Transformability of Skeleton-Infill Apartment Buildings in Japan (1982-2015)

A Synthetic Analysis on Their Intended and Experienced Transformations

By Vladimir Popović

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Division of Systems Engineering, Graduate School of Engineering, Mie University

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Advisor: Dr. Yoshito Tomioka

1. INTRODUCTION

The Author would like to contribute to discussion about sustainability by disseminating the transformability (ability to transform) of Skeleton-Infill apartment buildings. Transformability is, by considering time in building's design (the so called "fourth dimension") very important property of buildings for the effective use of resources. However, since the normal construction process recognizes only design-construction-exploitation sequences in life of a building, and since that implies that certain predictions have to be made early at design phase, its effective and logical control is an issue for Architect. This is because the experiences, if gathered, can be only examined afterwards, and can only influence another design, more precisely - another prediction.

1.1 Purpose and Significance of the Research

1.1.1 Purpose

Because of the above, the purpose of this research is to determine the transformability of Skeleton-Infill Apartment Buildings, built from 1982 in Japan with the intention of allowing more possibilities of transformation in order to fit better to inhabitants' needs. After more than 30 years, a considerable number of post-occupancy evaluation (POE) investigations appeared in the academia in Japan about these buildings. This research collected those materials, evaluated each building's actual transformations from the time they were built through 2015, and proposed a way to facilitate more effective transformability for this type of buildings by empowering the Architect[1] with knowledge to control transformability of Skeleton-Infill apartment buildings more effectively and logically, thus make better predictions.

1.1.2 Significance of Transformation Process for Built Environment

Human civilization is a history of using resources. The physical appearance of the planet is being constantly transformed by this process, to be in accordance to the need of civilization. This is exactly a sort of process in which some energy is spent to reshape a physical object that take up certain space and time (Fig.1-1).

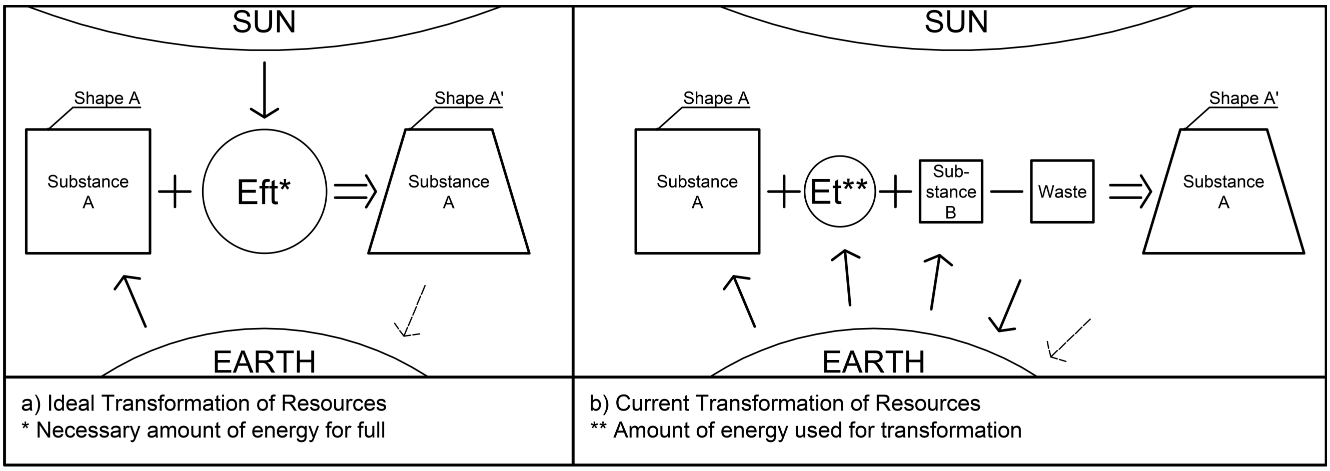


Fig.1-1 Transformation Process - Resources, and Energy

[1] Throughout the paper the word "Architect" will be used in its widest meaning - the plurality of designers.

Ideally, all the energy for transformation should come from source outside of the Earth, for example - the Sun. Then the nearly constant resources of the Earth can be transformed over and over again (Fig.1-1, a).

Upon discovering how to more efficiently release the immense power from fossil fuels, the energy became used and widely perceived as finite resource itself, and even more limited than other resources that we find in Earth's crust. This had to affect the economics of energy and by that indirectly the current transformation process (Fig.1-1, b), in such a way that, instead of spending a lot of energy to have full transformation, only a fraction of necessary energy is spent and a lot of waste is produced instead. This cannot go indefinitely because 1) the Earth's surface is limited, and 2) human life depends on a certain balance of substances in global ecosystem.

In both cases, transformations are inevitable (although, in different ways), therefore transformability of buildings remains important subject of research.

1.1.3 Different Views on Transformability - Architect, User and "Objective" Transformability

Transformability is seen differently from the viewpoint of Architect and User due to their roles in the process of transformation.

The Architect has high influence in the design phase, and the decisions that were made then have prolonged, indirect impact on the subsequent transformations. This impact may motivate architect to intentionally take certain measures to allow better transformability. In doing so, architects are prone to making predictions about the future transformation. Architect, as a trained professional and, in this case, consultant, gives his best guess about what will the future form of the object be, and adapts the technical solutions to respond to these expected events. In this work, the Architect's notion of transformability was called **INTENDED TRANSFORMABILITY.**

The User is the one that actually experience the transformation, and in most of the cases initiates it. A house exists because of and for the User so it is only natural to give the priority in consideration to User's preferences. These transformations, although certainly less often and on a lesser scale than ideal for User[2], are actually occurred transformations, so they can be precisely recorded and analyzed. Therefore, in scientific terms, they are the most reliable and realistic facts about transformability. In this work, transformability based on actually recorded and confirmed transformations was called **EXPERIENCED TRANSFORMABILITY.**

Finally, transformability as a property of all buildings is contained in the design of the building itself – in its design characteristics so it should be possible to deduce it from the design specifications (design principles, form and dimensions, partially applied design techniques, etc.), independently from the Architect's intentions or experienced transformations. In this work, this potential for transformation of a

[2] There is consideration that the best design could be the one that does not need to be transformed. However, since it is inevitable that the User occupies relatively large variety of worldviews/lifestyles and that the User changes quite significantly through life and over generations (and so does its needs) such a structure would be a Boolean union of all the settings that one is predicted to need in life, but hardly an actual building.

building itself was referred to as **SUBSTANTIAL TRANSFORMABILITY**. Substantial transformability exceeds both architect's intentions regarding transformability and experienced transformations, and in its most ideal case represents objective transformability. Ideally, the Architect should be able to fully understand the potential of a building to transform, and then exploit that, through design, to User's advantage, caring about the implications to sustainability of built environment.

Now, a valuable feedback to both Architect and User are confined in the differences that exist between these three independent views of transformability. In order to analyze the differences, a fair and reliable assessment method of the transformability itself is necessary. Formulation of this assessment method and analysis of the above described differences were the key topics of this dissertation.

1.1.4 Significance of SI Apartment Buildings for the Research on Transformability

SI apartment houses are the best available housing typology to start the research about transformability of multifamily housing, and housing at all.

First, in morphological sense Skeleton-Infill apartment buildings does not stand out particularly among the rest of the multi-family apartment buildings (except in a very few cases of daring experimental buildings), which allows the possibility to extend the findings of this work to other similar typologies. This comes from the fact that the division of Skeleton and Infill is not such uncommon in design of buildings. In Skeleton-Infill apartment houses this division was, generally speaking, only more carefully considered and emphasized.

Second, since the Skeleton-Infill division as idea attracted so much attention, the design, construction and exploitation was more closely and systematically documented. Precisely, there are three types of materials about the SI apartment buildings that were necessary for this research, as follows:

1) information about the intentions of Architect about transformability.
2) Records about the transformations that actually occurred after completion.
3) Detailed technical data about the design characteristics.

A number of SI apartment houses that were built in Japan since early 1980s[3], with high hopes for providing transformable housing, and in many cases a lot of materials on the three topics above were published and discussed in the academic society after their completion.

Because of this, an assessment which was detailed enough, and analyses that were deep enough to make useful general conclusions were possible. While this is an inductive approach *par excellence* it is at the same time a good opportunity to propose and discuss some generalizations which would otherwise remain undisclosed.

1.2 Research Agenda and Corresponding Goals

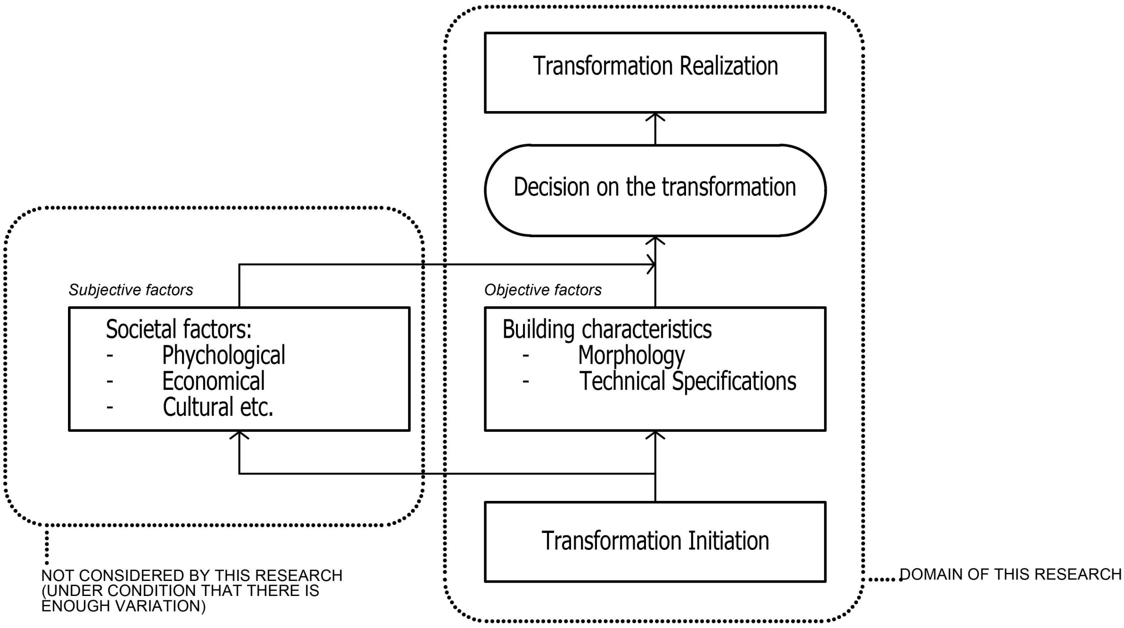
1.2.1 Research Domain

As shown in Fig. 1-1, this research was dealing with the objective factors that affect the buildings transformations. Subjective factors were considered neutral under the condition that there was enough

[3] Actually, the ideas have been developed since early 70s but the first fruits of those researches appeared in 1982.

variety in User's societal circumstances.

Fig. 1-1 Research Domain



1.2.2 Research Goals

RESEARCH GOAL No. 1 was to formulate a fair, general, intuitive, reliable and easily applicable method for the assessment of transformability. This is of crucial importance for the further disentangling of complex factors and understanding their influence to transformability.

RESEARCH GOAL No. 2 was the assessment of previous attempts of transformable design in case of the set of examples of SI apartment houses by analyzing their intended and experienced transformability.

RESEARCH GOAL No.3 was to develop a way to present the findings so that they can be useful for the designers. This was done by formulating a method for estimation of substantial transformability from the design specifications of buildings and to by testing several hypotheses about the general characteristics of transformability of SI apartment buildings.

1.3 Research Method and Basic Construction of the Discussion

The base for the research is the transformability evaluation analysis tools developed by the author – Degree of Freedom of Transformation Index (further: DFT Index) and Transformability Profile (TP). DFT is user-centered scale of transformation readiness and TP is DFT applied to certain building parts. These constitute the base for evaluation of overall transformability of buildings and their comparison.

Given that there are at least three independent viewpoints for assessment of transformability – *intended, experienced, and substantial,* DFT and TP of those can also have different values which were utilized to make comparative analyses of different DFT/TP in case of a single apartment examples, as well as among the different examples.

An inductive approach was used for testing the raised hypothesis. The analyzed examples cover wide variety of the SI apartment buildings' typology, however, the Example Set cannot be considered fully representative.

Basic Construction of the discussion is shown in Fig.1-2.

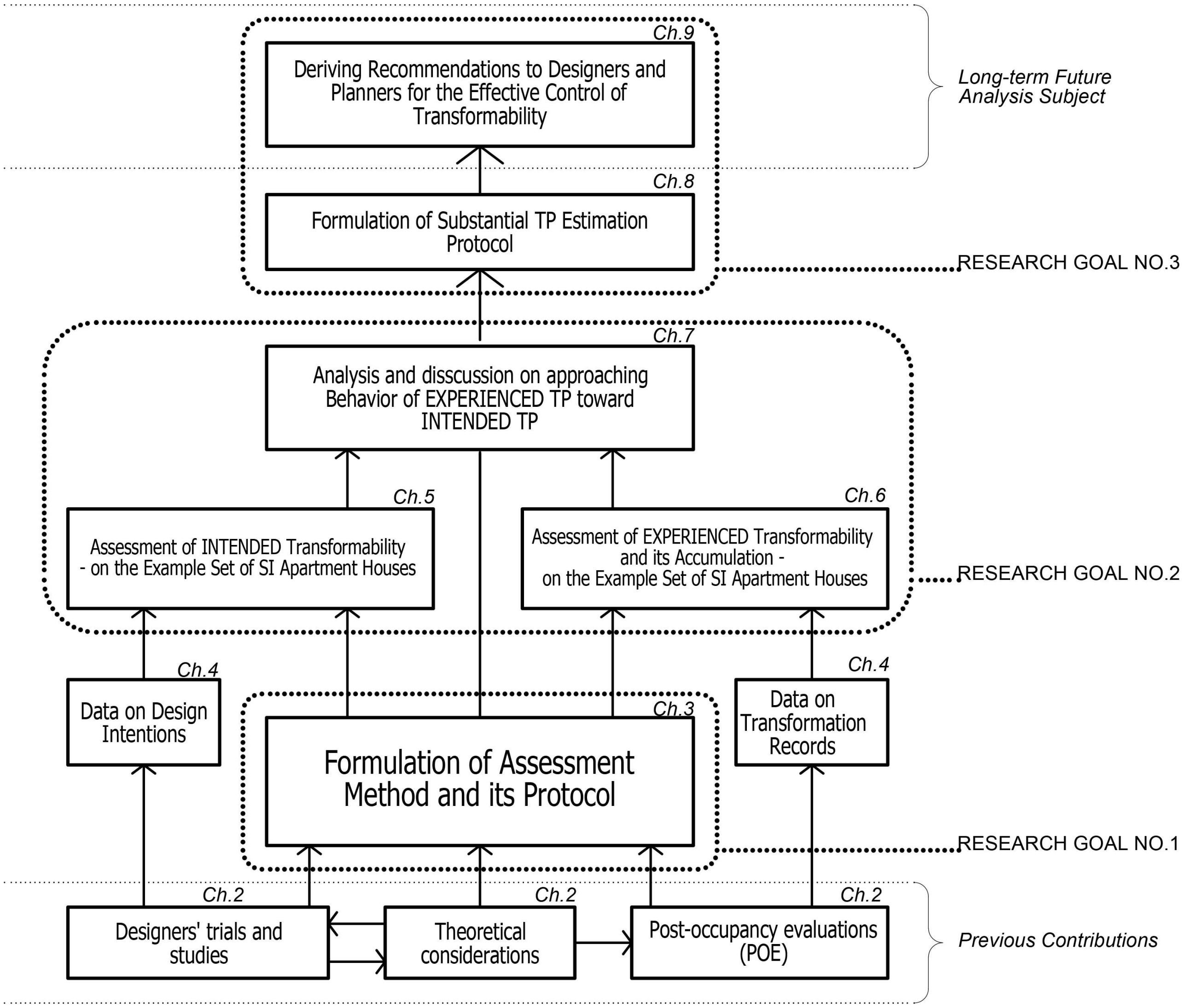


Fig.1-2 Basic Construction of the Discussion

In Chapter 2, divided in three parts (previous contributions on the transformable design, theoretical considerations of transformability, and post-occupancy evaluations related to transformability) were served as the base for developing the author's original assessment method and as a source of materials for analysis.

In Chapter 3, the core theory behind the proposed transformability assessment method, and tools for the analysis - DFT and TP were explained in detail. The chapter content directly corresponds to RESEARCH GOAL No. 1.

In Chapter 4, the outline of the Example Set was presented. The content consists of basic information on 16 selected examples of SI apartment buildings and their placement among this type.

In Chapter 5, Intended TP analysis was performed based on the assessment method proposed in Ch. 3.

Intentions regarding 13 out of 16 examples were evaluated, according to verbal statements and design materials provided by their Architect and their Intended TPs (INT TP) were derived.

In Chapter 6, Experienced TP (EXP TP) analysis was performed on 12 out of 16 examples. EXP TPs were derived for the examples which contained enough information on transformation records. For the examples that did not have enough information only the basic information about the actual transformation surveys were given.

In Chapter 7, using the results from Ch. 5 and Ch. 6, the approaching behavior was observed for the trend of EXP TPs toward INT TPs over time, for the examples that provide enough details about transformation over time. In order to overcome differences in investigative research materials the conversion of accumulated experience period was introduced. Chapters 5, 6 and 7 corresponds to RESEARCH GOAL No. 2.

In Chapter 8, idealistic Substantial TP (SUB TP) estimation procedure was discussed using the logical implications from the comparison of INT TPs and EXP TPs. SUB TP Estimation Chart was formulated and used to determine partial SUB TPs of several important design characteristics. Two hypotheses were tested in order to reveal general characteristics of substantial transformability. This chapter corresponds to RESEARCH GOAL No. 3.

In Chapter 9, as a summary, general and specific conclusions about the transformability of SI apartment buildings were given, and prospects for further work on applying SUB TP to design and assessment of enriched set of examples was discussed.

1.4 Terminology

The term “transformability” is carefully chosen although this field of research knows many other terms that are describing the similar property. Considering the research domain (1.2.1), “transformability” is the most appropriate since it is directly related to the morphology of the building and its physical appearance, and does not contain any notion of subjective factors for transformation. The other terms that can be found widely in literature are “flexibility”, and “adaptability”. Also, “changeability”, “responsive architecture”, “adjustable architecture” can be found, although rarely.

Transformability is also used for the real-time mechanically transforming structures such as tensegrity structures so one should be still careful not to confuse it with this usage. These structures are, although non-static, still just a niche category of all the structures, and because this research treats any structure as transformable this meaning of “transformability” should be considered as wider.

In addition to this, a list of specific technical terms introduced and used in this thesis in English and Japanese, as well as their abbreviations and definitions, are shown in Table 1-1.

Table 1-1 Technical Terms Used in This Thesis

Technical Term			Definition
English	Japanese	Abbr.	
Transformation	変形	/	A physical change on any aspect of the building.
Transformability	変形可能性	/	The ability of building to transform.
Intended _	意図された__	INT _	Transformability based on predictions of the Architect at the design phase (before completion).
Experienced _	経験された__	EXP _	Transformability based on transformations that actually occurred in reality (after completion).
Substantial _	潜在的__	SUB _	Potential transformability of the building itself based solely on its design specifications.
Transformability Profile	変形可変性プロファイル	TP	The representation of the overall characteristics of transformability for the total building.
Degree of Freedom of Transformation	変形容易性	DFT	The freedom of User to realize transformation expressed through degrees of involvement of parties other than User and means that are outside of User's control.
Degree of Freedom of Transformation Index	変形容易性指標	DFT Index	The Index of DFT expressed through 9 values from 1 to 9 which correspond to appropriate indicator (party and means involved in the process of transformation).
Accumulated Experience Period [unit-year]	累積経験機関［戸年]	/	Total period of experiencing transformations converted through multiplying number of surveyed units and number of years through which the survey was performed.
Transformation Timespan [unit-years]	変形周期［戸年]	/	Period past between two transformations (or before the first transformation after completion) of the same building among the apartment units of the same type.

2. REVIEW OF PREVIOUS RESEARCH ON TRANSFORMABILITY

This chapter deals with the history of development of transformable design in architecture through three aspects: realized and unrealized architectural works (2.1), post-occupancy evaluations on realized works (2.2), and theoretical considerations about and related to transformability (2.3).

2.1 Development of Transformable Design through Architectural Works

In the history of human settlements there is a general trend: from most of the people who can build their own house, to highly specialized minorities which can together build a house. Let us just start with the cave – anyone could find one, and then anyone could transform it by excavating. Then, most of the people could use raw materials scattered all around to construct a simple shelter. Be it wood or soil, ice or stone, the structural logic was simplistic and intuitive (i.e. simple beam, architrave system), and construction technologies and techniques were simple enough that anyone could contribute (soil/straw mixture, drying in the sun). The more sophisticated the house, the more specialized are the works necessary to complete it, so the trades appeared. The same system worked for transformations. If not possible by user himself, highly commoditized services like masonry works could be easily acquired and the transformation would still be under User's control.

Somewhere on the way the Architect as someone who articulate the needs of the User started mediating between Users and tradesmen. In single-family housing this has relatively short history. In case of current global civilization that originated in Europe this started happening in the 20th century. Before that, architects dealt exclusively with the public buildings and housing for the rich, emancipated minority, while overwhelming majority continued to rely on their work power and tradesmen of low level of specialization. However, with the intense urbanization which became possible upon developing good enough technology to utilize immense power concealed in fossil fuels the architects showed interest for dealing with the problem of general housing. This has profound impact to transformability as now two parties had interest for it, the interest not necessarily be the same. In this chapter the issue and its implications will be covered in more detail.

2.1.1 Pre-Industrial Vernacular Housing

Pre-industrial and vernacular housing can be seen as the general housing architecture before the Architect took their role in the construction process. The form was a consequence of formal system established through plans of higher order, such as space plans and general urbanistic plans, and through certain building codes as well as local construction rules and even traditional unwritten rules.

Formal systems allowed forming of various shapes of same form, through manipulation of the established elements. This is very important for theoretical considerations of transformability. Humans have certain needs for housing which are changing through the life and are met with a range of different volumes. If a form is made capable of taking the subsequent transformations and shapes but keeping the continuity to the original form and identity, that makes an important precondition for high transformability.

Most of the construction technologies and techniques applied in this period were available to anyone to apply with a very simple learning curve. The level of specialization was low, so that one veteran could instruct dwellers/villagers how to carry out the time-consuming construction works[1]. Bringing rocks, molding adobe bricks, thatching roof, mixing plaster are some of the examples. Simplistic and intuitive structural systems secured that common people could completely understand how the forces are distributed through the building, what can be modified, what has to be supported in that case etc. secured that there were no experts needed to give advices, so that the user had full control of building transformations.

2.1.2 Industrial Mass Housing

This vernacular system first diverged into a great number of types and typologies, expressing cultural, regional, local, environmental, and other such specifics. Globalization process does the opposite – the types and typologies are slowly converging. Construction technologies and techniques are a matter of various highly specialized professionals from engineers to tradesmen. Structural systems are not necessarily intuitive to users (truss, continuous beam, frame systems, etc.) This especially affects transformability, more specifically, the user's discretion, comfort and privacy in the process which became much more complex over the time. It can be said that the architect took major role in deciding the design and even determining the future transformations.

After industrial revolution finally came to level of general housing, different principles were applied to design it. First, the economy of scale and mass production provided cheaper materials. To maintain the rationality of production certain standardizations were done. Modules based on anthropometrics were introduced. Then, the reasoning that sharing will reduce cost was overwhelming. Two non-connected houses have four walls each, two connected houses have one wall less, and the more houses is connected the more reduced the material consumption is. Also, the uniform span meant great reduction in production and assembly time, and the general housing started getting new form - multi-family housing. The users who indeed have some universal needs but also some very specific, were averaged, and the optimization was done for the model of average/standard family, not for each of the users independently. The typical examples would be Le Corbusier's *Unite d'Habitation* (Fig. 2-1) and *La Ville Radieuse*. The Architect proposed solution which treats the multi-family building with the same care as it was public or extended housing program. Studies on proportions, rhythm, detailing, and such create non-material barrier for transformation. At the same time Le Corbusier was one of the first to consider the problem of variety of apartment units which were built in a massive numbers. Le Corbusier, as well as some other architects, had been actively proposing their solutions, mostly technical ones. For instance, there were sliding doors between two children rooms that can be moved to expand the daily living space (Fig. 2-1c).

