tr>
<td>FACADE</td>
<td>Opening Disposition</td>
<td>Not predicted.</td>
<td>Page 19</td>
<td>○</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>Storage Disposition</td>
<td>Not predicted.</td>
<td>Page 20</td>
<td>○</td>
</tr>
</tbody>
</table>

TM3

- Surface selection
- Material selection
- Group displacement
- Movable displacement
- Movable partition
- Area
- Number of rooms
- Individual room size
- 1. Movable partitions and movable storage developed and provided
- Opening Disposition
- Storage Disposition
- Not predicted

CHM

- Surface selection
- Material selection
- Movable displacement
- Movable partition
- Area
- Number of rooms
- Individual room size
- Movable partitions and movable storage developed and provided
- Opening Disposition
- Storage Disposition
- Not predicted

FCY

- Surface selection
- Material selection
- Movable partition
- Group displacement
- Specific area
- Individual room size
- Movable partitions and movable storage developed and provided
- Opening Disposition
- Storage Disposition
- Not predicted

Note: The design concept is described in the zoomed-in images of the report referenced as 6. In this figure, pagination of the original material is used.

Fig.6 Analysis of Design Intentions and Intended TPs of the Three Examples
Fig. 7  Experienced Transformations, Experienced TP and Its Accumulation in Case of Tsurumaki-3 Estate
4. Transformability Assessment of the Three Actual Examples

Figure 8 shows the results of the evaluation of Intended and Experienced TPs of all three examples. Evaluating the experiences from the investigative researches, we dealt with different number of units investigated at different points after completion. This means that the “width” of these experiences is different. To overcome these differences and to convert the experienced transformability of the examples into comparable format, the Authors introduced the period of accumulation of experience — “unit-years”. It is derived from the period of time after completion (in years) multiplied by the number of investigated units, and it can be represented by contour lines as in Fig.8. Experienced TP has been accumulating over the years so that at some point it reached Intended TP, and in some building parts even exceeded it. As it can be seen in Fig.8 this matching is almost complete at the point of 93 unit-years contour which suggests that approximately 100 unit-years might be taken as enough duration for assessment of the matching of intended and actually experienced transformations.8

Also, the noticed differences in paces of transformation of certain building parts suggest that Brand’s Shearing Layers of Change could be confirmed as reliable. Similar observations were already made by Minami in 2015, when the effectiveness of intended pace of change was concluded for building components designated to be updated 15–25 years after completion21.

However, due to the very limited number of examples, further research on a larger set of examples is necessary to confirm these observations.

5. Toward the Substantial TP Assessment Applicable to Design

Intended TP is designers’ subjective assumption which is to be proven afterwards by occupants’ experiences represented by Experienced TP. On the other hand, Experienced TP has factual reliability itself but it is never available to designer in the design phase. To overcome this gap and achieve real transformable apartment houses of longer lifespan and so affect positively the sustainability of built environment, it is necessary to develop Substantial TP assessment method.

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Fig.8 Analysis of Approaching Behavior of Experienced TP toward Intended TP
To achieve this, it is necessary not only to collect more of the analyses on the same basis but also relate them toward the concrete design specifications of each building. From here certain conclusions can be drawn based on the inductive logic as follows:

i) If any of plural examples employs identical design feature or technique and thus the same or fundamentally similar DFT value in certain part of Intended TP,

ii) and if the intentions were proven by Experienced TP of each,

iii) That implies the causal relationship between the technique and the focused DFT value. Based on this, as far as the identical technique is used, the same DFT value can be estimated as a part of Substantial TP of the current design.

Among the examples we dealt in this paper, the technique of movable partition is shared by TM3 and FCY, their DFT values on <PLAN> in Intended TPs are exactly the same, and those of Experienced TPs after 93 unit-years are almost the same (in FCY, experiences even exceed intention). Although the Authors were reluctant to conclude any of inductive maxims from only two examples, it can be said that the phenomenon suggested by the above mentioned logic was observed.

As for the design specifications of building, in order to be useful to designers, they should be classified and organized corresponding to the sequential phases in design process like: a) features of housing building such as planning / access / structural principles, b) features of unit such as plan and sectional form and their dimensions, and c) partial techniques such as movable partitions applied in the certain parts in a unit.

Through careful analysis and examinations on the extended number of examples on the above-mentioned basis, the Authors expect the establishment of Substantial TP assessment.

6. Concluding Remarks

Based on the proposal of the assessment method of transformability, the Authors pointed out the following:

1) Using the proposed method, the matching of Intended and Experienced TPs was observed in three actual examples over the course of time after the buildings were built.