[1] Depending on the culture, level of development of society and economy, and the dominant building material the level of specialization could vary greatly. However, for the sake of the argument the notion that common people were normally fully involved with building their own house even if not being trained professionals is stressed.

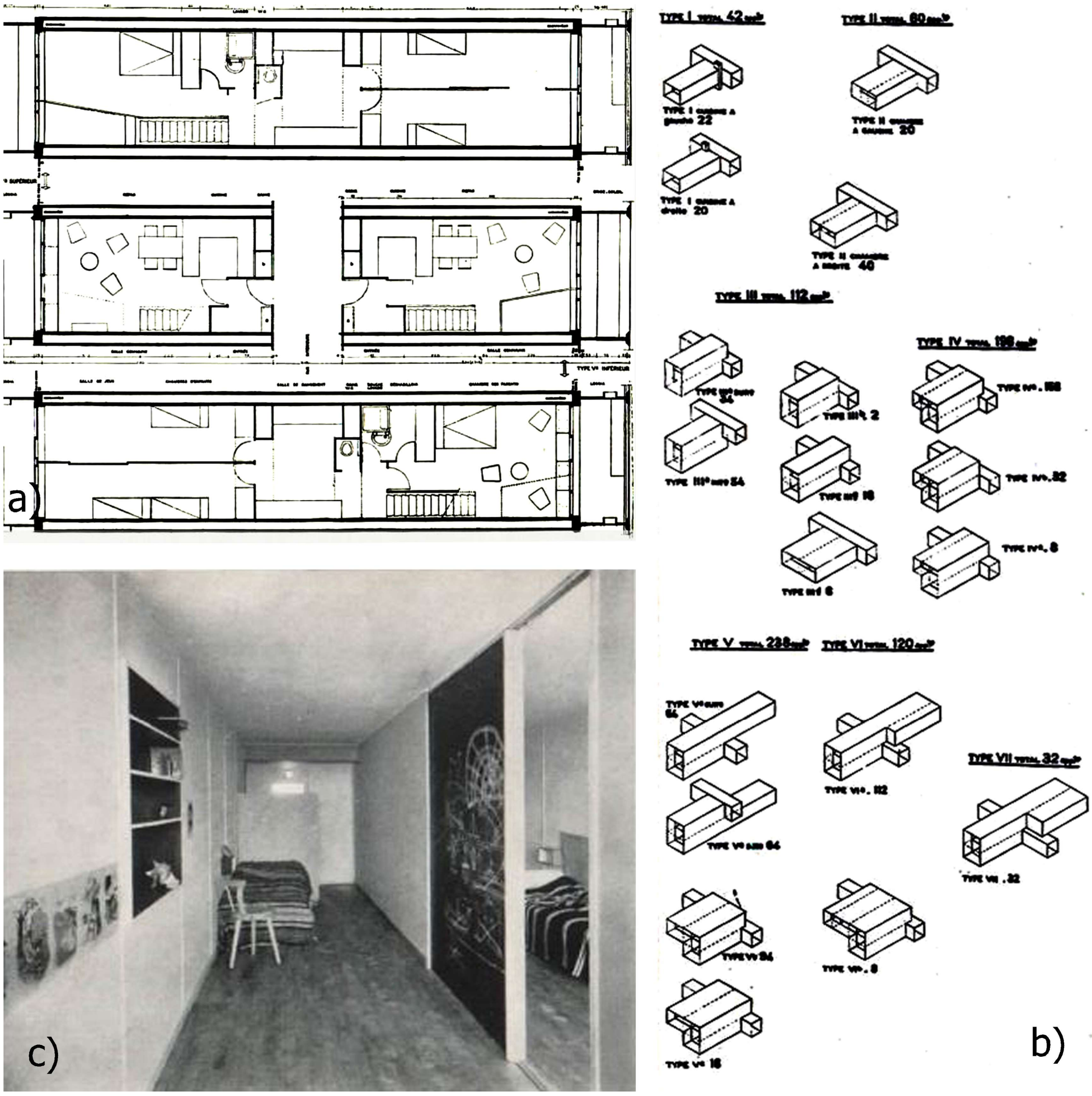


Fig. 2-1 Unite d'Habitation a) Typical plan of apartment unit; b) Unit types combinations with basic elements; c) movable partition in children room

Also, the apartments were composed of boxes (Fig. 2-1, b) of different functions which correspond to structural bays and partitions, so re-composition of the apartments was envisioned by the Architect. However, one must notice that the structural system, masses on a façade, installation shafts and other elements create stiff frame for transformation not only in terms of the whole building but also in terms of individual apartments alone.

2.1.3 Metabolists' Ideals

During 60s and 70s there were two groups of architects who were actively proposing solutions to this problem. In Britain there was Archigram group, and in Japan - Metabolists. Their avant-garde radical proposals were to make the User more mobile and the city organically evolving through replacements and relocation of modular dwelling units (pods). So, once the space does not fulfil the needs anymore, user should flee and acquire new, better one. The society should provide massive infrastructure on which the pods of all kinds could be attached/detached and supplied (Fig. 2-2).

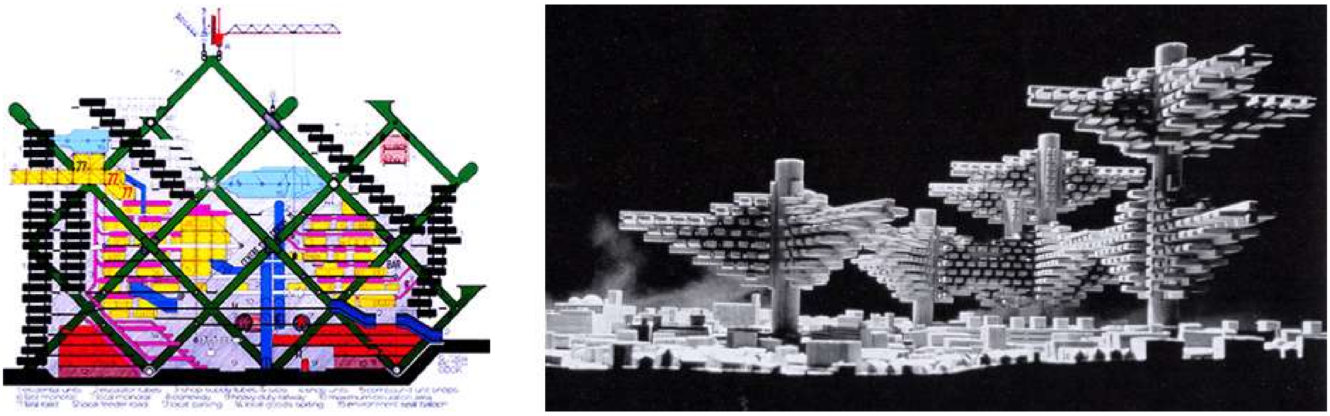


Fig. 2-2 1960s Avant-garde movements: Archigram's Plug-in City (left); Isozaki's Clusters in the Air (right)

The only actually built structure of such concept is Kisho Kurokawa's Nakagin Capsule Tower (Fig 2-3). It is important to notice here that the housing got the role of consumer goods, while the main structure is the extension of classic infrastructure. Kurokawa envisioned towers to be in place for 60 years, and that the capsules will be replaced every 10-15 years comparing their price with luxury passenger car. However, none of the replacements actually happened for more than 40 years, and the building is about to be destroyed and replaced with new[2]. This is where author for the first time noticed the huge mismatch between the Architect's intentions and experienced transformation.

Fig. 2-3 1972 Kisho Kurokawa – Nakagin Capsule Tower a) Exterior; b) Capsules; c) Interior

2.1.4 Democratization of Mass Housing

After the initial phase of fast urbanization and after the shortcomings of standardization of building elements and uniformity became obvious, architects started thinking again about the users as individuals who might not be ready to blend in into average size. This customization of a dwelling unit can take various forms, and in some of them the Architect and the User are directly connected and cooperate.

One of the most famous examples of this cooperation is Frans van der Werf's Molenvliet housing complex in Netherlands, where the Users were involved into the design process with the demarcation line between the two parties at load bearing structure. Aside from permanent structural grid and modularly coordinated

[2] Ref 2-1

façade system, user could negotiate the initial floor plan, and choose some façade elements from the provided catalog to form unique façade (Fig. 2-4).

Fig. 2-4 SAR - Molenvliet – common elements and individual elements co-existing

2.1.5-SI Housing Development in Japan

The trend mentioned in the previous sub-chapter had been especially pursued in Japan. It did not become mainstream for multi-family apartment buildings, but it had attracted significant resources for development and experimenting with various types of multi-family dwelling based on Skeleton/Infill paradigm. There were three main streams for this development:

-Tokyo group around Prof. Uchida who was the main figure in Kodan Experimental Project (KEP). KEP was characteristic for its distinction of housing components based on their durability, and for its modular coordination. The housing system, meant to involve various design and manufacturing companies to design infill, came with a catalog of the components.

-Kyoto group around Prof. Tatsumi who, together with prof. Takada, took a softer approach by developing the Two Step Housing System (TSHS), which considered the deep involvement of the user into the design process, and generally less technical but abstract approach to building compositions in comparison to prof. Uchida's group.

-Public sector - Japanese government through Ministry of Land, Infrastructure, Transport and Tourism and Ministry of Construction, public housing supply companies and research institutes (most notably, Japanese Housing and Urban Corporation).

As a result, many system buildings, guidelines, rule books related to transformable housing were proposed (GOD, KEP, CHS, TSHS, House Japan, Better Living, KSI, Tsukuba method…).

The three streams were gradually converging toward each other, and with the help of private sector investment all these development and experimentation culminated in a world famous project NEXT21, that has been regarded as the state-of-the-art when it comes to synthesis of the eco-friendly technologies, including special considerations about transformability [3].

[3] Ref. 2-2

The three most influential among the mentioned building systems - KEP, CHS and TSHS - were developed during 70s, and were actualized in 80s through several large scale housing complexes, mostly in Tokyo and Osaka. These buildings constitute the main body of the examples covered later in the analyses. The rest of the examples were mostly developed through 90s using the same or slightly advanced concepts, but more sophisticated technologies (frame structural systems, larger spans, etc.)

2.2 Post-Occupancy Evaluations of Transformability

Parallel to many experimental projects and SI housing development there was a lot of interest in the confirming many assumptions that were made about these designs and planning. Naturally, some amount of time had to pass for the results could be observed, so these researches started appearing in the middle of the 90s, and the most extensive and coordinated efforts were made around year 2000, when KEP, CHS and TSHS projects reached around 15 years after completion. These surveys and analyses were mostly done by a new generation of scholars from Tokyo U and Kyoto U, mostly students of prof. Uchida and prof. Tatsumi. Among them: Tomoko Sawada (Toyogaoka, Hikarigaoka, Green Village Utsugidai), Kazunobu Minami, (three housing complexes of Tsurumaki-3), Mitsuo Takada (Flex Court Yoshida), Seiichi Fukao, Kozo Kadowaki (Green Maison Tsurumaki), Hiroyuki Takai (CHS – CI Heights Machida), Hideki Kobayashi (single-family housing), and others.

Presently, most of these buildings are 25-30 years after completion, and all of the examples analyzed in this paper at least 15 years after completion, so it is a good time to collect all of these individual surveys, conduct meta-analysis and try to draw some general conclusions, as well as discuss how to improve the POE in the future.

Most of the surveys used the questionnaire, some of them conducted interviews with residents, and some even made a visual inspection inside of apartments, and made some photo-documentation at that occasion. The percent of responses from interviewees greatly differed depending on which of these methods were used due to sensitivity of the private information, so there is more generalized data published and much less of detailed information about individual transformations available. For example, a summary of number of apartment units that had experienced transformations such as addition or reduction of number of rooms, maintenance jobs that were performed such as replacement/renewal or installation of the equipment etc. The researchers were interested in demographic and societal factors as well as specific technical solutions that might be reasons behind certain patterns of transformations.

The most detailed research was performed by Kazunobu Minami et al. He continued the survey on transformations of Estate Tsurumaki-3 [ETM] housing complex that was started by Hatsumi Manabu in 1995, and surveyed the same housing complex two more times, in 2006 and 2014. The survey recorded the actual transformations by visual confirmations and through interviews with residents. Upon that for several apartments of the same type, multiple layout conditions were reconstructed, and analyzed.

2.3 Theoretical Considerations of Transformability

2.3.1 Support/Infill and the Theory of Levels

In early 60s Prof. John Habraken proposed the concept of Support & Infill[4] which had a profound impact to research on transformability. It was for the first time that the conceptual division of a building to shared part and individual part was academically elaborated. Although Habraken carefully emphasized the social, and refused to precisely define the technical context of this division, in subsequent development the Support was often interpreted as "skeleton".

Later in 80s, but to all accounts independently, Francis Duffy was thinking of architecture "as a several layers of longevity of built components"[5]. He formulated his 4S (Shell, Services, Scenery, and Set) which were later expanded in 1994 by Steward Brand to 6S (Site, Structure, Skin, Services, Space Plan, and Stuff) or, as it is better known, "Shearing Layers of Change"[6]. The idea was that each of these layers has different "pace of change" which was supported by rich anecdotal evidence but has not undergone the academic scrutiny yet.

2.3.2 Transformability Assessment and its Models

Transformability of buildings holds inherent notion of efficiency, and it is the principal reason why it has been researched. Because of that there is strong need to compare different design approaches and determine which are more efficient than the others (partially, or in whole), and maximize the use of the better. In order to compare there is need to measure, or at least classify.

In this part of the review, the most significant contributions to the theory of assessment of transformability will be covered.

In 2000, Kadowaki et al. used the experts' evaluations on 30 SI housing examples and multiple regression analysis to assign a weight to the dependency among characteristic items of skeleton, and then composed two indexes representing the skeleton capacity (SC), one of 9, and the other of 5 of these items (M9 and M5 in Fig. 2-5).

Using these indexes and the correlation factors, Skeleton Capacity was expressed as a single numerical value through two formulas[7].

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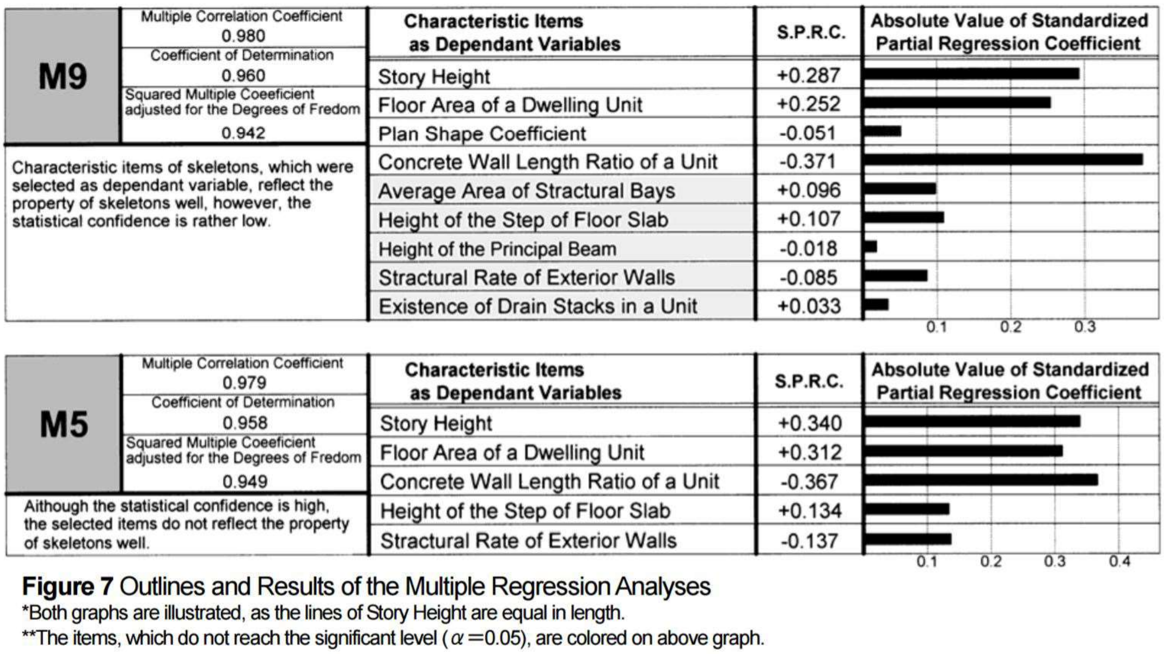
[4] Ref. 2-3

[5] Ref. 2-4

[6] Ref. 2-5

[7] Ref. 2-7



M9	Characteristic Items as Dependant Variables	S.P.R.C.
Multiple Correlation Coefficient 0.980	Story Height	+0.287
Coefficient of Determination 0.960	Floor Area of a Dwelling Unit	+0.252
Squared Multiple Coeeficient adjusted for the Degrees of Fredom 0.942	Plan Shape Coefficient	-0.051
Characteristic items of skeletons, which were selected as dependant variable, reflect the property of skeletons well, however, the statistical confidence is rather low.	Concrete Wall Length Ratio of a Unit	-0.371
	Average Area of Stractural Bays	+0.096
	Height of the Step of Floor Slab	+0.107
	Height of the Principal Beam	-0.018
	Stractural Rate of Exterior Walls	-0.085
	Existence of Drain Stacks in a Unit	+0.033

M5	Characteristic Items as Dependant Variables	S.P.R.C.
Multiple Correlation Coefficient 0.979	Story Height	+0.340
Coefficient of Determination 0.958	Floor Area of a Dwelling Unit	+0.312
Squared Multiple Coeeficient adjusted for the Degrees of Fredom 0.949	Concrete Wall Length Ratio of a Unit	-0.367
Aithough the statistical confidence is high, the selected items do not reflect the property of skeletons well.	Height of the Step of Floor Slab	+0.134
	Stractural Rate of Exterior Walls	-0.137

Figure 7 Outlines and Results of the Multiple Regression Analyses
*Both graphs are illustrated, as the lines of Story Height are equal in length.
**The items, which do not reach the significant level (α =0.05), are colored on above graph.

Fig. 2-5 Kadowaki's M9 and M5 indexes as they appear in Ref 2-7 (p.139)

In 2006, Durmišević published a dissertation that was dealing with the similar approach. She argued that "disassembly potential of building structure is indicator of Transformation Capacity (TC)", and developed a model for calculating TC. The model is based on fuzzy logic input (linguistic variable) of 17 independent, and 14 dependent variables which are hierarchically ordered in four "levels of dependencies" and then into a knowledge model by assigning the weight to each node[8]. The output can be either radar graph showing the overall character of TC, or expressed through single numerical value. In Fig. 2-6, as an example, the results of calculations for flexible wall system (SMR) and traditional block wall. In the left, the value of TC was expressed through single numerical value, and on the right, in radar graph showing the TC aspects.

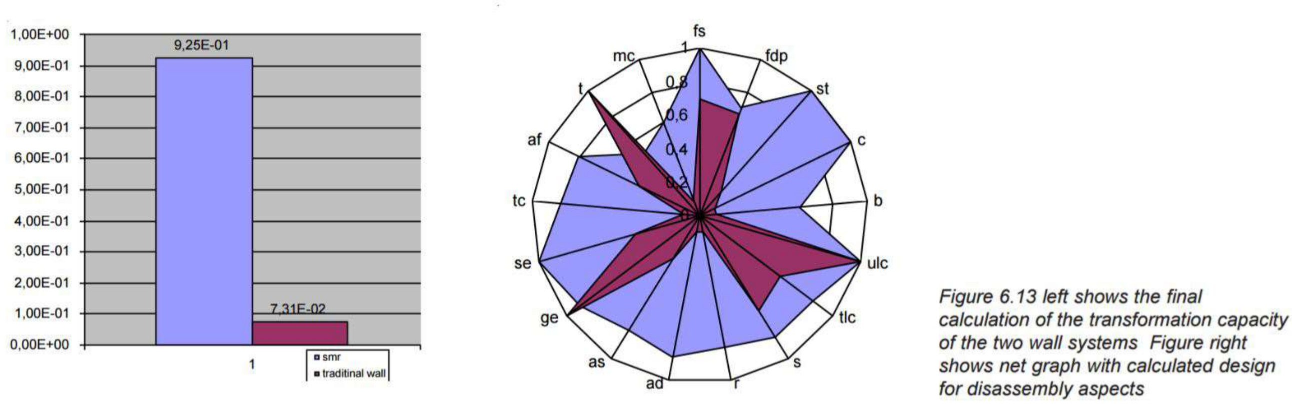


Fig. 2-6 Transformation Capacity – numerical value, and radar graph as appeared in Durmišević's dissertation (Ref. 2-8, p.238)

8 Ref 2-7

In 2007, Schneider and Till researched about various approaches toward transformability, and classified them in two groups – Soft and Hard Flexibility - stressing the choice of the Architect to determine the subsequent transformations weakly or strongly. They gathered a formidable database of different designs, realized or not, and suggest a simple manual for designing transformable houses (they consistently use the word flexibility). They distinguish pre- and post-occupation transformability and design strategies that support one or the other or both. Also, they roughly estimate the 5 degree-scale of "potential cost", three degrees of "cost benefit" and three degrees of "priority", and assign them to each of the design strategies. Further, Schneider and Till are suggesting a series of questions which the Architect can ask himself about the various aspects of design (Use, Plan, Construction, Services). However, they admit that the best way to evaluate flexibility of building would be to see if it actually „worked" in reality and reports on an insufficient POE data to investigate that. [9]

For all three above described assessment methods, two common characteristics were shared, as follows:

a) The evaluation depends on the weights which were given to each of the selected component.

b) There is no feedback from the actual experience of transformation as a base for the evaluations or as a correction factor.

The objectivity of the methods is therefore hindered by two subjective procedures: through selection of relevant components, and through applying the weight coefficients (even if the statistical operations were used to reduce these effects in case of TC and SC).

[9] Ref. 2-6

2.4 References

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2-8) Elma Durmišević. *"Transformable Building Structures: Design for Disassembly as a Way to Introduce Sustainable Engineering to Building Design and Construction".* Disseratation. Delft U. 2006. http://www.4darchitects.nl/download/Transformable_building_structures.pdf. 01. Dec. 2016.

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Fig. 2-1) W. Boesiger. Le Corbusier. 6th ed. 5 vols Zurich: Artemis, 1970. a) p.106, b) p.107, c) p.110.

Fig. 2-2, left) Piter Cook. Plug-in City. www.archigram.net. Web. 30 Jan. 2017.

Fig. 2-2, right) Arata Isozaki. Clusters in the Air. Web. 30 Jan. 2017.

Fig. 2-3) Kisho Kurokawa. www.kisho.co.jp. N.d. Ginza, Tokyo. Web. 30 Jan. 2017.

Fig. 2-4, left) Kazunobu Minami. Molenvliet - external view. 2001. Papendrecht, Netherlands. http://news-sv.aij.or.jp/keikakusub/s13/molenvliet01.html. Web. 30 Jan. 2017.

Fig. 2-4, right) John Carp. N.d. Papandrecht, Netherlands. Residential Open Buildings. By Stephen Kendall and Jonatan Teicher. London and New York: E & FN Spon, 2000. 83. Print.

Fig. 2-5) Fig.7 in Ref 2-7, p.238.

Fig. 2-6) Fig.6.13 in Ref 2-8, p.139.

3. TRANSFORMABILITY ASSESSMENT METHOD

In this chapter, transformability assessment method was proposed and explained. The method was developed by the author and it is the core of this dissertation.

First, three main problems of evaluation of transformability -- *complexity, objectivity and representation*—which emerged from the previous efforts in this field as mentioned in Chapter 2, were discussed (3.1).

Then, a solutions applied to it, proposed method and tools for analysis – Building Parts, Degree of Freedom of Transformation Index, and Transformability Profile – were thoroughly explained (3.2).

Finally, as a summary of the chapter, logic of the analyses implied by usage of this method was outlined (3.3).