2) Approximately 100 unit-years of accumulated experience of transformation might be enough to confirm whether the design intentions regarding transformability were achieved in reality.

3) The necessary directions for the future research development were pointed out in order to develop the assessment of Substantial TP. Concretely, a reasoning procedure is formulated and described through steps i), ii), and iii) in Chapter 5.

Acknowledgement

The Authors would like to express deep gratitude to Prof. Dr. Kazunobu Minami who generously revealed his opinions based on his long term study of apartment transformations.

References


9) New Generation Housing System Flex Court Yoshida, promotion pamphlet. Publication date not indicated. Appeared in 8) in Appendix. (in Japanese)


Notes

1) While both groups were proposing various designs, the Metabolists’ ideas were more realistic. Kisho Kurokawa’s Nakagin Capsule tower was actually realized with the intention to transform. However, the building remained in its original state until the present.


3) A number of contributors from this group (Uchida, Tatsumi, Fukao, Takada) were also involved in designing of transformable apartment buildings, and belong also to the first group of contributors.

4) In Dürmišević’s dissertation, one whole sub-chapter (3.5) named “Theory of levels” thoroughly explained the development of the idea.

5) Brand concretely outlined the expected lifetime of each layer before being replaced. In Figure 2 (left) thicker lines means that the layers have longer cycle of change, and thinner lines shorter.

6) The Authors are aware that, at this moment, the number and the selection of the examples carry certain limitations regarding the reliability of conclusions, however, it is necessary to present the method to the academic society. Nevertheless, the examples are selected with the respect to rather wide variety of planning/access/structural principles of SI apartment buildings, as shown in Table A. These principles are, in part, derived from previously investigated box, panel, and skeleton space systems.

Table A. Planning/Access/Structural Principles of the Examples

<table>
<thead>
<tr>
<th>Examples</th>
<th>Planning Principles</th>
<th>Access Principles</th>
<th>Structural Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CHM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCY</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7) There are different types of apartments in the housing complex. Type B was analyzed, since it has the highest number of units covered in detail.

8) This conclusion is quite conditional, and the Authors have to stress that the following considerations would be necessary: a) the balance between the number of units and experienced years should not be too excessive to avoid the unreliable ranging of samples, b) the consideration on the wide variety of dwellers on their age, family structure, occupation, economic situation, health condition etc. when the “number of years” (investigation period) is relatively limited. The total experience represented by unit-years may vary rather greatly due to the relative uniformity of dwellers. If dwellers were similar to each other, the unit number multiplication would not be justified because all units can experience the identical transformation in the same period. In the respect of the above mentioned matter we have to recommend careful consideration on the dispersion of dwellers.

In the case of FCY the transformations were recorded only three years after completion, however the designer provided and encouraged the immediate transformations (which is a reason why the thorough investigation was made so early) thus enough number of transformations was realized.
1. 序論

スクエルトン・インフィル型（以下 SI）集合住宅については、居住履歴の詳細な調査が進み、当初の設計意図が実地にどの程度実現されたかを評価するとともに、そのような評価方法が一般的にどうあるべきかを論識する基盤が整いつつある。

本稿の目的は、1）SI 集合住宅の変形可能性（transformability）の評価手法を提案し、2）すでに居住後（post-occupancy）調査が発表された 3 事例に試行的に適用して実地適用性を確かめ、3）この評価手法を設計時＝居住前（pre-occupancy）評価に適用できるよう発展させるため、今後の研究の方向を明らかにするところである。

2. 変形可能性の評価方法の提案

筆者は、変形可能性の評価指標として、従来提案されてきた変形可能性の部位別評価（Fig.2）に加え、変形容易性指標（Degree of Freedom of Transformability: DFT-TP）を提案し、両者を掛け合わせた形で、変形可能性プロファイル（Transformability Profile TP: Fig.4）を構成する方法を提案した。

変形の容易さや困難さを表す指標には、変形にかかる居住者の心理的障壁や、必要費用なども考えられる。しかしこれは居住後の調査指標としては用いられない客観的であるとしても、居住後の評価指標（すなわち設計時に利用可能な指標）には通らない。そのため本稿では、変形を実施する土体識別を段階の指標として利用することにした。すなわち変形可能性は、居住者が自在に変形できる場合が高く、工事業者が依頼したり建築家による設計を必要とする場合には低く評価するよう、分析プロトコルを設定した（Fig.3.3）。

以上のように構成された変形可能性プロファイルには、次の 3 種が考えられる。

1. 意図された TP（Intended TP）：設計時にどの程度の変形可能性が見込まれていたかを表す TP で、設計趣旨や入居募集案内、設計図や説明図などの入居者情報のみから導出される。