3.1 Discussion Agenda for Improved Transformability

Three main problems of assessment of transformability were identified as follows:

1) Complexity

When one is evaluating a complex system (especially the one where social matters have a role) on any matter, a question is usually raised about what parts of system (subsystem) are more "important" than the other, and the appropriate weight is assigned accordingly. This research takes different approach. Buildings are such complex systems of many subsystems which also can be organized in few levels affecting each other in numerous ways, however, a weight is not necessary to be assigned in the evaluation, rather the quality of the relations between the parts needs to be explained. Then weight can be assigned by designer in response to any specific objective of any project. For instance, Architect, as a system engineer, could control complex systems more effectively according to the needs of the specific project while understanding the implications. To gain such knowledge, these systems have to be first disentangled in a meaningful way, so that each subsystem can be analyzed and transformability of the building can be represented as an overview (not as an algebraic sum) of transformability of its subsystems. A list of subsystems, however divided, should represent totality of building system, and should be sensitive to the question "WHAT transforms?". In this work those will be referred to as BUILDING PARTS. This very research will be dealing with multifamily apartment houses, so the building parts will be identified accordingly. However, the principle is universal and can be applied to different building properties with certain adjustments.

2) Objectivity

As we could see in the historical overview (2.3.2) there have been indeed quite different methods of assessment: from strictly technical (DfD), numerical (Skeleton Capacity) to very abstract ("soft" and "hard" flexibility), each of which each of which relied on some sort of assigning weight to a certain aspects of transformability. The universal process that applies to any transformation has to be identified. This is a key for systematical approach and objectivity. The important simplification that is done in this research is asking "HOW EASILY something transforms?" As a result, a more nuanced approach can be formalized, an approach which takes both societal and technical aspects in consideration at all times. Another simplification is rather self-imposing and takes the user of the object as the central figure of the process of transformation.

Ideally, the building should transform directly in accordance to user's actions without any delay, cost or help from the outside. According to this, Degree of Freedom of Transformation Index Determination Protocol (DFTIDP) is made. It has to be mentioned that not all of subjectivity is eliminated from the evaluation (perhaps it cannot be), but that the subjectivity is added at the end of the objective procedure, not built into it, so it can be easily revised upon obtaining new or more precise data.

3) Representation

Transformability of a building contains complex information since there are many parts that can transform independently, and in different manner. Because of this, a single synthetic value is not informative enough, and the graphical representation was applied. WHAT and the HOW EASILY are synthesized into comprehensive representation of overall transformability of any building – Transformability Profile (TP). As such, it becomes a tool for analyses of independent buildings and comparisons among the buildings.

3.2 WHAT is To Be Transformed - Building Parts (BP)

What parts of building are to be transformed?

This has been discussed in the past 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 (Fig.3-1, left). Brand's Layers were too abstract to be used for an actual analysis so they are carefully simplified to Building Parts (BP) shown on the rights side of Fig. 3-1. Building Parts can correspond to standard architectural materials (drawings such as plan, elevation, details, etc.) but were still too broad for a "WHAT transforms" question. Therefore, Building Parts parameters as the main parts/subsystems of each Building Part.

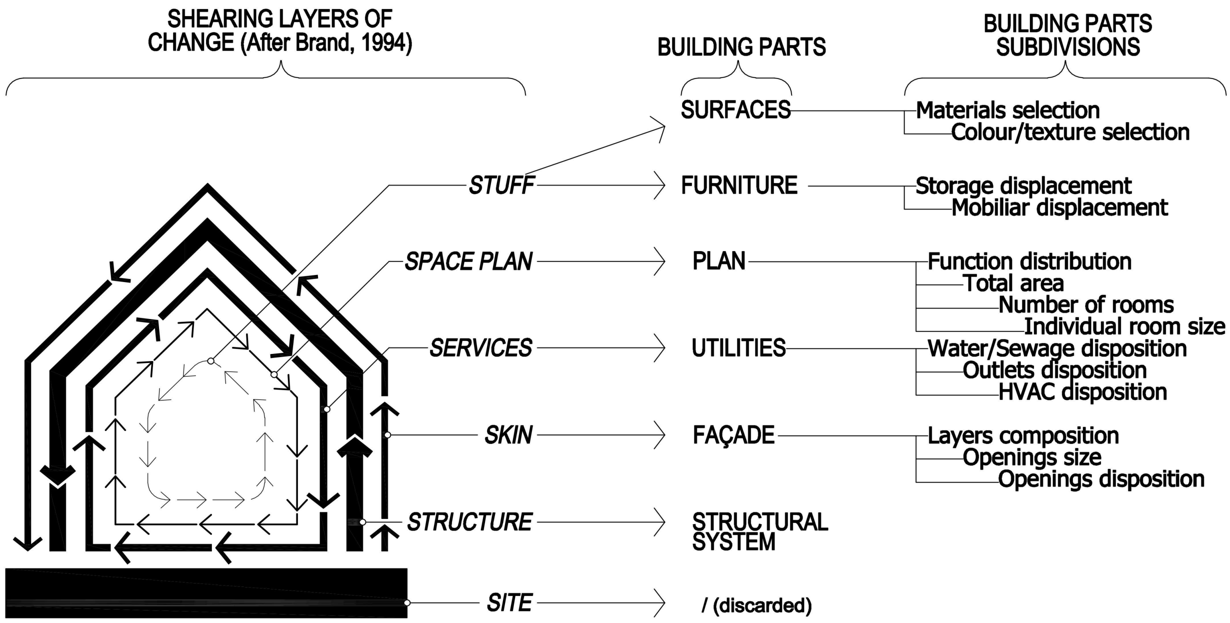


Fig.3-1 Shearing Layers of Change and Building Parts (After Brand, 1994[1])

[1] Based on Figure *Shearing Layers of Change* on P.12 in Ref. 3-1

<SITE> is discarded as it is almost never transformed.

<STRUCTURE> is simplified to <STRUCTURAL SYSTEM>. Only such transformations that affect the number of structural members or its disposition relative to each other are of interest of this research. For instance, opening a door or window in a bearing wall is not considered a transformation of structural system as the forces continue to be transferred through the building in principally the same way as before intervention. Addition of another floor or row of columns, would be an example of transformation of structural system.

Abstract <SKIN> is reduced to <FAÇADE> which is possible to describe with elevation drawings and façade details or just wall composite. For the purpose of this inquiry, composition of the outer wall layers, size of the openings and its disposition are parameters which transformation is observed. User can hope for a wall that has better insulation properties, more or less light, more or less privacy, and such, in which cases the problem is typically solved with larger or smaller openings, addition of another layer in the wall composite, or by displacing the opening or opening new one. Minor transformations such as replacement of windows are considered maintenance and not transformation.

Broad <SERVICES> are reduced to those <UTILITIES> systems that has profound impact to the other systems in a building. For instance, internet network is a service, however the underlying technology is such that it is of no interest for architects. Being wireless or cable technology, it is always possible to be installed by user himself. On the other hand, there are utilities that require significant space or specific position, which has to be carefully implemented in the design which is often done by a whole team of experts competing for the same space. Also, these systems have quite different requirements among themselves. HVAC installations and water/sewage installations are both the matter of fluid movement mechanical engineering, however, the movement of air and liquid require quite different design (ducts vs. water-tight pipes, ceiling vs. floor placement, curving rules, etc.) Thus, **<Water/ sewage disposition>**, **<Heating/ventilation/air condition (HVAC) disposition>**, and **<Outlets disposition>** were adopted as they have the most distinct and the most profound impact on the overall architectural design. Again, not its replacement but its displacement was taken as a threshold for transformation.

Abstract <SPACE PLAN> is reduced to just <PLAN> since the vast majority of housing, and especially multifamily housing is limited to one level floor plan with uniform floor height. <PLAN> is defined by parameters such as **<Total area>**, **<Function distribution>**, **<Number of rooms>**, and **<individual room size>** which transformations can be recorded reliably. Here, it is important to clearly distinguish the layout from the plan, as the former includes the equipment and furniture, and the later includes only physical boundary, subdivisions, and general purpose of the area.

Most ambiguous <STUFF> is separated in two Building Parts – <FURNITURE> and <SURFACES>. Furniture is again described to most often movable furniture **<Mobiliar displacement>** and most often stationary **<Storage displacement>**. While it is tempting to consider furniture as straightaway "always easily transformable" there are some designs that include specially designed furniture which is by that entangled in other aspects of design in a way that it is a realistic obstacle to transformation. Similarly, built-in storage, standalone storage or specially designed movable storage has all different implications to transformability.

<SURFACES> cover the transformations that cannot be described by simple displacement of the elements.

A large part of maintenance works belongs to this category. Changing tiles, water faucets, flooring <**Texture selection**> or a simple painting of walls into a new color **<Color selection>**, while generally easily done, can be impacted by the finishing construction technique or choice of material decided by architect. Thus

By analyzing transformations of this 6 Building Parts and its 14 parameters it is considered that the transformation of the building in its entirety can be described.

Needless to say, there could be other parameters included, or the third level of detailed analysis could be introduced, but it should be always kept at the same level. The depth of the BP parameters is also influenced by an effort of making the transformability of the entire building easily comprehensive at the first sight. Increased number of parameters would compromise this objective.

3.3 HOW EASY the Transformation Is – Degree of Freedom of Transformation (DFT) Index

How easily the transformation can be realized from the perspective of the User?

This is very important question for more efficient realization of intended transformations, but it has been rarely discussed systematically, on a level of the whole apartment or building. It can be evaluated from psychological, economical, and/or other aspects, however, those are not always suitable in design phase when the assumptions are made. In other words, there can be no instant feedback and the designer has to make assumptions.

To overcome this there has to be systematic thinking about the transformation as a process that has to have certain logical steps in order to be finished. It is observed by the Author that the involvement of certain parties in the transformation process is a good enough indication of transformation easiness. From the viewpoint of User, the transformation is ideally performed without any delay, any cost or help from other people, at any moment in time, without any initiation. On the other end of the possibilities spectrum there are transformations that require time, resources, professional help, consulting, and various permissions, agreements from neighbors or the official authorities. Between the two there is a gradation of situations as various combinations of all this factors. However, it has to be noticed that the cost of material is always lower than the cost of material + installment service. Similarly, the time to perform a transformation increases significantly with the involvement of professionals in the process, along with the cost. Further, the decision making becomes more complex if more than one person is included, with the complexity rising with the number of consultants.

It is not to be underestimated that the quality of the decision is generally better when the adequate experts are consulted, but the decision itself becomes less likely to be adopted if such consultancy is necessary. This was partially recognized by designers who were providing movable partitions for the apartments or interfaces for transformation that were not requiring third party involvement, but it needs to be recognized widely as an inherent problem of transformation. So the Author argues that the transformation easiness of certain transformation is indicated by a number and professional level of the parties that has to be involved in process.

Based on this, Degree of Freedom of Transformation Index is made (Fig.3) in order to make a gradation of transformation easiness. 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 Author 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. The series of question is to identify the necessary parties in transformation. Each transformation has the following steps:

1) First, it is *initiated* by someone ⇒**Q1: Who initiates the transformation?**
2) Then, the decision whether to execute it or not is made by someone ⇒**Q2: Who is making final decision?**
3) Then it is executed by someone ⇒**Q3: Who performs the transformation?**
4) and that is done in certain manner ⇒**Q4: How is the transformation performed?**

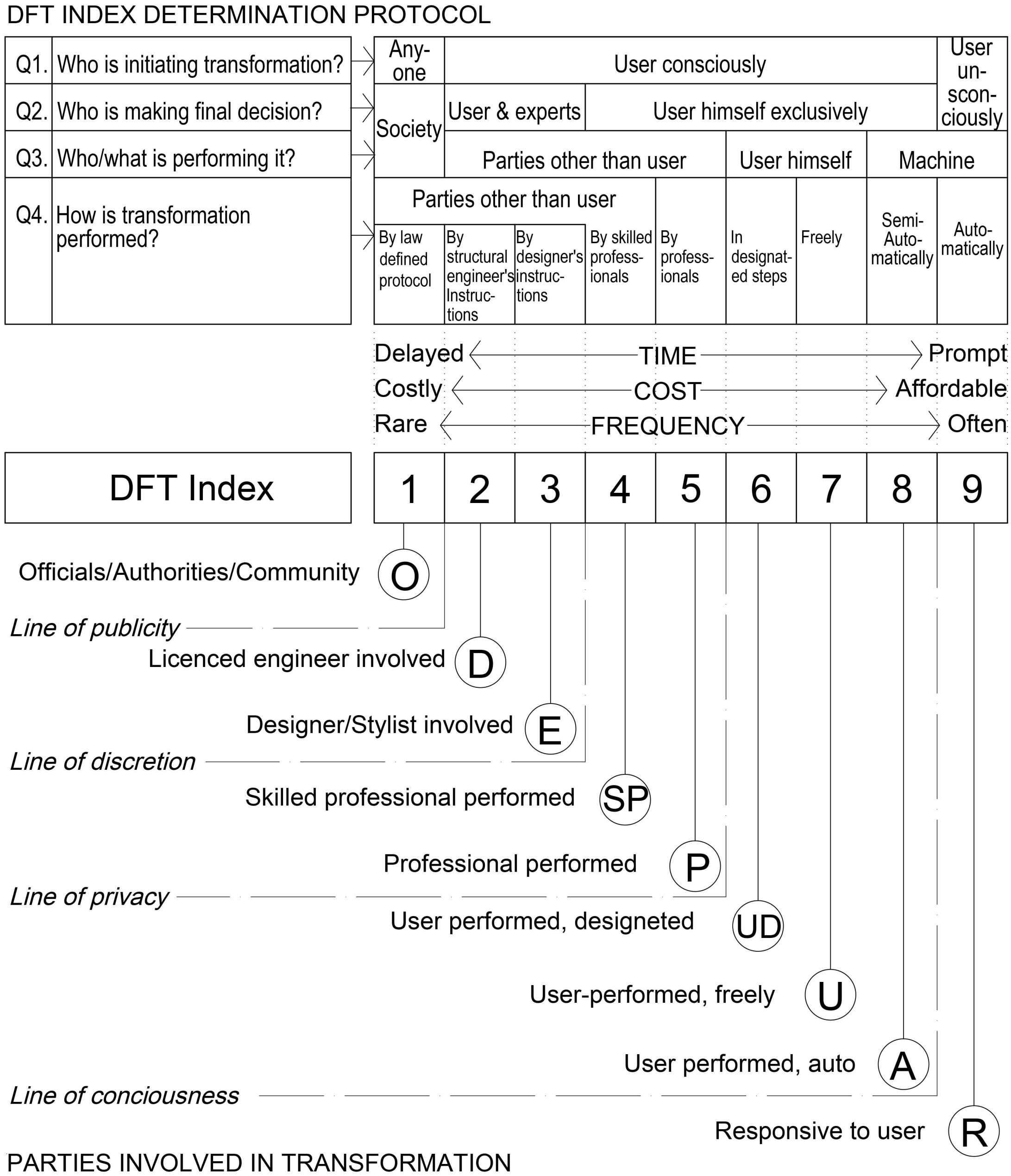


Fig.3-2 DFT Index Determination Protocol & Corresponding Parties

This means that for each intended transformation the process would require certain parties and the DFT Index would correspond to the party of highest order of complexity. For instance, if a transformation requires obtaining a permission from the planning authority, or it is forbidden by law, then the eventual involvement of other parties and technical complexity of the transformation are mostly irrelevant. In a first place, if something is regulated by law, then it is probably delicate enough as a task. Sure, the exceptions (outdated laws) can be found, but the objective of this work is to prove that this approximation can be taken as a rule of the thumb by designers. Similarly, if a technology requires usage of non-conventional tools for moving a provided partition wall then its stated simplicity of displacing is less important than the fact that professional workers have to be invited, an appointment, consultations, and negotiations made, and then be present when the works are being performed. The difference in time and money spent in comparison to what would be spent if conventional methods were applied are far less significant than the whole logistics of the transformation.

3.4 Transformability Profile (TP)

To assess the character of transformability of a building (or apartment unit), Transformability Profile was developed by combining BP and DFT Index in a consistent assessment system as shown in Fig.3-3.

Building Parts' Parameters were placed vertically, and DFT Index was plotted horizontally. Connected values represent the Transformability Profile (TP).

3.4.1 TP types – Intended, Experienced, Substantial

Transformability has a slightly different notion depending on the role that one has in the transformation process. We can recognize Architect and User 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 (Fig.3-3), 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.

It is important to emphasize that the TP and DFT values are not to be confused with quantitative values. In that sense, mathematical operations such as addition or subtraction is not possible.

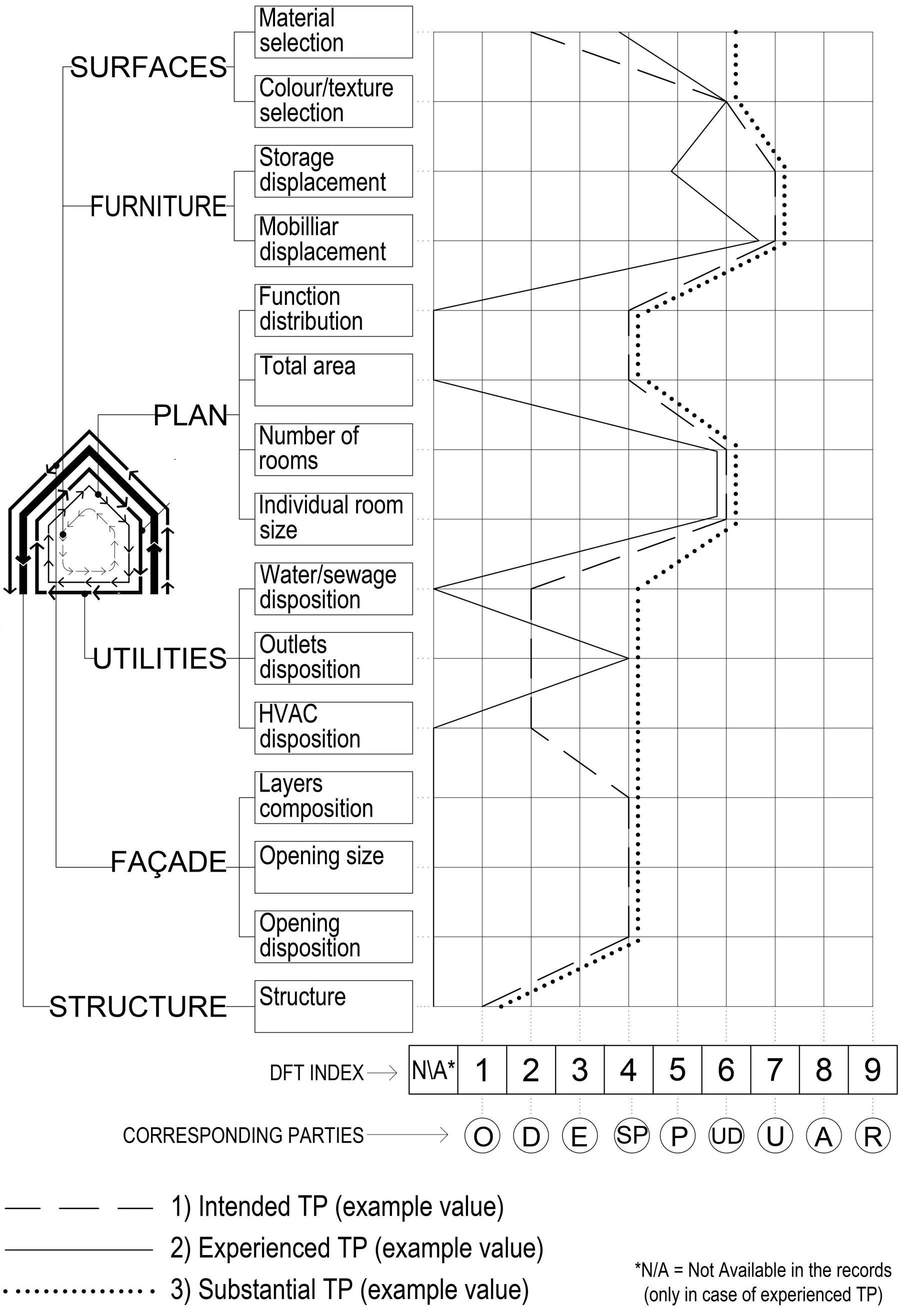


Fig.3-3 Three Kinds of Transformability Profiles

1

3.5 The Discrepancy between Architect's Intention and Transformations Experienced after Completion

The author noticed the discrepancy for the first time in well-known case of Nakagin Capsule Tower, designed by Kisho Kurokawa and built in 1972. The building was made with explicitly articulated intention to be transformable by means of replacing capsules which were attached to the independent load-bearing part of the structure – massive concrete core that doubled as a vertical communication. Each unit was attached to the core with only four bolts, by which the easiness of replacement was stressed. Even the price of the capsule was projected to be as "price of new luxury car" emphasizing the consumer goods character of the dwelling unit. The transformation was supposed to occur every 25-35 years in case of capsules, and the core and installations was supposed to be replaced every 60 years. However, until today, not a single unit was replaced and the building is facing demolition[2].

It may only be speculated what was the dominant reason among many for capsules not being replaced *as it was intended*, especially as it was reported that the interior of many of them did experience spontaneous changes (even complete renovations) but it is a fact that a lack of agreement between the owners was one of them. Now, if we consider the great effort to develop and apply technical solution to hang the capsule to the core with only four bolts, and a fact that that was not enough to overcome societal obstacles, there we can see quite significant discrepancy between intended transformability and experienced one. This focusing of the Architect to a problem of lesser importance was interesting to this research.

Considering the above, the author identified some discrepancies between the intended and experienced transformability in case of SI apartment houses Example Set which will be discussed below.

There were quite a lot of examples featuring installation pits, different modular coordination, special zones with elevated or lowered slabs, etc. in case of water/sewage and other installation subsystems. This special attention alone points to how much this was important in terms of transformability to the Architects[3]. However, TP analysis shows consistently that there was no significant difference among the examples in the experienced transformations of this area, just a rare and simple changes in displacement of kitchen and bathroom, and more often, just a replacement of the equipment. To add to the paradox, there were some units with conventional distribution of pipes that experienced some of those rare transformations. That means that the attention given to this issue might have been in vain regardless of the technique applied.

[2] Ref. 3-2

[3] 12 out of 15 examples have some sort of extensive technical approach to solving the problem.

3.6 References

3-1) Stewart Brand. *How Buildings Learn: What Happens after They're Built.* New York: Penguin, 1994.

3-2) Zhongjie Lin. "Nakagin Capsule Tower: Revisiting the Future of the Recent Past", *Journal of Architectural Education*. 65-1 (2011): 13-32.

4. THE EXAMPLE SET OF SI APARTMENT HOUSES

Set of 16 SI apartment houses examples, built in Japan in period from 1982 to 2000, were selected in this work for analysis (further: The Example Set) which is shown in Table 4-1. The examples were placed in alphabetical order and for easier reference in further mentioning, abbreviated to three-letter codes.

Table 4-1 The Example Set of SI Apartment Houses

Example No.	Example Name	Abbreviation
1	Centuri Heights Aira/Station Heights Kinko	CHA/SHK
2	Cherry Heights Kengun	CHK
3	CI Heights Machida	CHM
4	Estate South Senri (Inokodani)	ESS
5	Estate Tsurumaki-3	ETM
6	Flex Court Yoshida	FCY
7	Flexsus House 22	FH22
8	Green Maison Tsurumaki-3 High-rise	GMT-H
9	Green Maison Tsurumaki-3 Middle-rise	GMt-M
10	Green Village Utsugidai	GVU
11	Hikarigaoka Parktown	HGP
12	Momoyama-dai B Housing Complex	MDB
13	NEXT21	N21
14	San Life Sanda (Hyogo Century Housing)	SLS
15	Toyogaoka-1 Tama New Town	TGT
16	Town Estate Tsurumaki-3	TET

In the rest of this chapter, criteria for its selection, and basic characteristics of the examples were presented and explained. Concretely, main design principles of building composition (planning, structural and access principles), plans, utilities ducts, and construction methods were explained.

4.1 Criteria for Selection

As mentioned before, the key materials of interest were:

a) data about intentions of Architect,
b) data about subsequent actual transformations,
c) detailed specifications of buildings.

Since all three types of materials, especially surveys about actual transformations were not possible to collect the Example Set is rather the best possible mix of examples that allows good enough analyses to be made. For instance, some examples were followed with excellent materials for detailed and reliable assessment of Intended TP, and were necessary in order to prove the applicability and reliability of the assessment method. On the other hand, they were not so well documented when it comes to actual transformation records after completion. Similarly, the opposite situation existed, when materials about actual transformations were detailed, but the one about the intentions not as much. For the next level of analysis, covered in Chapter 7, when INT TP and EXP TP were directly compared there were 8 examples that cover in enough detail both actually experienced transformations and stated intentions of Architects.

Finally, in Chapter 8, where the Substantial TP was discussed, detailed characteristics of the examples were necessary but the other two were not. So some examples that completely lack one of the three types of materials were also included, but the composition of the Example Set was enough to display and prove the underlying logic of the assessment method and reasoning derived from it. In Fig.4-1 the Example Set, availability of materials and corresponding analyses were shown by Venn's diagram.

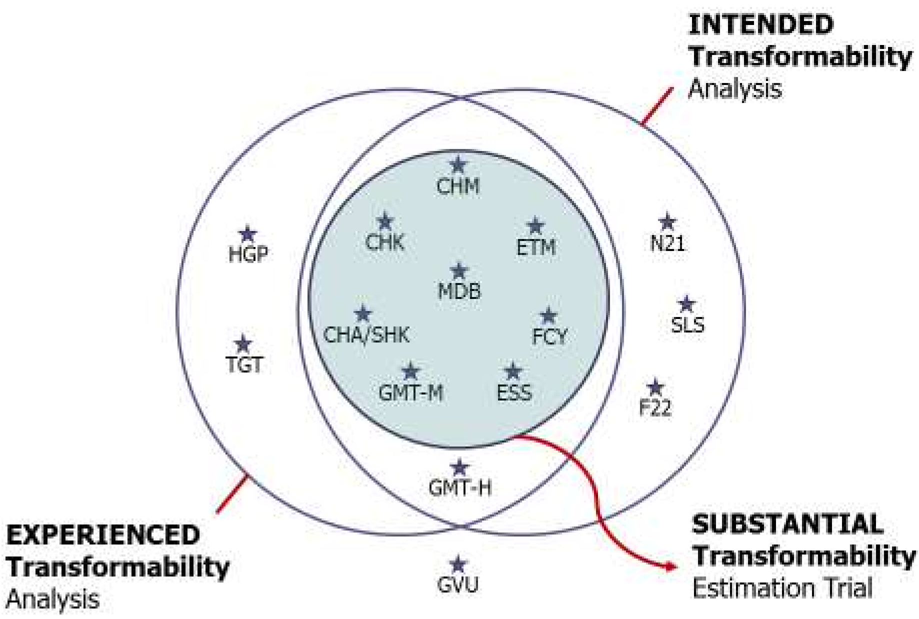


Fig.4-1 The Example Set, Availability of materials, and Corresponding Analyses

Aside from the criteria of availability of materials there was a criteria of diversity of basic architectural characteristics of the examples. This is important because if the logic and findings of this paper are to be applied to wider type of housing there has to be enough diversity to support that.

4.2 Planning/Access/Structural Principles

In Table 4-2 the examples were classified according to their planning, access, and structural principles. The table shows that the Example Set has satisfactory range to cover the typical building form of Japanese condominiums.

In case of planning principles, there is obvious dominance of I slab type of buildings. While this is not unusual for apartment buildings it is emphasized by the popularity of southern orientation in Japan. The effort was made to include the buildings of other planning principles, so one tower type, and two buildings of U shape were also included in the Example Set.

As for the access and structural principles, there is much more diversity.

Table 4-2 The Example Set According to Planning/Access/Structural Principles

EXAMPLES			Planning Principles			Access Principles			Structural Principles					
No.	Name	Abbrev.	I shaped	Tower	U shaped	Staircase for a pair of units in the middle	Staircase + EV for a pair of units in the middle	One sided corridor	Wall	Wall + Wall-frame	Wall-frame	Wall-frame + Frame	Frame	Wall + Frame
1.	Century Heights Aira/Station Heights Kinko	CHA/SHK				●				●				
2.	Cherry Heights Kengun	CHK	●			●				●				
3.	CI Heights Machida	CHM	●							●				
4.	Estate South Senri (Inokodani)	ESS	●			●				●				
5.	Estate Tsurumaki-3	ETM	●			●			●					
6.	Flex Court Yoshida	FCY	●					●					●	
7.	Flexsus House 22	F22	●					●			●			
8.	Green Maison Tsurumaki-3 (High-Rise)	GMT-H		●			●		●					
9.	Green Maison Tsurumaki-3 (Middle-Rise)	GMT-M	●			●					●			
10.	Green Village Utsugidai	GVU	●							●				
11.	Hikarigaoka Parktown	HGP	●			●				●				
12.	Momoyama-dai B Housing Complex	MDB	●			●				●				
13.	NEXT21	N21			●			●					●	
14.	San Life Sanda (Hyogo Century Housing)	SLS	●					●					●	
15.	Toyogaoka-1 Tama New Town	TGT	●			●								●
16.	Town Estate Tsurumaki-3	TET	●					●	●					

4.3 Example Set of SI Apartment Houses – Technical Description

In this chapter, for each of the examples some basic information and technical descriptions were given. Precisely, info about designer(s), location, type of apartment housing, types, sizes and numbers of apartment units were inscribed in the upper left corner of all the figures starting from Fig.4-2 to Fig.4-16. Whole Building plan and plans of typical units were shown in scale 1:500 and 1:200, respectively. The drawings were based on published materials referenced at the end of this chapter.

4.3.1 Century Heights Aira/Station Heights Kinko [CHA/SHK]

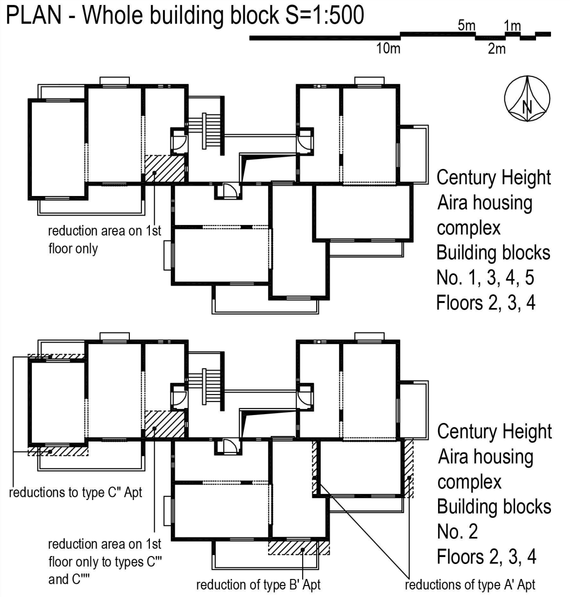
Century Heights Aira and Station Heights Kinko were built as public housing projects with the notion of securing skeleton as a public asset. The units are as separate from each other as they could be for a multi-family housing, providing a lot of natural light and access to fresh air to any side of the apartments. There are three "zones" in each of the apartments – fixed zone (exclusively kitchen and bathroom), multifunctional Japanese tatami zone, and "flexible zone" in which special movable partitions and movable storage were designed to allow it. There were 3 different settings for that zone as in Fig. 4-2.

1 CHA/SHK

Name	Century Heights Aira/Station Heights Kinko
Designer(s)	Ichiura Planning & Housing Consultants Co. Ltd.
Location	CHA Aira-city/SHK Kajiki-city, Aira-gun, Kagoshima prefecture
Year of completion	CHA1987/SHK1989
Housing type	Condominium
Unit types	3* (A, B, C + 5 menu plans for "flexible zone")
Source of drawings	Ref. 4-1; Ref. 4-2
No. of units	56 + 90
Usefull area	A-66.08m2, B-66.76.5m2, C-66.08

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
U shaped	A staircase for three units in the north	Wall + Wall-frame

PLAN - Whole building block S=1:500



*All the apartment types come in two sizes so, strictly speaking, there are at least type A (66.08m^2) and A' (63.82m^2), type B (66.08m^2) and type B' (64.50m^2), and type C (66.08m^2) and type C' (63.82m^2). These differences are caused by flattening of buildings southern facade to one plane (type B), and slightly reducing the "continuity fixed zone" (Type A and C) by two tatamis (half tatami in legth, so the whole space is reduced from 14 to 12 tatamis). In case of CHA complex only building block no.2 (1 out of five building blocks), and in case of SH, 4 out of 7 building blocks (building blocks numbers unknown) contain type B' apartments.
C type apartments actually come in four sizes, so we can say that there are "regular" type C and C' apartments that come in two sizes which are on 2nd floor and above, and type C'' and C''' apartments which are reduced type C and C' apartments located on 1st floor (ground floor) of each housing block in both housing complexes. Type C'' and C''' are reduced in a way that part of the "fixed zone", where kitchen would normally be in type C and C' (but also in other types as well), was cut to make a pedestrian passage through the buildings, and the kitchen is then joined to the "flexible zone".
However, the main difference between the types is the way of combining of the three spatial/functional elements - "fixed zone", "transformable zone" and "continuity fixed zone", so in order to emphasize that in the analysis, the other differences between the apartment types will be considered minor and therefore ignored, so the division on three types - A, B, and C, was adopted in this work. Since the largest variants of the three are also the most numerous those were taken to represent each type.

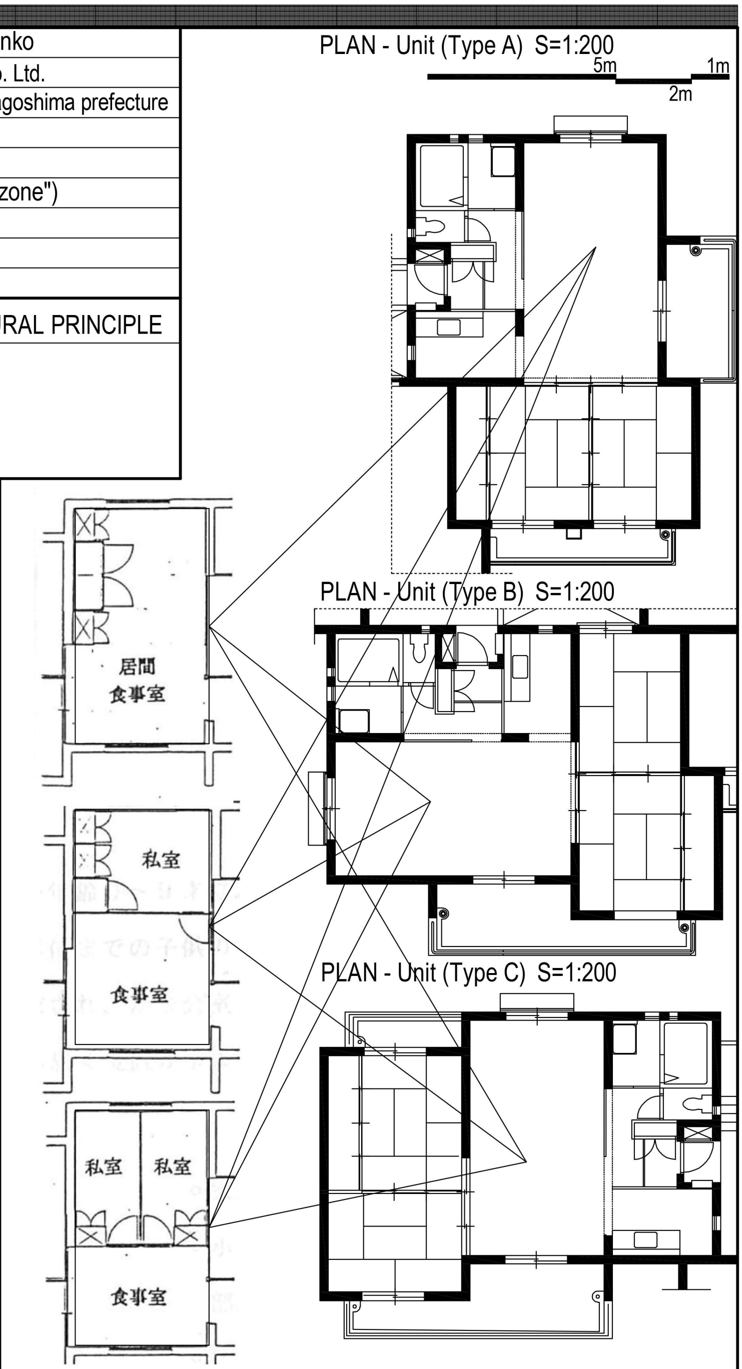


Fig. 4-2 Basic Information - Century Heights Aira/Station Heights Kinko

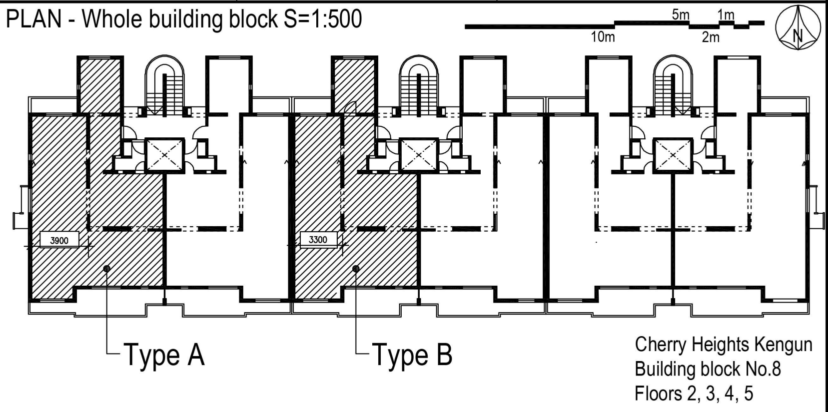
4.3.2 Cherry Heights Kengun [CHK]

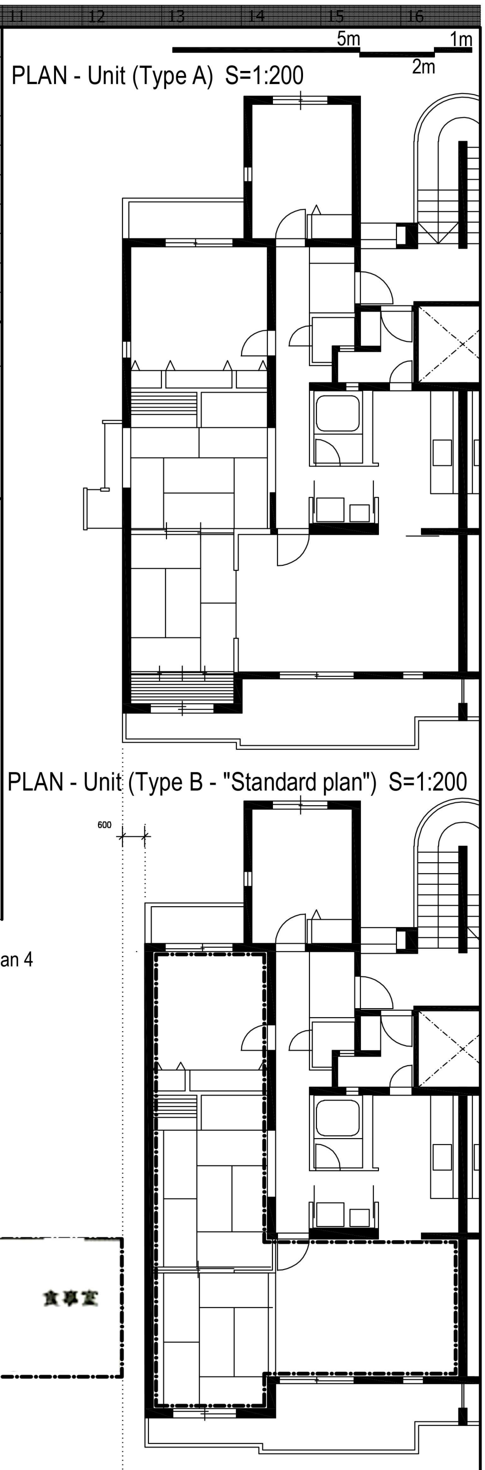
Cherry Heights Kengun (Fig.4-3) is public housing project made in accordance with CHS principles in order to make maintenance and layout transformations easy. There is strong division, both functional and structural, of fixed part (K+B+T) from variable part (L+D+R) with the communication space running between them. There is additional room in the north which is not a part of the same structural scheme The transformations were suggested through menu plans which were based on "life cycle" and "life stage" ideas.

2 CHK

Name	Cherry Heights Kengun
Designer(s)	Kumamoto Prefectural Housing Supply Company, Ichiura Planning & Housing Consultants Co. Ltd.
Location	Kumamoto-city
Year of completion	1984
Housing type	Condominium
Unit types	2 (A, B + menu plans for "flexible zone")
Source of drawings	Ref. 4-3; Ref 4-4; Ref. 4-5
No. of units	140 units (A-53; B-101)
Usefull area	A-103.91m^2; B-97.36m^2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	Staircase for a pair of units in the northern zone	Wall + Wall-frame





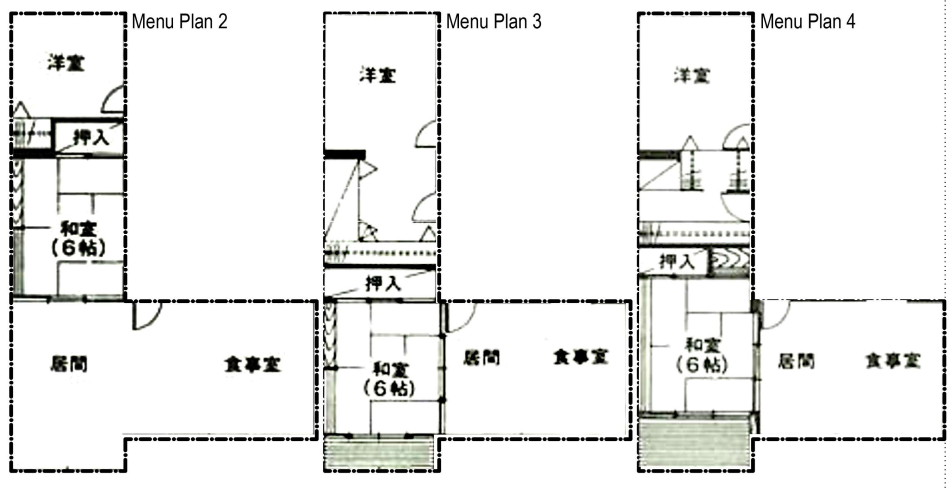


Fig. 4-3 Basic Information - Cherry Heights Kengun

4.3.3 CI Heights Machida [CHM]

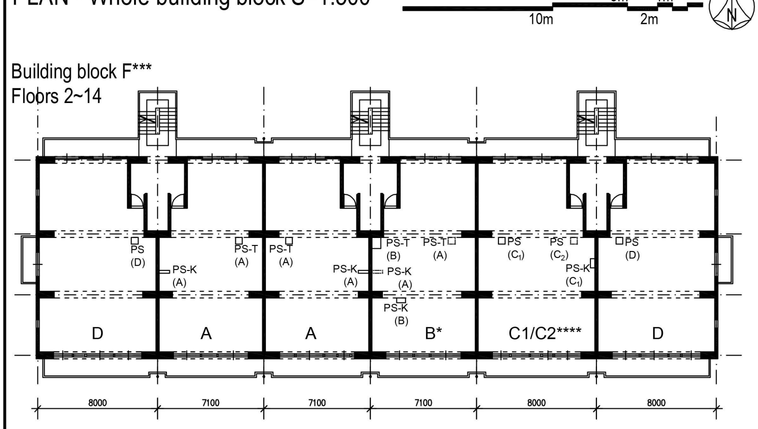
CI Heights Machida was designed and constructed by Takenaka Corporation in four phases. The second phase was developed officially as CHS project, so there were various considerations about transformability. There are four apartment types (Fig. 4-4). Type A and Type D are the most numerous. Each apartment was divided into three structural bays, however the main span differed among the unit types from 7100 mm to 8500 mm. There are also differences in the positions and number of the installation. Principally, they were in the middle structural field. The entrance is through the slightly reduced northern structural field, every two units sharing one access through externally placed staircases. The skeleton got special attention in design. It was designed as series of rigid wall-frames with large openings between the bays. The rectangular columns and beams although reduced in size are still observable in the interior.

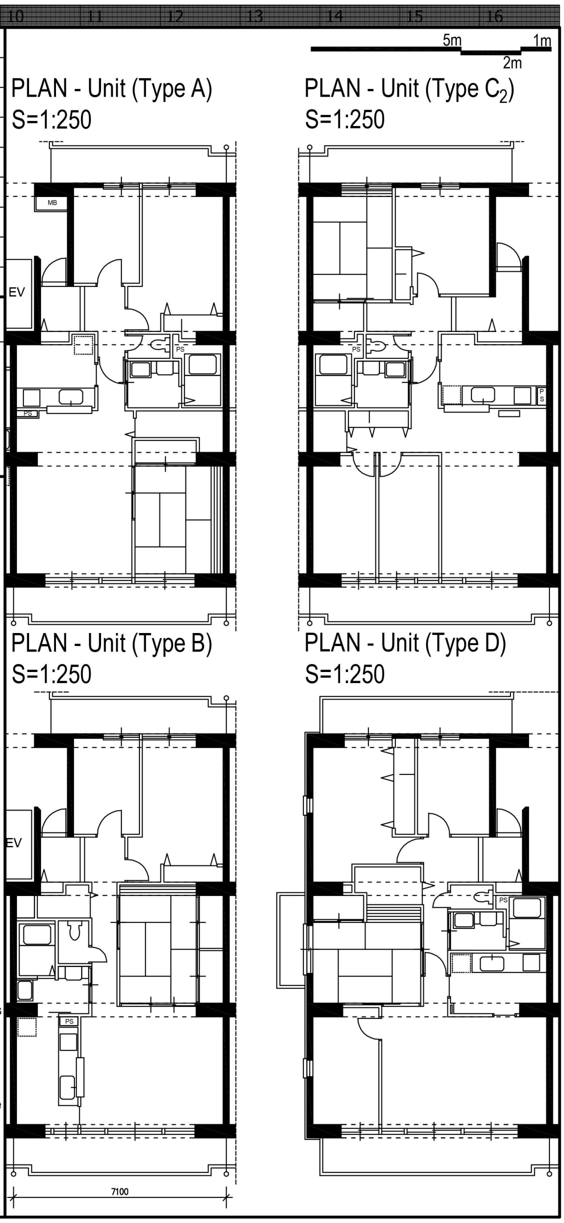
3 CHM

Name	CI Heights Machida (2nd phase)
Designer(s)	Takenaka Corporation
Location	Machida-city, Tokyo
Year of completion	1982
Housing type	Condominium
Unit types	4* (A, B, C, D + menu plans for "living zone")
Source of drawings	Ref. 4-6
No. of units	226** (A=102, B=15, C=26, D=83)
Usefull area	A, B-85.87/85.42m^2; C, D-97.77/97.32m^2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase + EV for a pair of units in the north	Wall-frame + Wall

PLAN - Whole building block S=1:500





* Actually, there are more then four unit types, however, this four were designed according to CHS rules, and were later as such investigated and their transformations were recorded. Beside these four unit types it could be interesting to investigate types I and J since those have different main span-6500mm, compared to 7100mm (A and B) and 8000 (C, D). Other types are all variations of the main types in ground floor and top floor and are minor in number of units.

** 226 is number of CHS apartments only. The second phase of four stage CI Heights Machida project consists of 3 building blocks (D, E, F) completed in 1986, which has a total of 263 units.

*** Building block F does not contain Type B units, but instead type A units. To avoid adding another plan of yet another whole building block and to emphasize that A and B type apartments share the identical structure, one type A unit is substituted by one type B unit. Notice the difference in the pipe shaft (PS) disposition of the type A and B.

**** The unit shown in the plan of building block F is C_2 type apartment unit. Type C_1 unit has different number and disposition of pipe shafts (PS) which are conveniently shown here with dotted line for the ease of comparison. The actual type C_1 unit would be a picture in a mirror of the type C_2 with the differently organized water section (kitchen and toilet) in the middle structural bay (type C_1 has the two rooms separated physically and placed on the opposite sides of the middle structural bay and each connected to a different PS, while in the C_2 unit Kitchen and toilet are adjacent to each other and are connected to the same and only PS).