2. 経験された TP（Experienced TP）：入居後の特定時点までにどの程度の変形可能性が経験されてきたかを表す TP で、居住後の調査データのみから導出される。

3. 潜在的 TP（Substantial TP）：建築物そのものが潜在的にどの程度の変形可能性を有するかを表す TP で、建築物の設計仕様のみから導出される、設計時に適用可能な変形可能性評価。

以上のことから評論で述べた「当初の設計意図が実地にどの程度実現されたか」という問題は Intended TP と Experienced TP（第 3 章）の一致観として観察される（第 4 章）、また Substantial TP は、本稿が究極の目標とする「設計時に適用可能な変形可能性評価」であり、これは事例分析を蓄積し、設計仕様と Experienced TP の対応を知ることで、今後進歩的に到達すべき問題となる（第 5 章）。

3. 対象事例の DFT-TP 評価

居住後調査の発表されている SI 集合住宅のうちアクセス形式・構造設計の異なる 3 事例、オーストラリア牧-3（住宅・都市整備公団：東京都多摩市 1983）、シーアイウィツ町田（竹中工務店：東京都町田市 1986）、ふれあうコーポ吉田（公益社団法人数世代都市型集合住宅建設委員会・建築環境研究所：大阪府大阪市 1990）をとりあげた（Fig.5, Table A）。3.1 では設計者の言説および設計上の工夫を部位ごとに整理し Intended TP を導出した（Fig.6）、3.2 では 3 事例の居住後調査（南ほか 2015 28, 29, 17）、高木ほか 2002 28, 19, 18、高田ほか 2006 28, 18）に基づいて Experienced TP の累積を適時的に整理した。このうち本稿では累積経験が細かく理解できるエクステント数-3 の分析を例示した（Fig.7）。対象 3 事例それぞれの Experienced TP の時間的累積（経験された最大の DFT を累加する方法による）を U 3 時間に、全住戸の累積結果を下段に提示した。さらに後述する累積変累年数を新たな時間軸として付記した。

4. 対象事例の Intended-Experienced TP の一致経過の分析

3 事例について竣工後の Experienced TP の累積変動をまとめた（Fig.8）。本稿において 3 事例共通に Intended-Experienced TP の一致経過が観察され、設計意図が実現されていったことを検証した。

これより 3 事例では、ほぼ同型の異なる数の住戸が調査されており、いわば経験の「幅」が異なっている。この違いを相互に換算するため、各事例の竣工後 1 年に調査戸数を乗じた累積累年数（単位：戸年：unit-years）という指標を導入して表示すると（Fig.8 中の等高線）、おおむね 100 戸年のラインに Intended-Experienced TP の一致が見られることがわかる。このことから、少数事例に基づく暫定的な結論ながら、100 戸年程度の累積変累年数で設計意図の実地検証が可能であるとの知見が得られた。もちろん、戸数および年度数に極端な偏りがないこと、さらに調査対象が複数の場合、調査対象の居住世代や家族構成が十分にばらついていることなど、母集団についての注意深い条件付けが必要であることは言うまでもない。

5. 設計時に利用可能な Substantial TP 評価の実現に向けて

Intended TP は設計時にの評価には違いないが、常に Experienced TP によって検証される性格のものであり、かつ Experienced TP は実地信頼性が高く、設計時には利用可能である。真に変形可能性に富んだ長寿命の集合住宅を実現するためには、設計時に適用可能な Substantial TP 評価を作り上げなければならない。

そのためには、本稿で述べた変形可能性の評価方法を、個々の事例の設計仕様（a. 住宅のアクセス形式および構造形式、b. 住戸の平面・断面計画や寸法・規模、c. 可動部設切切りなどの個別の設計技法の採用状況、d. 3 段階が考えられる）と積み上げの結果必見がある。

すなわち「特定の設計仕様を共有する複数の事例について、その設計仕様で第 3 案の累積変動を考察し、新たな住家の当該設計仕様の採用を根拠に Substantial TP 観察も」いう帰納的論理に基づき、研究を前進させていく方向性が考えられる。

6. 結論

変形可能性の部位別評価と変形容易性指標を掛け合わせて変形可能性プロファイルを構成する評価方法を提案し、1）提案した方法に基づき 3 事例共通に Intended-Experienced TP の一致蒸発が観察されたこと、2）100 戸年程度の累積変累年数で設計意図の実地検証が可能と考えられること、3）Substantial TP 評価が実現に向けて必要な研究の方向性を示したこと、の 3 点を結論として提示した。

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