Fig. 4-4 Basic Information - CI Heights Machida

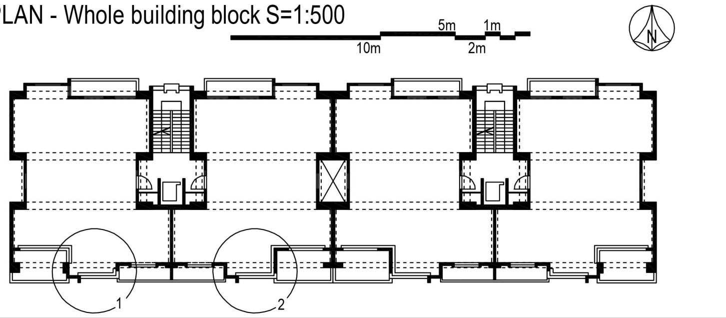
4.3.4 Estate South Senri (Inokodani) [ESS]

South Senri housing complex was the second housing complex to be built in accordance to Two Step Housing System (TSHS). While the skeleton was same for all 36 units, only 6 of them were design as TSHS. Beside separation of Skeleton and Infill, characteristic for the TSHS is that the User is involved in the process of infill design. Several meetings were organized between the future residents and the Architect in order to revise the infill blueprints while the skeleton was already under construction. Complex system of coordinators for various infill segments and buildings overall design was established. The Architect had to make compromises to initial design ideas and give up from the modularly coordinated façade.

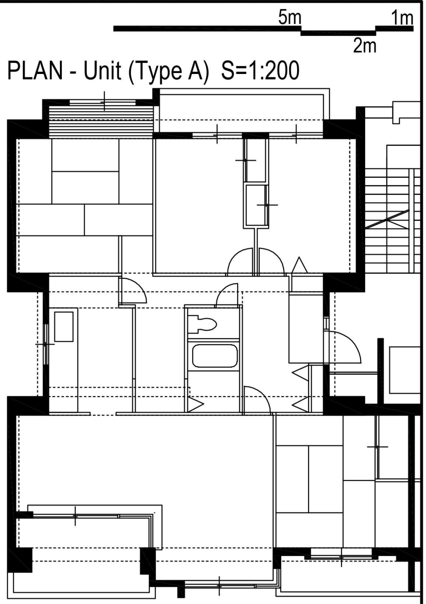
Name	Estate South Senri (Inokodani)
Designer(s)	Ichiura Planning & Housing Consultants Co. Ltd.
Location	CHA Aira-city/SHK Kajiki-city, Aira-gun, Kagoshima prefecture
Year of completion	1989
Housing type	Condominium
Unit types	2*
Source of drawings	Ref. 4-7; Ref. 4-8
No. of units	33; 6 were designed as TSHS** (A-2, B-1)
Usefull area	103.15/103.86m^2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase for a pair of units in the north	Wall-frame + Wall

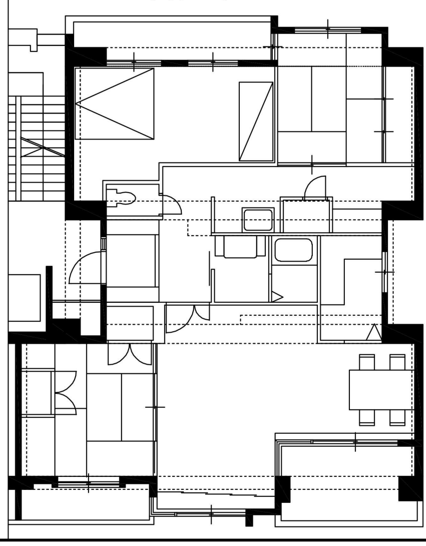
PLAN - Whole building block S=1:500



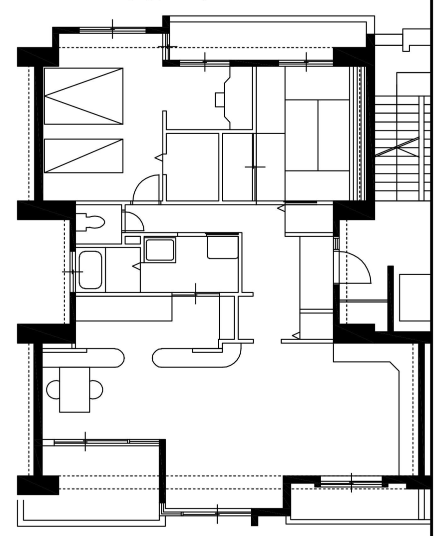
PLAN - Unit (Type A) S=1:200



PLAN - Unit (Type A) S=1:200



PLAN - Unit (Type B) S=1:200



*There are two slightly different apartment types on typical floor plans (2, 3, and 4), and there are additional types on ground and top floor. At first sight, it seems that each pair of the apartments which share the same staircase is identical, in other words-the apartments are "a picture in the mirror" of each other. However, they are not entirely symmetrical which can be seen in the south facade (marked by 1 and 2 in the whole building floor plan).
** TSHS stands for the Two Step Housing System, which is a design process that includes the participation of the future dwellers.

Fig. 4-5 Basic Information - Estate South Senri (Inokodani)

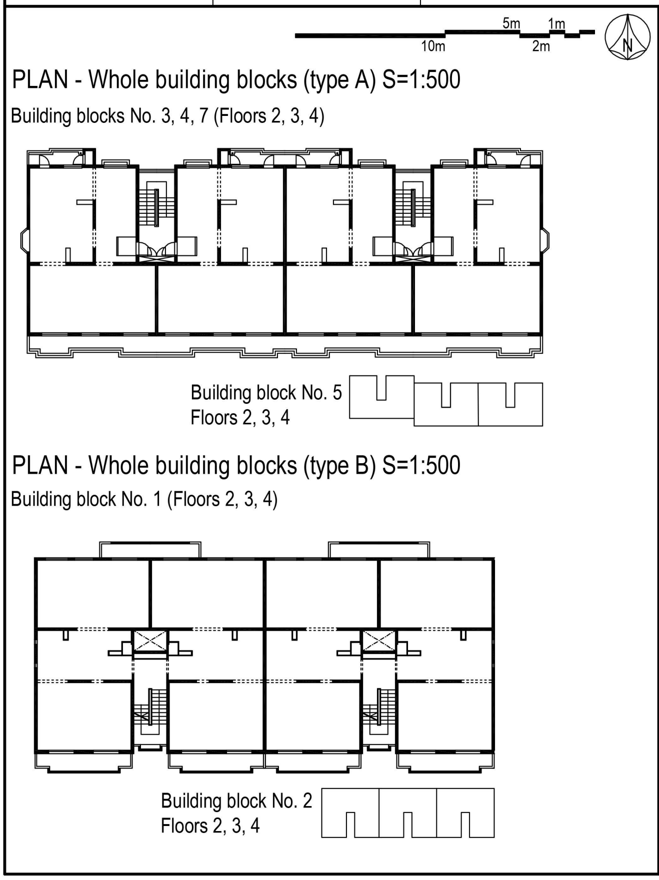
4.3.5 Estate Tsurumaki-3 [ETM]

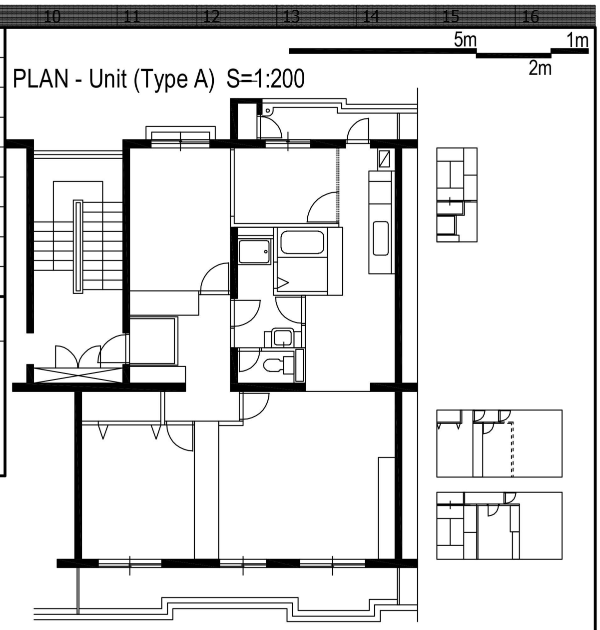
Estate Tsurumaki is one of the pioneering housing projects of Kodan Experimental Project (KEP) which was developed since the middle of 70s. Since the structure at the time was based on concrete panels there could be no large openings between the structural bays so the functional zones were assigned to each of them. In Fig.4.3-5 two (of three) apartment types having the three structural/functional zones organized differently. In both cases the southern zone for living and dining is rectangular and elongated. In some units in these southern zones specially developed movable partitions and movable storage units were designed with the intention to allow subdivision of the space according to the menu plans.

1 2 3 4 5 ETM 6 7 8 9 10 11 12 13 14 15 16

Name	Estate Tsurumaki-3
Designer(s)	KODAN
Location	Tama New Town, Tokyo
Year of completion	1983
Housing type	Condominium
Unit types	3* (A, B, C + menu plans for "flexible zone")
Source of drawings	Ref. 4-9
No. of units	192 (A=72, B=40, C=80)
Usefull area	A-88.93/89.07m^2; B-88.96/89.16m^2; C-86.85/87.03m^2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase for a pair of units in the north	Wall + Wall-frame





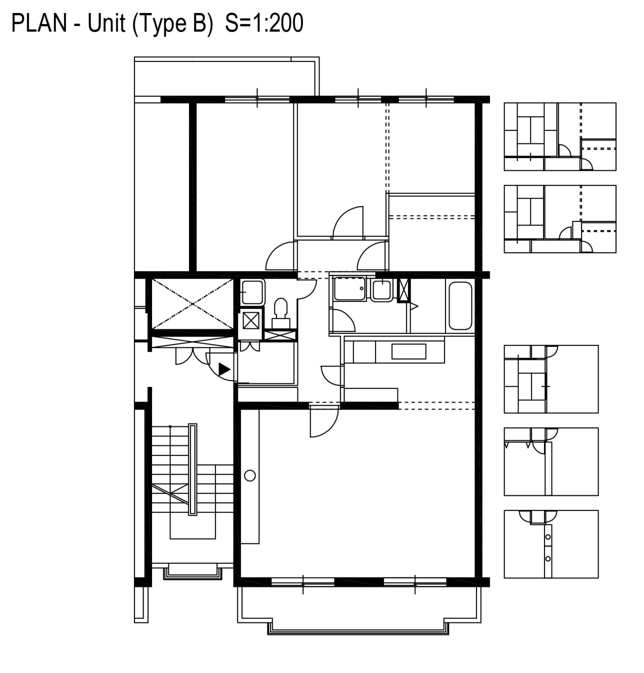


Fig. 4-6 Basic Information - Estate Tsurumaki-3

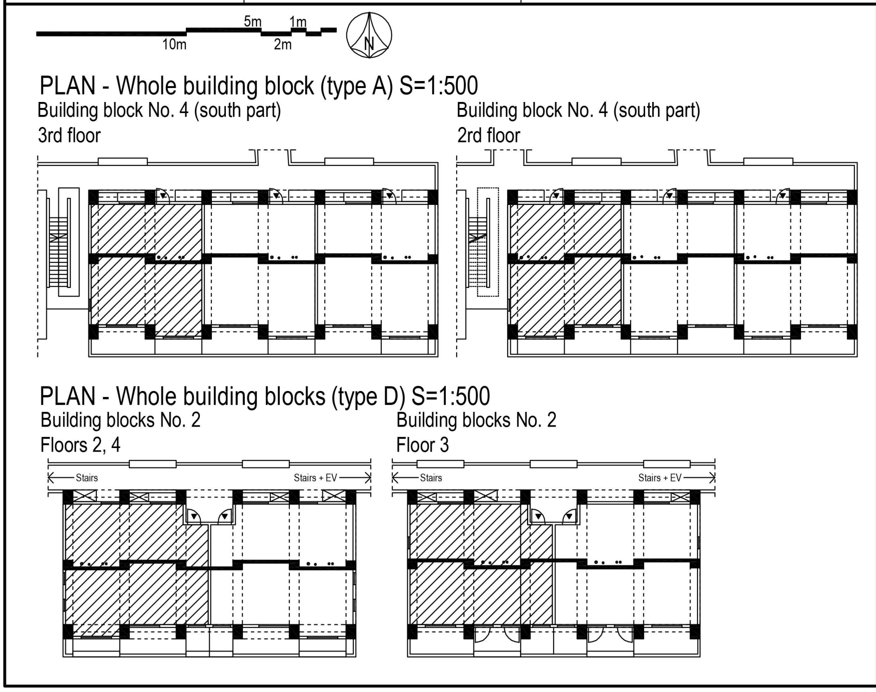
4.3.6 Flex Court Yoshida [FCY]

Flex Court Yoshida was designed at the end of the 20th century, after many ideas about the transformable design were already developed. Innovative solution for slab was proposed: slab of every other structural field was lowered entirely (represented by partial section in the plans of the whole building in Fig.4-7). By this, a space for installations was created in one part of the apartment (apartments consists of two [type A] or two and a half [type D] structural fields). The rationale for this is that the limited transformability of water section is enough, so the otherwise economically unfeasible hollow ceiling was justified. TSHS is further developed now including Infill Management System which was supposed to help coordinate the infill transformations. To reduce the friction, even graphic application software was developed to help the User decide on the position of movable storage units and movable partitions that were also designed. Here, it is important to mention that the Architect recognized the need for open interpretation of the infill and outsourced the infill design to other companies, precisely three of them.

1 2 3 4 5 6 FCY 7 8 9 10 11 12 13 14 15 16

Name	Flex Court Yoshida
Designer(s)	Design Committee for Next Generation Housing
Location	Osaka-city
Year of completion	1999
Housing type	Rental Housing
Unit types	3* (A, D, M + menu plans for "flexible zone")
Source of drawings	Ref.4-10
No. of units	53 (A=31, D=18, M=4)
Usefull area	A-65m^2; D-80m^2; C-95m^2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	One sided corridor + staircases between each building block	Frame



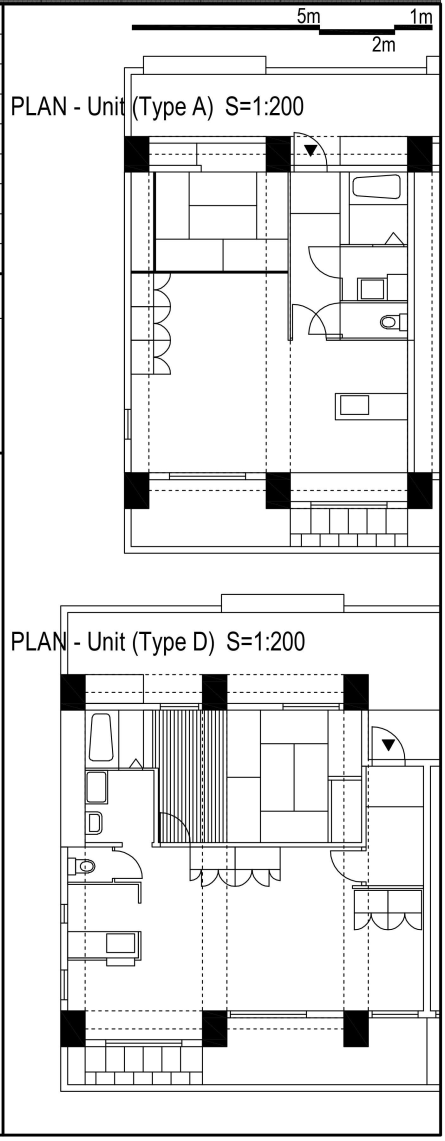


Fig. 4-7 Basic Information – Flex Court Yoshida

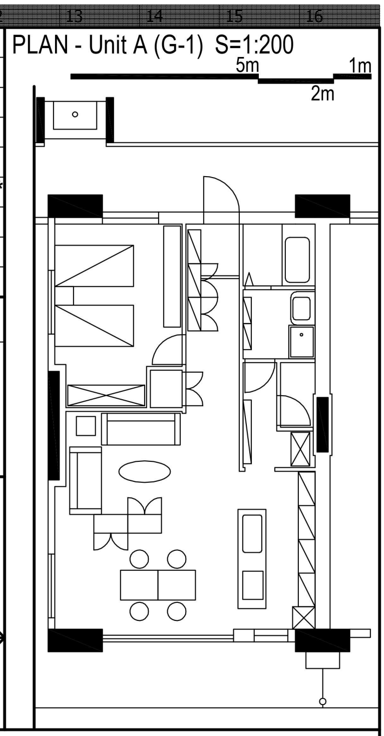
4.3.7 Flexsus House 22 [FH22]

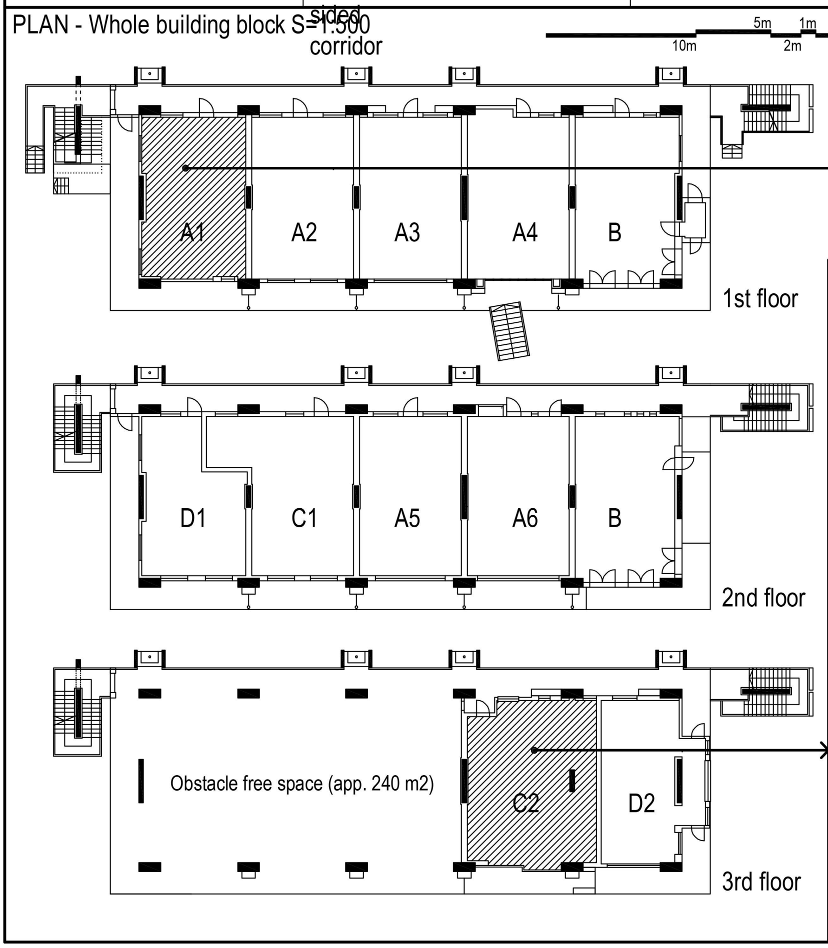
Flexsus House 22 was developed as part of the House Japan project by Takenaka Corporation. Heavily reinforced concrete and earthquake cushions allowed an elegant frame with no concrete panels and thin columns, both between the structural bays and toward facades. Eleven units were designed by several infill designers who had to follow the design interface and to coordinate the façade with skeleton designer. The façade itself was advanced modularly coordinated system. Therefore, position of doors, apartment area, duplex apartments, office-living and other variations could be achieved. Two systems of outside installation shafts were designed (in north and south) and double floor (250mm).

1 2 3 4 5 6 7 F22 8 9 10 11 12 13 14 15 16

Name	Flexsus House 22
Designer(s)	Takenaka Corp., Matsushita Corp., Inax Corp., Kajima Corp., Tokyo Gas Co. Ltd., Toho Gas Co. Ltd.
Location	Seto city, Aichi prefecture, Japan
Year of completion	2000
Housing type	Condominium
Unit types	A (6, standard type), B (1, duplex), C (2, larger than A), D (2, smaller than A)*
Source of drawings	Ref. 4-11; Ref.4-12
No. of units	11
Usefull area	Type A - 83m2 (approx); B, C, D, E , F - 69m2~155m2 (estimated from plan)

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	Two staircases + one sided corridor	Wall-frame (beams hidden)





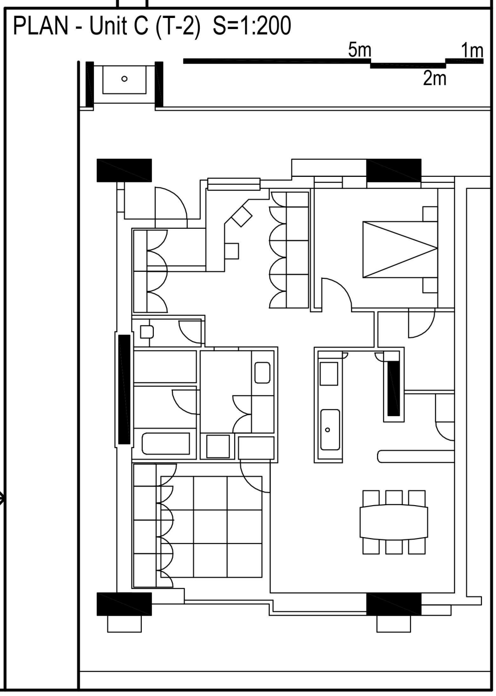


Fig. 4-8 Basic Information – Flexsus House 22

4.3.8 Green Maison Tsurumaki-3 High-rise [GMT-H]

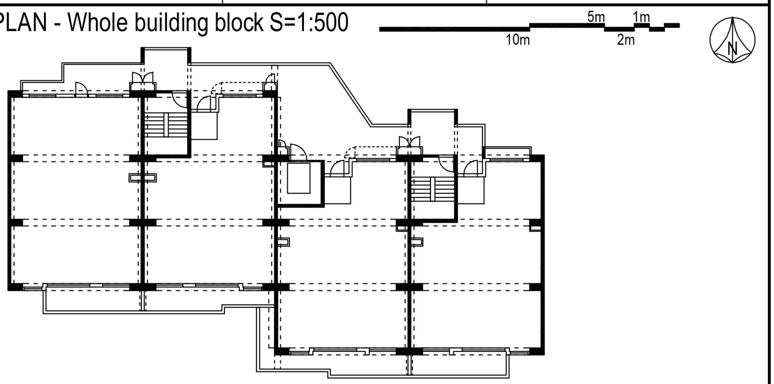
Green Maison Tsurumaki-3, built in 1983 is an I shaped tower type building. Each apartment is occupying three structural fields, however staircases, elevators, and access from the corridor were placed in northern field reducing its size. Middle field, beside for connecting northern and southern doubles as a water/sewage zone so bathroom and kitchen were placed there, on opposite sides of the field, leaving the middle for communication. There were two installation boxes (different shape and size), also placed on opposite sides of the middle structural field. The southern façade is free of load-bearing elements.

1 2 3 4 5 6 7 8 GMT-H 9 10 11 12 13 14 15 16

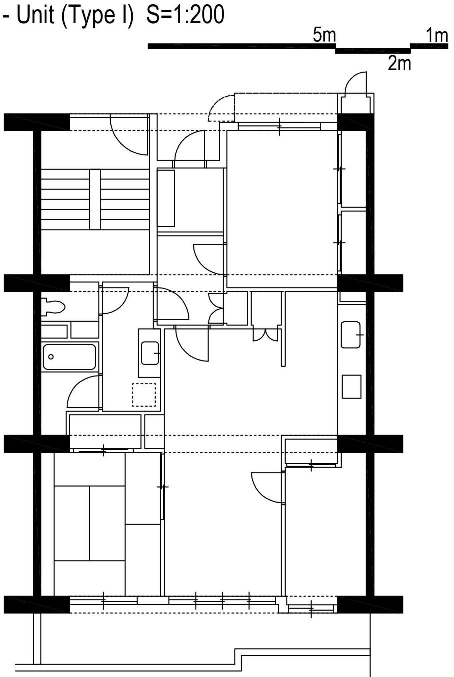
Name	Green Maison Tsurumaki-3 (high-rise)
Designer(s)	KODAN (present: HUD)*
Location	Tsurumaki-3, Tama New Town, Tokyo
Year of completion	1983
Housing type	Condominium
Unit types	4 (A, I, U, E);
Source of drawings	Ref.4-13
No. of units	43 (A-11, I-11, U-10, E-11)
Usefull area	A-99.14m2, I-86.75m2, U-89.80m2, E-86.08m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped tower	One sided corridor with three vertical communications inside the structural bay	Wall-frame + Wall

PLAN - Whole building block S=1:500



PLAN - Unit (Type I) S=1:200



PLAN - Unit (Type A) S=1:200

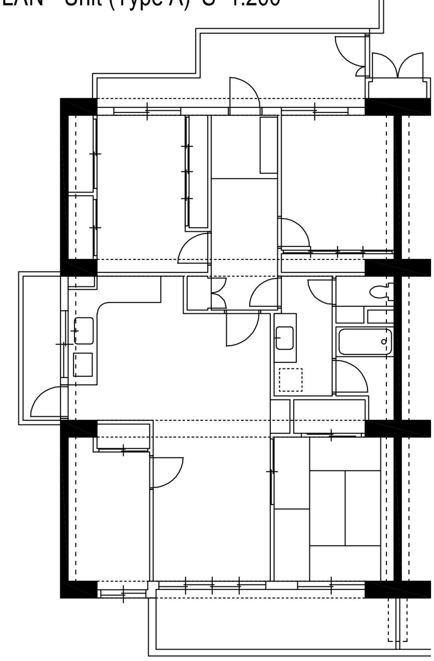


Fig. 4-9 Basic Information - Green Maison Tsurumaki-3 High-rise

4.3.9 Green Maison Tsurumaki-3 Middle-rise [GMT-M]

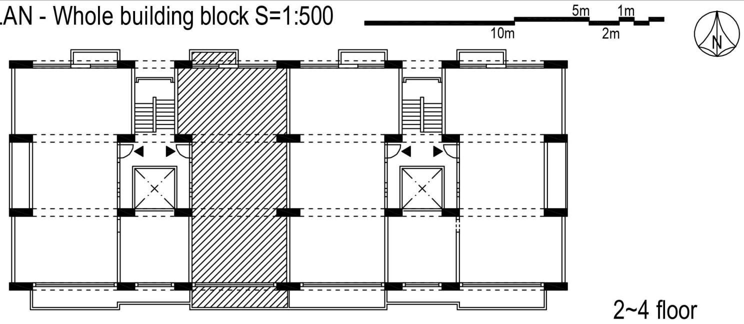
The middle-rese buildings of Green Maison Tsurumaki-3 housing complex, designed by KODAN in 1983 have similar structural principles (a series of wall-frames in east-west direction) as the tower type of GMT-H. However, the access principle is a staircase between a pair of units, so the entrance is through the middle field. This made both north and south field free of obstacles, so these zones were planned to support variable layouts. Some of the apartments were equipped with movable partitions and movable storage units for that purpose, but also initial "menu plans" variations shown in the bottom of Fig.4-10 were proposed. Slab in the middle zone was lowered by 300 mm to allow free distribution of installations bellow a double floor installation. Remaining structural field in the south side was joined to C type units, creating more spacious apartment. Doors were left in a concrete panel which doubles as a seismic screen. Like in GMT-H beams and columns are visible in the interior, however their size was reduced. Despite the physical barriers between the structural fields were reduced, they were strictly divided functionally.

1 2 3 4 5 6 7 8 9 GMT-M 10 11 12 13 14 15 16

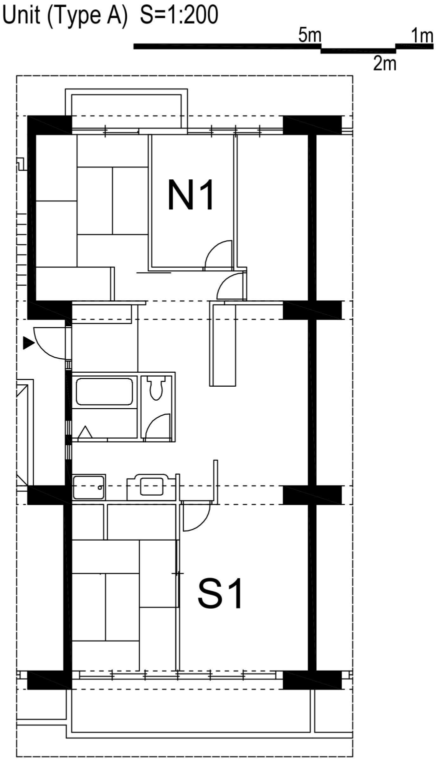
Name	Green Maison Tsurumaki-3 (middle rise)
Designer(s)	KODAN (present: HUD)*
Location	Tsurumaki-3, Tama New Town, Tokyo
Year of completion	1983
Housing type	Condominium
Unit types	3 (A, B, C); A type: 4 variants for north and 4 for south zone
Source of drawings	Ref.4-14
No. of units	16 (A-8, B-2, C-6)
Usefull area	A-98.22m2, B-99.73m2, C-118.52m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase for a pair of units in the north	Wall-frame + Wall

PLAN - Whole building block S=1:500



PLAN - Unit (Type A) S=1:200



North zone

South zone

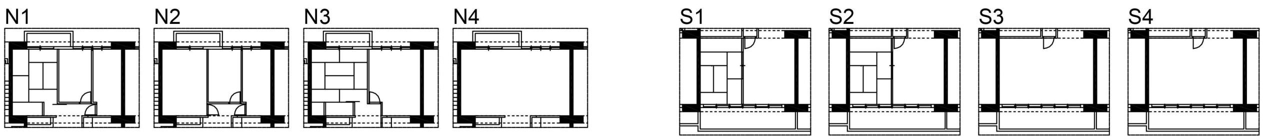


Fig. 4-10 Basic Information - Green Maison Tsurumaki-3 Middle-Rise

4.3.10 Green Village Utsugidai [GVU]

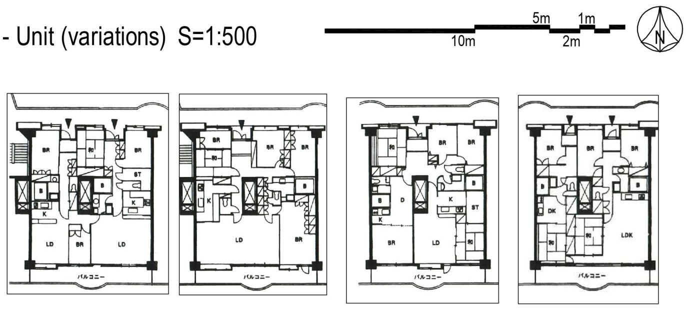
Green Village Utsugidai is included in the Example set for its unorthodox but interesting solution for skeleton (Fig.4-11). Set of four columns with large spans (11 m X 8 m) secured a space for each of the apartment units. In the middle of it, little eccentrically, an installation shaft doubling as bearing walls was placed. Two installation pits, 3000 mm wide were leading from it to the opposite sides of the apartment units. This was a base for a layout pattern in which installation were placed around the installation shaft freely. This was encouraged by the Architect, who included the user into the process of design of layout. Additionally, large areas of facades, uninterrupted by load bearing elements in combination with one sided corridor access allowed the variable position of entrance doors, and other openings.

1 2 3 4 5 6 7 8 9 **10 GVU** 11 12 13 14 15 16

Name	Green Village Utsugidai
Designer(s)	KODAN (present: HUD)*
Location	Hachioji-city, Tokyo
Year of completion	1992
Housing type	Condominium
Unit types	N/A
Source of drawings	Ref.4-15
No. of units	76 (A-8, B-2, C-6)
Usefull area	97～173 m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	One-sided corridor	Frame + Wall

PLAN - Unit (variations) S=1:500



PLAN - Unit S=1:200

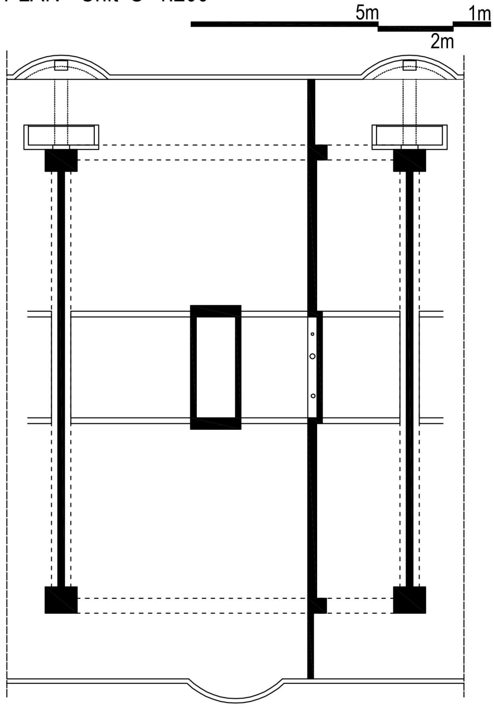


Fig. 4-11 Basic Information - Green Village Utsugidai

4.3.11 Hikarigaoka Parktown [HGP]

Hikarigaoka parktown is yet another project carried out by KODAN in 1986. It was made in accordance with “free plan rental” experiment which considered legal division of the infill and skeleton, three levels of freedom in determining the layout (free space, semi-free, and menu select), and certain coordination and assistance by KODAN for buying and selling of the infill elements. Structurally, concrete walls with uneven spacing were used to form 5 rectangular spaces (Fig.4-12) which were then combined to make apartment units of different sizes. Important technical feature is the water section. Water section zone was planned, however there was no trench, but the units were equipped with multiple access and drainage points for water/sewage installations, and by utilizing double floor these access pints could be extended by 1.5 meters.

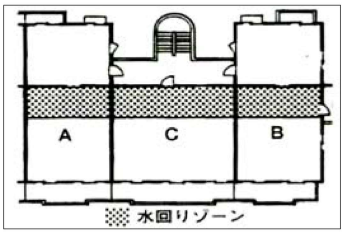
1	2	3	4	5	6	7	8	9	10	11 HGP	12	13	14	15	16

Name	Hikarigaoka Parktown
Designer(s)	KODAN
Location	Nerima, Tokyo
Year of completion	1986
Housing type	Rental
Unit types	2 (A, B, C)
Source of drawings	Sawada Tomoko, report
No. of units	30
Usefull area	A/B-72m2, C-62m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase for three units in the north.	Wall + Wall-frame

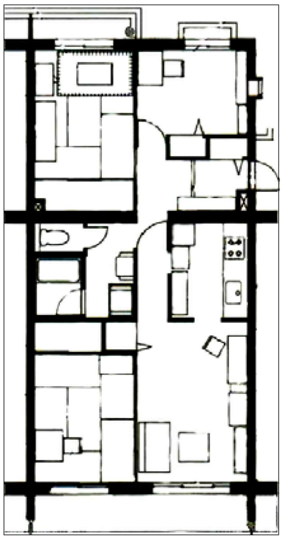
PLAN - Whole building block S=1:500

5m 1m 10m 2m N

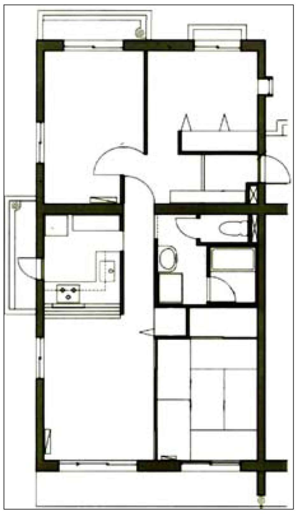


PLAN - Unit (Type A) S=1:200

5m 1m 2m



PLAN - Unit (Type B) S=1:200



PLAN - Unit (Type C) S=1:200

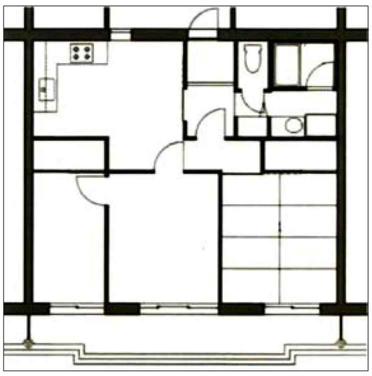


Fig. 4-12 Basic Information – Hikarigaoka Parktown

4.3.12 Momoyamadai-B Housing Complex [MDB]

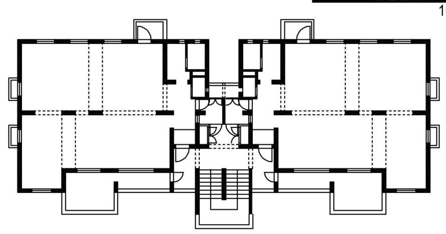
Momoyamadai-B Housing Complex is a large scale application of TSHS principles. There is fixed water section adjacent to entrance, and two elongated rectangular spaces supported by walls which were loosely connected by large openings between the two structural fields). This setting, and the inclusion of the future residents into design process, allowed for extremely large number of variations of layout to be built. Modular coordination was considered, partitioning suggested by fixed openings (although this was a compromise, since the original proposals were including free forming of the façade), however, there was enough space for "fine tuning". This was probably achieved by unconventionally designed beams, which were, contrary to structural logic wider but lower, which helped perceive the space as single when needed. Aside from kitchen which was fixed to the wall equipped with water installations, no other spaces were predetermined for any of the functions, so living and dining could be freely combined or separated in numerous ways. Also, the individual rooms could be added, subtracted, connected, reduced or increased in size along the structural fields with enough room for living/dining and kitchen to be adjusted to the transformation.

12 MDB

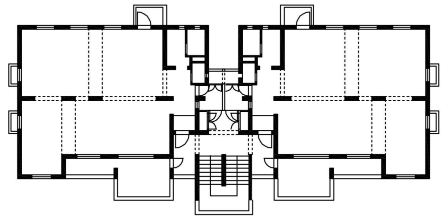
Name	Momoyama-dai B Housing Complex
Designer(s)	Osaka City Housing Supply Corporation Design Dept., Tatsumi Lab. (Kyoto Univ.), Seikatsu-kuukan Keikaku-Jimusho
Location	Sakai City, Osaka
Year of completion	1982
Housing type	Condominium
Unit types	2 (A, B)
Source of drawings	Ref.4-8; Ref.4-17
No. of units	98 (2SHS=18; A=18, B=80)
Usefull area	A-103.99m2 (+balcony 20.2m2), B-109.5m2 (+balc. 32.7m2)

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase for a pair of units in the south. Units not having common walls!	Wall + Wall-frame

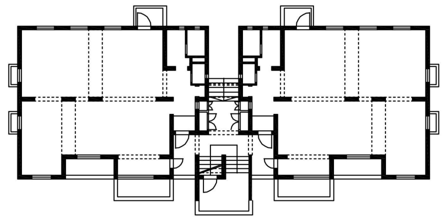
PLAN - Whole building block S=1:500



Building blocks No. 1, 2, 5, 6 3rd and 5th floor

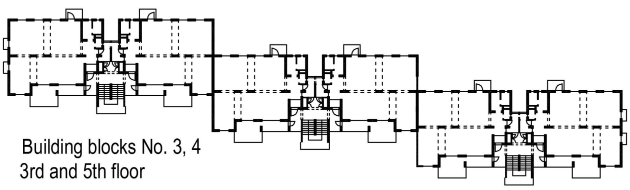


Building blocks No. 1, 2, 5, 6 2nd and 4th floor



Building blocks No. 1, 5, 6 1st floor

PLAN - Whole building block S=1:1000



Building blocks No. 3, 4 3rd and 5th floor

PLAN - Unit (Type A) S=1:200

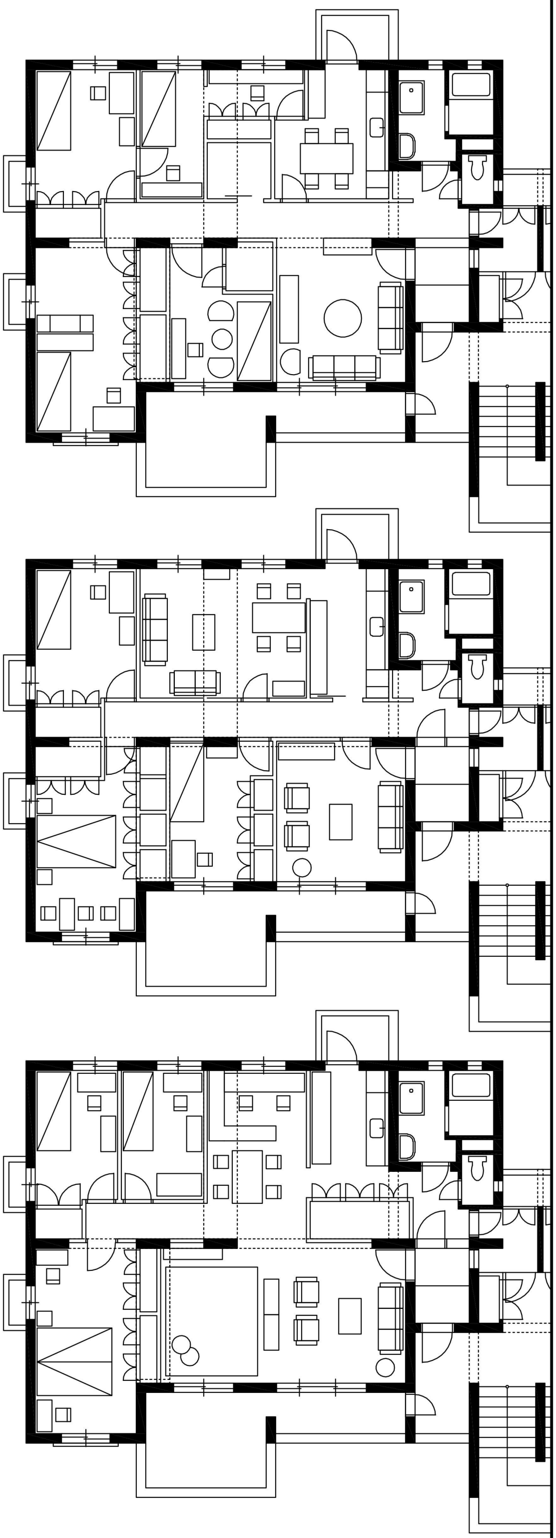


Fig. 4-13 Basic Information – Momoyamadai-B Housing Complex

4.3.13 NEXT21 [N21]

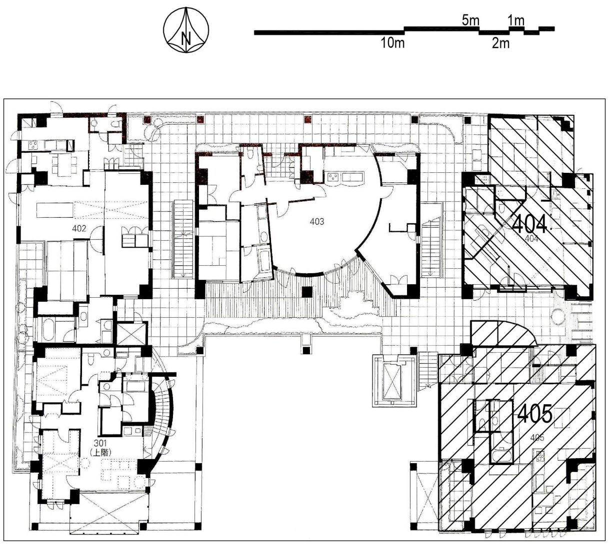
NEXT21 is a culmination of the efforts in development of SI apartment buildings. However, it has highly experimental character, and cannot be considered equally to other examples in this research. Its significance is twofold: 1) for the analysis of intended TP, since there are vast primary materials related to its design, and 2) for providing an orientation in interpretation of Transformability Profiles, since it tends to be recognized as the most advanced project in that sense. While many of the other projects had experienced significant compromises, the Architect in the case of NEXT21 had the most chance to achieve the highest INT TP. Although the building experienced transformations they were not spontaneous, but planned and controlled by the researchers so they cannot be counted as “actually experienced” and its EXP TP was not determined.

1 2 3 4 5 6 7 8 9 10 11 12 13 N21 14 15 16

Name	NEXT21
Designer(s)	Design committee of experimental apartment building NEXT21
Location	Osaka
Year of completion	1993
Housing type	Rental
Unit types	N/A (all units unique)
Source of drawings	Ref.4-18
No. of units	19 (initially)
Usefull area	32〜166

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
U shaped	Multiple staircases per floor	Frame

PLAN - Whole building block 4th floor S=1:500



PLAN - Unit 404 S=1:200

PLAN - Unit 405 S=1:200

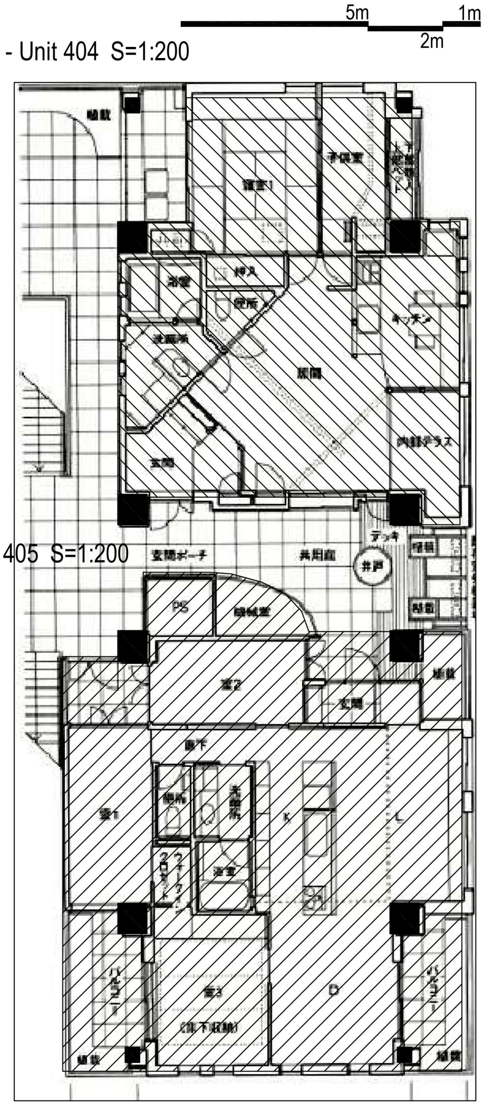


Fig. 4-14 Basic Information – NEXT21

4.3.14 San Life Sanda (Hyogo Century Housing) [SLS]

San Life Sanda is large housing complex which shares the main design characteristics with FCY, except for the slab, which is inverted type in case of SLS so the free distribution of installations is possible under the whole unit area. Frame has 6x6 m span, however, the apartment units were formed freely as it can be seen in Fig.4-15. Movable partitions and storage units were used as well.

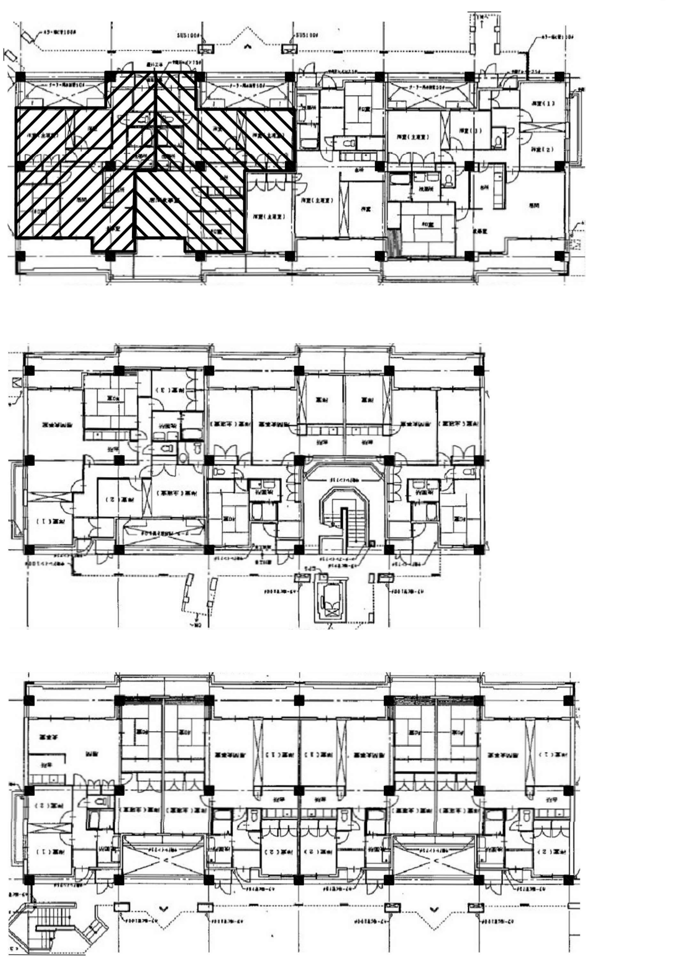
1 2 3 4 5 6 7 8 9 10 11 12 13 14 SLS 15 16

Name	San Life Sanda (Hyogo Century Housing)
Designer(s)	Hyogo Century Housing Research Investigation Committee, Ichiura Planning & Housing Consultants
Location	Sanda City, Hyogo prefecture
Year of completion	1997
Housing type	Condominium
Unit types	3 based on size: type 80 (A, B,C,D), 95 (A, B), 125 (A, B)
Source of drawings	Ref.4-19
No. of units	104 (Type80=48; Type95=36, Type125=12)
Usefull area	A-80m2, B-92m2, C-124m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	Two staircases + one sided corridor	Frame

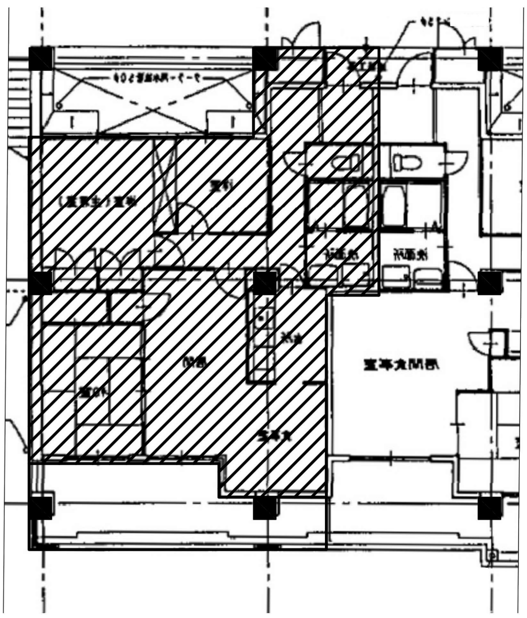
PLAN - Whole building blocks S=1:500

5m 1m 10m 2m



PLAN - Unit type 80A S=1:200

5m 1m 2m



PLAN - Unit type 80B S=1:200

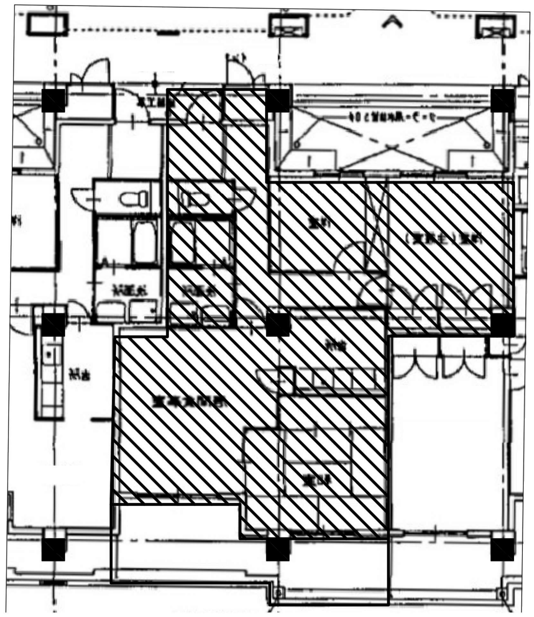


Fig. 4-15 Basic Information – San Life Sanda (Hyogo Century Housing)

4.3.15 Toyogaoka Tama New Town [TGT]

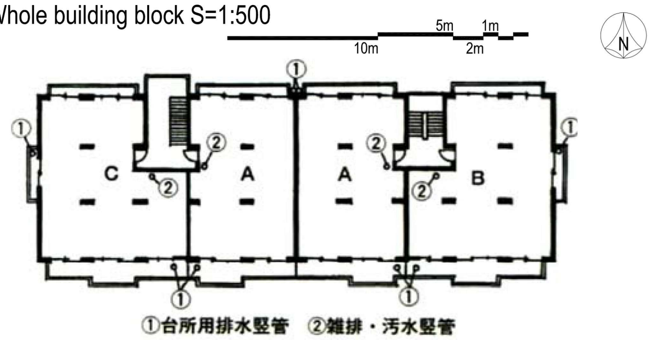
Toyogaoka housing complex is another free plan rental apartment building. Similarlly to GMT-H, GMT-M, there is three structural bays formed by set of four parallel wall-frames. There are three types of apartments. Free distribution of water/sewage installations was attempted by providing several supply/drainage points in opposite sides of teach unit.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 TGT	16

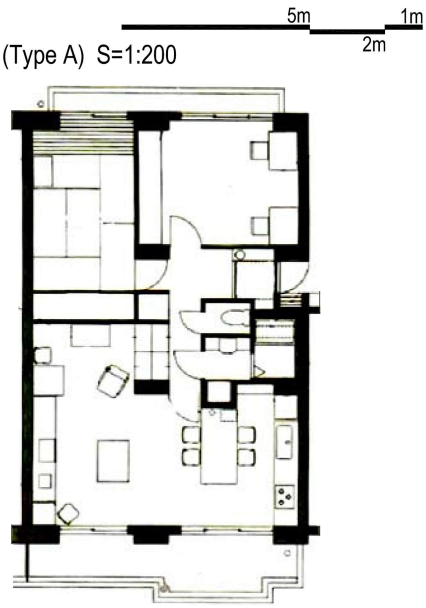
Name	Toyogaoka Tama New Town
Designer(s)	KODAN
Location	Toyogaoka-1, Tama New Town, Tokyo
Year of completion	1989
Housing type	Rental
Unit types	3 (A, B, C)
Source of drawings	Ref.4-16
No. of units	19
Usefull area	A-78m2, B-93m2, C-95m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	A staircase for three units in the north.	Wall + Wall-frame

PLAN - Whole building block S=1:500



PLAN - Unit (Type A) S=1:200



PLAN - Unit (Type C) S=1:200

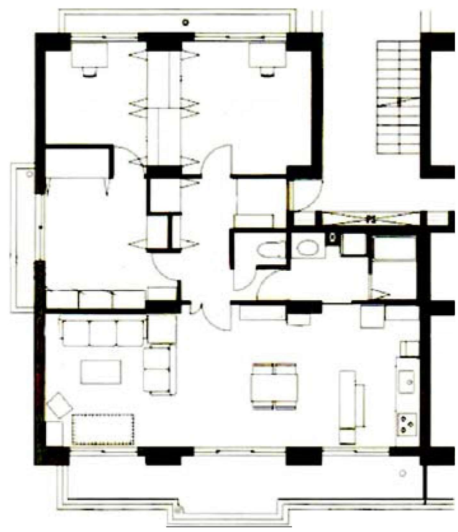


Fig. 4-16 Basic Information – Toyogaoka Tama New Town

4.3.16 Town Estate Tsurumaki-3 Low-rise [TET]

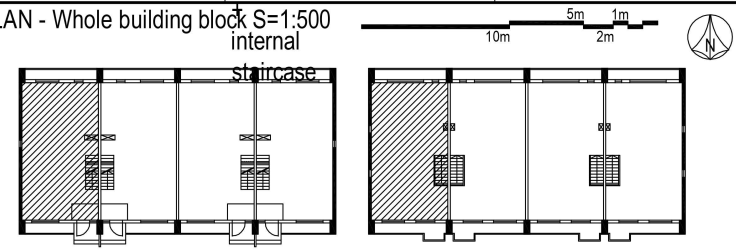
Town Estate Tsurumaki-3 is fairly different to all the other examples in the Example Set. It is a maisonette type. There are two space cells stacked one on top of the other which were formed by 4 elongated columns and concrete panels in one direction. The units are put next to each other forming rows of terraced houses. The space in each of the cells (floors) is further subdivided by non-bearing elements, including movable partitions and movable storage units which is common for the KEP buildings. There are three levels of finished layouts – free, semi-free, and all-set which were offered for User's choice.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 | 16 TET

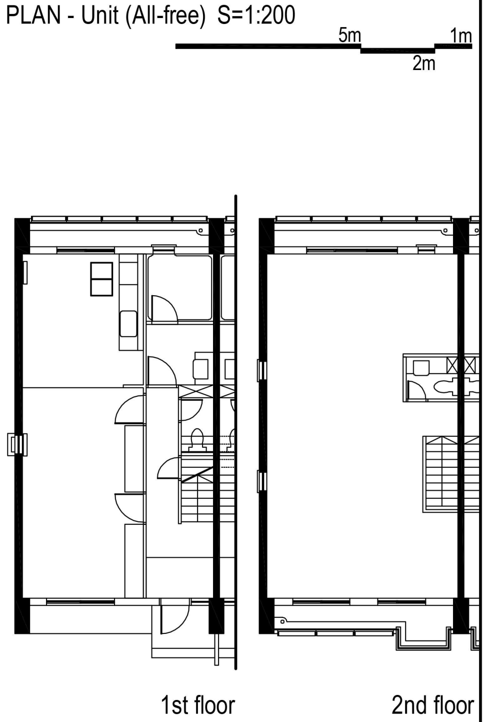
Name	Town Estate Tsurumaki-3 (low rise)
Designer(s)	KODAN (present: HUD), Kan Sogo Design Office, Soken Assoc. and Alsed Arch. Lab.*
Location	Tsurumaki-3, Tama New Town, Tokyo
Year of completion	1983
Housing type	Maisonette; Terraced houses
Unit types	1 Unit type with infill completed as: All-free, Semi-free, All-set
Source of drawings	Ref.4-9
No. of units	29
Usefull area	99~105m2

PLANNING PRINCIPLE	ACCESS PRINCIPLE	STRUCTURAL PRINCIPLE
I shaped	Entrance for each unit + internal staircase	Frame + Wall

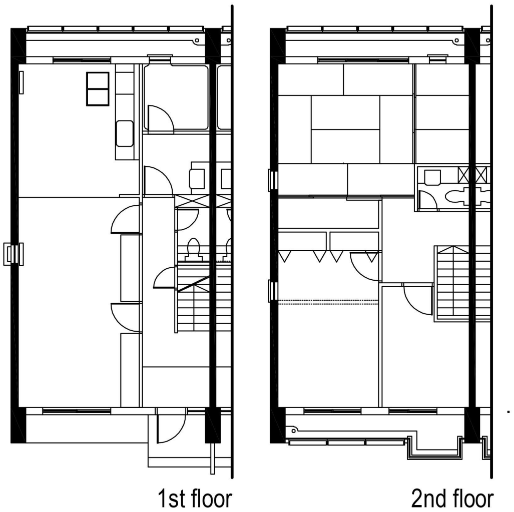
PLAN - Whole building block S=1:500



PLAN - Unit (All-free) S=1:200



PLAN - Unit (All-set) S=1:200



PLAN - Unit (Semi-free) S=1:200

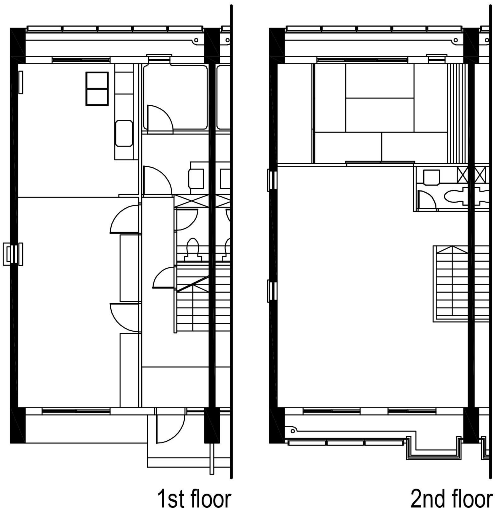


Fig. 4-17 Basic Information – Town Estate Tsurumaki-3

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5. INTENDED TP ANALYSIS

In this chapter, designer's intentions regarding transformability for each building/housing complex presented in Chapter 4 were analyzed. The objectives of this analysis are three-fold:

1) Confirming the applicability of DFT Index Determination Protocol to analyzing of designer's intentions.

2) Identifying and systematizing design strategies toward transformability as a property of building[1] in case of multi-family SI apartment houses.

3) Contributing to analyzing designer's intentions confined in architectural material[2].

As available materials for each example varied greatly the depth of the analysis varied as well, however, in order to confirm the applicability of the DFT Index Determination Protocol proposed in Chapter 3, the focus was rather on having as many examples covered in a consistent way and outlining the logic behind the protocol than on drawing undisputable conclusions from the results. The analysis of intentions from architectural materials is a two-way-street, and sometimes it is necessary to formulate the protocol and indicate important point even before the data exist so that the attention to such details can be paid in the future.

5.1 Method and Materials

DFT Index Determination Protocol (DFTIDP) was used to analyze materials relevant for designer's intentions that affect transformability. Not only direct statements about the issue but also any materials that were made before or during planning/designing or shortly after it as description of the design were relevant. Such materials inevitably contain designer's intentions regarding transformation, however, due to the non-existence of the single concept of transformability as a property of building in the past they may not be always clearly expressed and/or articulated in a systematic and consistent manner. Since DFTIDP takes only necessary and universal steps of transformation process (corresponding to Q1~Q4), the intention can be extracted even if designer did not bear the concept of transformability same as defined by this work[3] in mind, and even if the intention was not considered important enough for architect to dedicate it a special mention. Therefore, TP derived by this method describes overall intention regarding transformability as of design stage, and as such it can be used for various comparisons and further analysis.

The materials were searched primarily for the statements that explicitly state designer's intentions regarding transformations of certain Building Parts, but the intention was also deduced from the neutral design materials when that is necessary and possible. For instance, designing movable partitions in certain

[1] In this case only multi-family Skeleton/Infill apartment houses were analyzed, but the same logic can be applied to any building.

[2] Obviously, the analysis of intentions of architects confined in the documents related to design is of interest to many other fields.

[3] Designer might have known adaptability, flexibility, responsiveness or some other concept instead.

manner have logical implications to transformability of PLAN, and even if not explicitly claimed by designer it is safe to assume it as his/her intention and indicate that the source for the conclusion is secondary material. When there was no sufficient information or the information could be interpreted in more than one way or led to contradicting conclusions, then the intention is judged as not available (DFT[4] =N/A[5]).

Because of the above, in order to fairly evaluate intended transformability, it is necessary to indicate reliability and relevance of the data so the contents that led to positive conclusions on DFT Index were separated in two groups:

i) explicit statements in written form[6] – verbal or drawn statements made by designer that describe certain transformation(s).

ii) observed in technical materials – standard technical documentation and technical descriptions are statements as well, however, they may lead to more than one conclusion so that they must be considered material of secondary reliability and since their theme is not focused on any aspect of transformability, it is less relevant.

5.2 Analysis of Intended Transformability

Concretely, for each BP, materials relevant to designer's intentions regarding transformability were searched. When related material was found, transformation(s) that it suggests/implies is examined by DFTIDP (Q1~Q4)[7]. The results were presented like in the Fig. 5-1.

For the purpose of showing the detailed explanations for determined DFT Index values, TP in this figure is deformed: on the left-end side of Fig.5-1 there are Building Parts and its selected parameters, on the right-end side there is TP mesh with DFT Index values, so the space in-between the two is used for explanation boxes which are also separated in two columns, based on reliability and relevance of the materials (i & ii). Dotted line ending with arrow starts from the explanation box, goes over the box in which the sources are indicated, and points to DFT index value in TP mesh. Intended TP line was always marked by dashed line to be consistent to comparative analysis covered in Chapter 7.

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[4] Shorter for "DFT Index value"

[5] Though it has to be noted that a lack of clear intention regarding certain BP is also a valuable information about overall intention toward transformability of the whole building.

[6] This is not to be confused with a casual statements or opinions that are not elaborated enough. Not only that designers cannot always express their own ideas accurately by words only, but also the possibility that they deliberately choose to be ambiguous must not be excluded. For that very reason the author ruled out conducting a survey of designers' opinions/assessments of their own intentions as a material for this analysis. However, if certain intention/idea is stated clearly and supported by certain scheme/diagram it is still the most direct insight into designer's intentions.

[7] The analysis of the actual examples in this paper will not present all of these steps. The Author would like at this time to discuss only the most important points and not to lose readers' attention. Also if there are relevant information in both primary and secondary materials only the primary one will be shown.

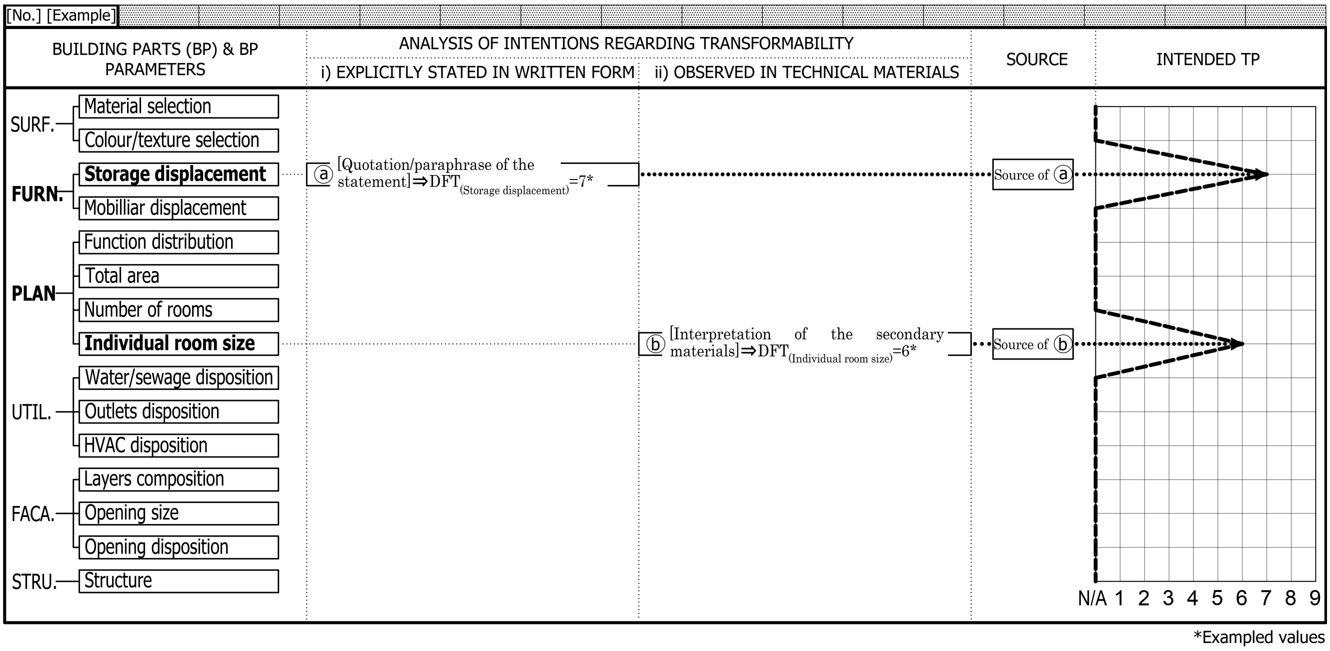

Fig.5-1 Analysis of Intentions Regarding Transformability

For easier navigation, the very content of the material that led to DFT Index value was indicated with an encircled alphabet letter (like this: ⓐ). In cases of explicit statements, the exact quote/explanation and reference to the source were given, however, when a reasoning for determining DFT Index value was not as straight-forward, additional explanations (including graphical contents on the right side of a page) were provided, and indicated by the same alphabet letter. The accompanying description in the text was also marked by the same symbol, so it should be easy to follow the reasoning procedure for each DFT Index value, as well as the TP in its entirety. To avoid redundancy of DFT Index evaluation reasoning, only the place where it was already discussed was indicated in brackets (like this: [Chapter number], ⓨ).

5.2.1 Century Heights Aira/Station Heights Kinko [CHA/SHK]

The housing complexes were built according to CHS ("C" stands for "century") so the durability of the fixed construction was considered as part that lasts 50-100 years (ⓐ in Fig.5-2). Because of this, and ⓑ, it may be concluded that the structure part of the façade is decided and controlled by the system outside of the User's discretion -society, therefore **<DFT$_{(STRU., FAÇA.)}$=1>**. ⓒ There is obvious intention of the Architect to provide all the rooms with natural ventilation, and designate the position of AC on façade, therefore **<DFT$_{(HVAC)}$=1>**. However, this is not supported by any explicit material stating such intention, but observed in the plan and elevations, so it is indicated as judgement based on secondary materials (ii). In ⓓ, it is assumed that the Architect intentionally used conventional construction methods for disposition of outlets, therefore the Architect must had been aware that it can be replaced by skilled professional **<DFT$_{(outlets\ disp.)}$.=4>** (the logic also applies to ⓚ). In ⓔ, ⓕ, ⓗ, ⓙ, some explicit statements in verbal form or drawings were given about transformability (Fig.5-3): limited possibilities of transformations according to “life stages of standard family”[8] in “transformable zone”, ergo **<DFT(No. of rooms, Ind. Room size)=6>**, but **<DFT(Funct. dist., Total area)=1>**.

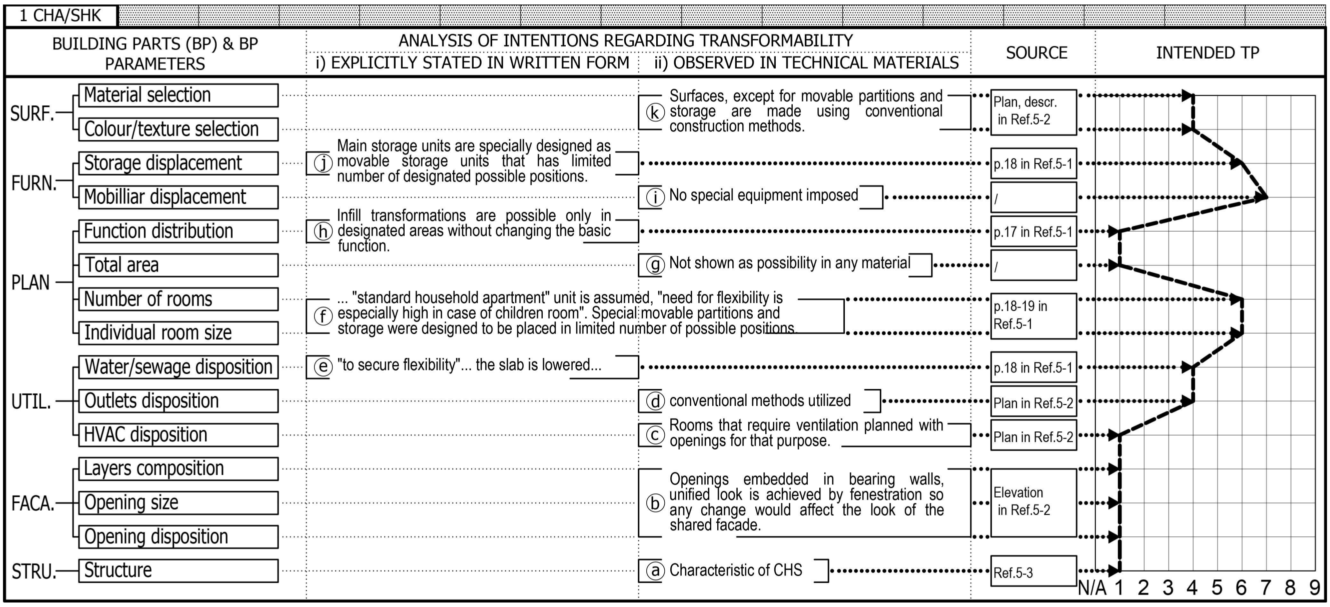

Fig.5-2 Intentions Regarding Transformability – Century Heights Aira/Station Heights Kinko [CHA/SHK]

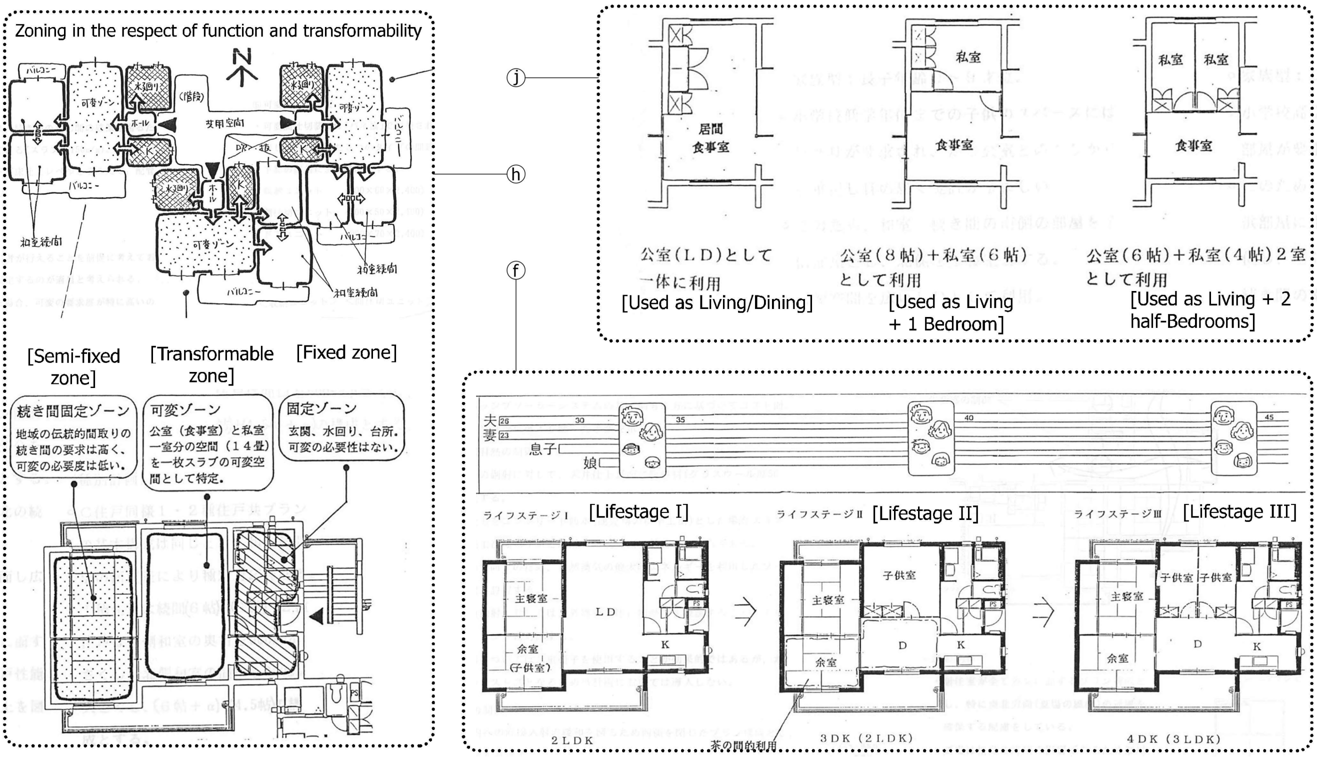

Fig.5-3 Figures from Original Materials[9] Explaining the Concept of [CHA/SHK]

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8 Another characteristic of CHS.

9 Ref.5-1

5.2.2 Cherry Heights Kengun [CHK]

In Fig.5-4, INT TP of CHK is shown. Statements ⓐ and ⓑ imply **<DFT(STRU., FAÇA.)=1>** (5.2.1 ⓐ, ⓑ). The ventilation shafts and other supply shafts/pipes/wires were intentionally grouped in the middle of each building, in “shared space” (ⓒ). Because of this, ventilated rooms had to be placed adjacent to it, and become “fixed zone” **<DFT(HVAC)=1>**. While CHS uses double floor/ceiling for distribution of pipes and shafts, its goal was an easy ”exchange/maintenance” (ⓕ). From ⓓ, there is certain space for adjustments of position of wall outlets, however, within the Architect-provided double wall, this still requires skilled professional. Similarly, from ⓔ, position of pipes, although shown as impermanent, actually depends on the skilled workers. Therefore, the intention was: **<DFT(Outlets disp., w/s disp.)=4>**. From ⓕ, although it is tempting to decide **DFT=6** because of the “life stages” and “menu system”, such partition walls were designed that skilled professionals are still required for its relocating: **<DFT(No. of rooms, Ind. Room size)=4>**. Positioning of mobiliar is not fixed in any particular way, like in ⓘ, from which: **<DFT(Mob. Disp.)=7>**. From ⓙ, skilled professional’s help is necessary, therefore: **<DFT(Stor. Disp.)=4>**. As noticed in ⓚ, usage of double wall system comes with complete wall, subsystems in it, and certain aesthetical statement. It is not possible to edit wall surfaces partially, but the overall reconsideration is imposed, therefore: **<DFT (SURF.)=3>**.

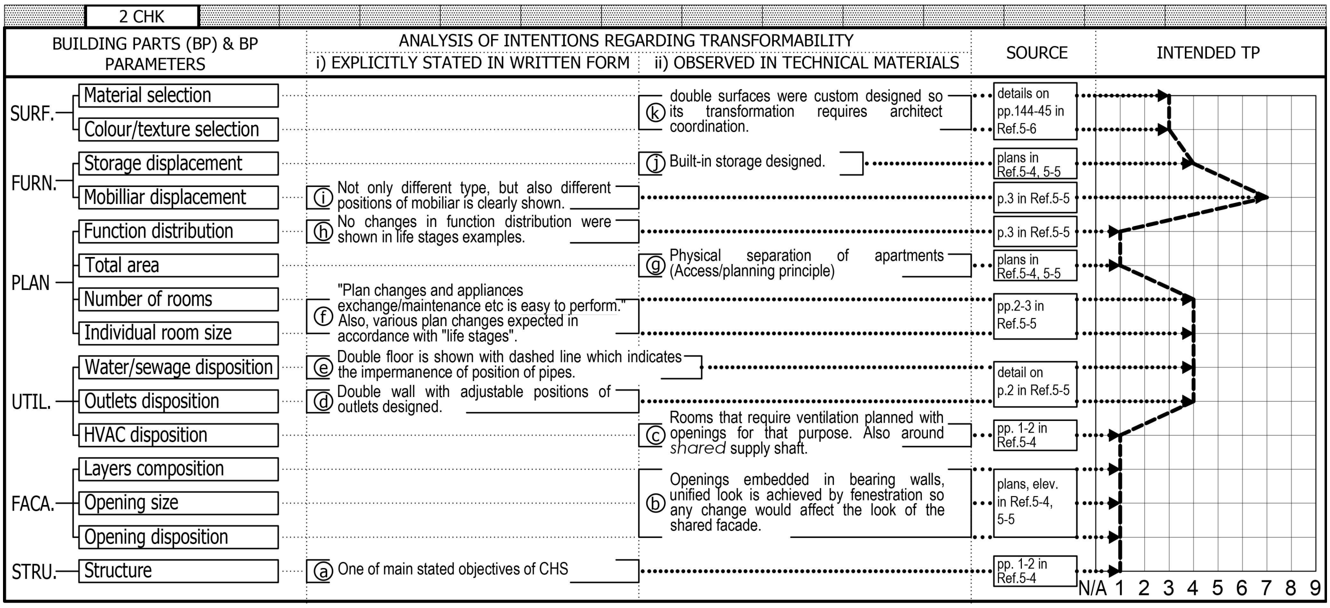


Fig.5-4 Analysis of Intentions Regarding Transformability – Cherry Heights Kengun [CHK]

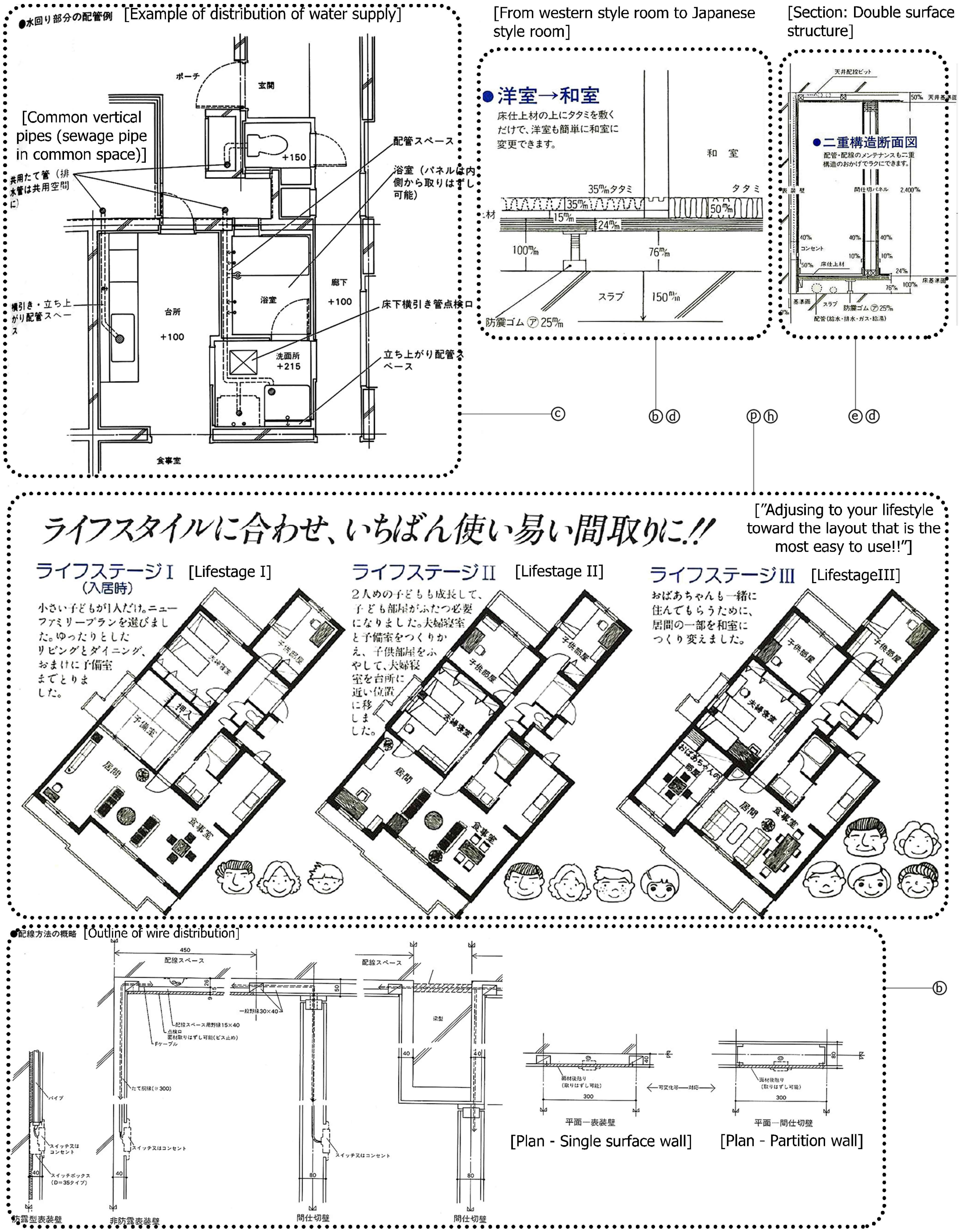


Fig.5-5 Figures from Original Materials[10] Explaining the Concept of CHK

[10] All figures from Ref.5-5, except ⓑ (in the bottom) and ⓒ, which are from Ref.5-6

5.2.3 CI Heights Machida [CHM]

From statements ⓐ and ⓑ: **<DFT(STRU., FAÇA.)=1>** (5.2.1 ⓐ, ⓑ). As stated in ⓒ (Fig.5-6 and Fig.5-7), certain advanced measures in design of utilities were taken. However, the adopted systems were not intended for manipulation by User himself, in other words, the designed system is still out of User's discretion zone, requiring skilled professionals to help. Therefore, **<DFT(FAÇA.)=4>**. There is actual confirmation that this issue was actively considered. The head of the design team of Takenaka Corp., Mr. Ando, in statement ⓓ, clearly expresses some of the intentions regarding transformability. He adds that "a layout has lifecycle of at least 5 years, and it is limited by patterns (of transformations). Therefore, there is no need for designing sophisticated movable partitions." Nevertheless, the "user himself" transformability is intended, just not very often, therefore **<DFT(No. of rooms, Ind. room size)=6>**. As for the storage (ⓕ) and mobiliar (ⓖ), it is: **<DFT(Storage disp.)=4>** (5.2.2 ⓙ), **<DFT(Mob. disp.)=7>** (5.2.2 ⓘ), respectively. The surfaces were partially made as double surfaces, whole ceiling, floor under bathroom, and small parts of outer walls - but not partitions (ⓗ). Most of these surfaces were finished by conventional methods (vinyl cross), so they can be transformed accordingly, by skilled professionals: **<DFT(SURF.)=4>.**

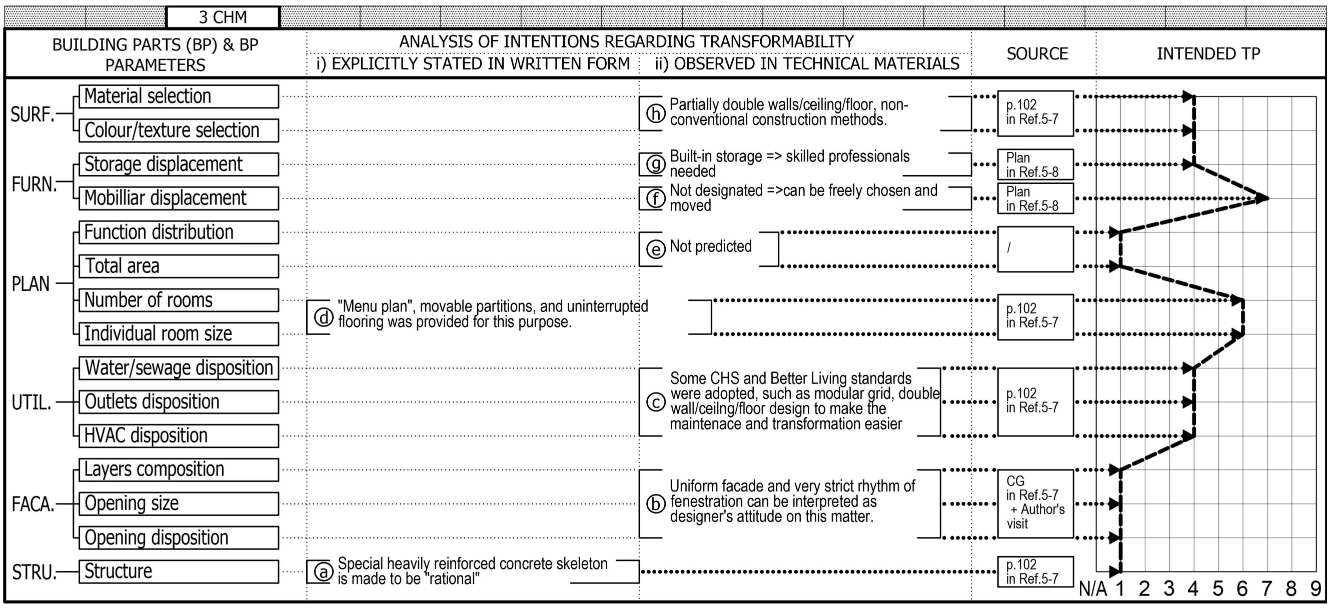


Fig.5-6 Analysis of Intentions Regarding Transformability – CI Heights Machida [CHM]

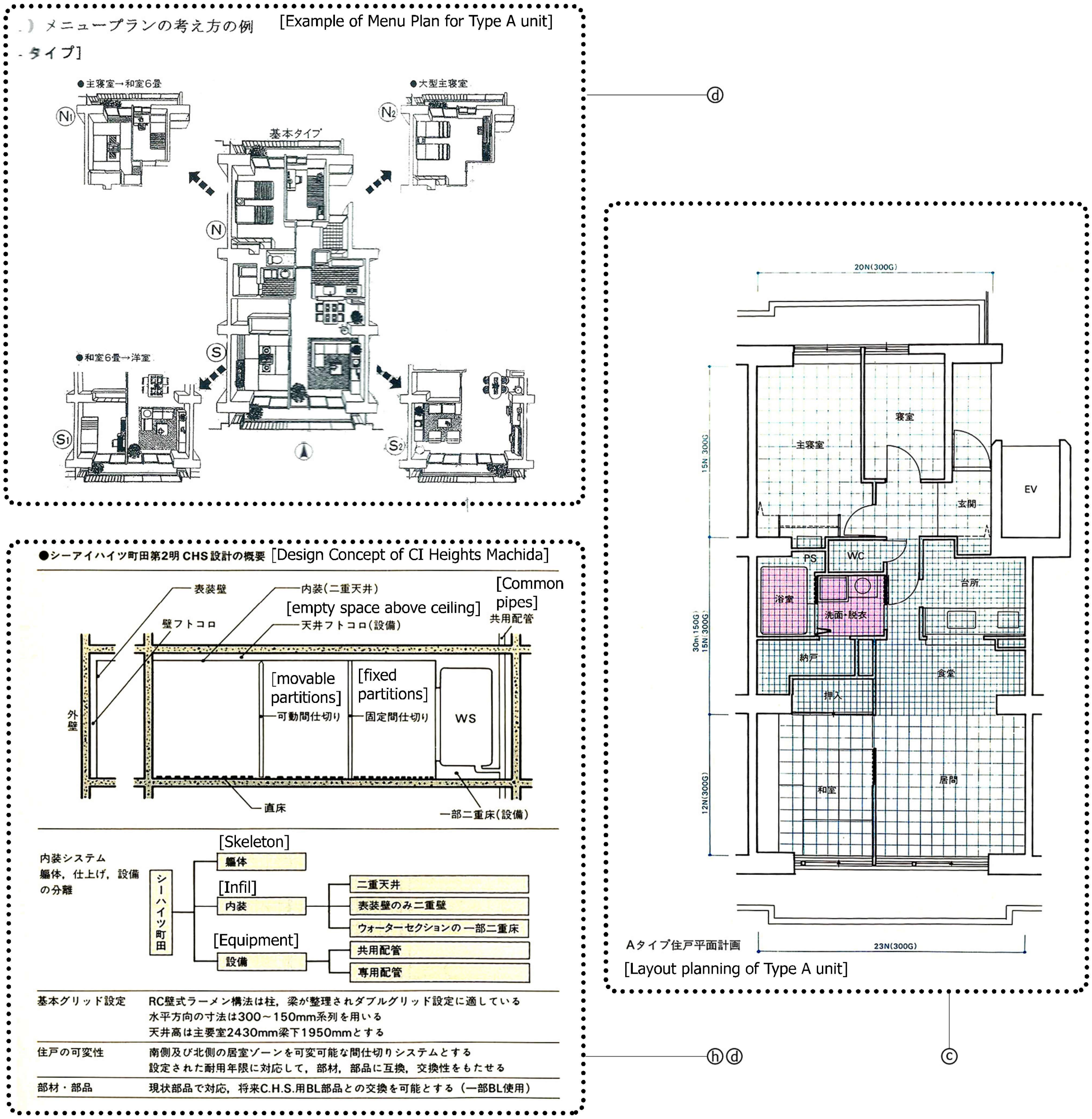


Fig.5-7 Figures from Original Materials[11] Explaining the Concept of CHM

[11] Pp. 102-04 in Ref.5-7

5.2.4 Estate South Senri (Inokodani) [ESS]

Estate South Senri belongs to different development stream than previous examples[12] and its INT TP is shown in Fig.5-8. There are many common points with previous examples, but more explicitly stated, such as classification of skeleton as fixed, as in ⓐ (Fig. 5-8, 5-9). Transformable façade was proposed in early phase (ⓑ′ in Fig.5-9), but finally fixed fenestration embedded in bearing walls was adopted like in ⓑ. Should the former was adopted **<DFT(FAÇA.)=4>** could be concluded, but since the position and size of windows were now part of shared façade it becomes **<DFT(FAÇA.)=1>**. Ventilation shafts were designated in upper part of "water/section zone" being leveled with beams ⓒ. This is very important information as it implies the aesthetic role of these elements, so their possible displacement has repercussions to overall look, thus requires expert opinion, therefore **<DFT(HVAC)=3>**. Statements ⓔ and ⓓ confine important information about Architect's intention – TSHS, which involves users in design, can benefit from it in design phase. However, that is flexibility of design, not transformability in sense of this work. Therefore, **<DFT(W/S disp., Outlets disp., No. of rooms, Ind. room size)=4>**. The Architect explicitly stated the goal of achieving more varied layouts, as shown by ⓗ (statement in Fig.5-8, and exampled apartments in Fig.5-9), which implies ⇒**<DFT(Func. distribution)=4>** since this is to be achieved with help of skilled professionals. As previously shown, from ⓘ, ⓙ, ⓚ ⇒ **<DFT(FURN., SURF.)=4>** (5.2.1 ⓘ, 5.2.3 ⓙ, 5.2.1 ⓚ).

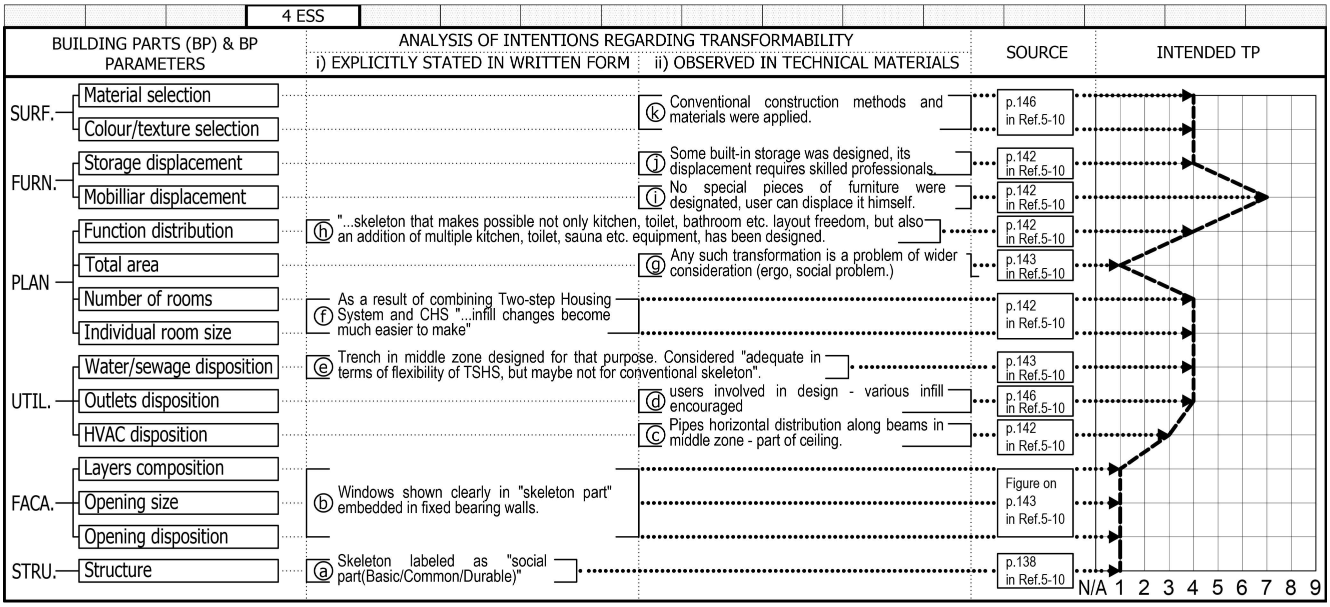


Fig.5-8 Analysis of Intentions Regarding Transformability – Estate South Senri (Inokodani) [ESS]

[12] At that time CHS and TSHS had still been developed separately.

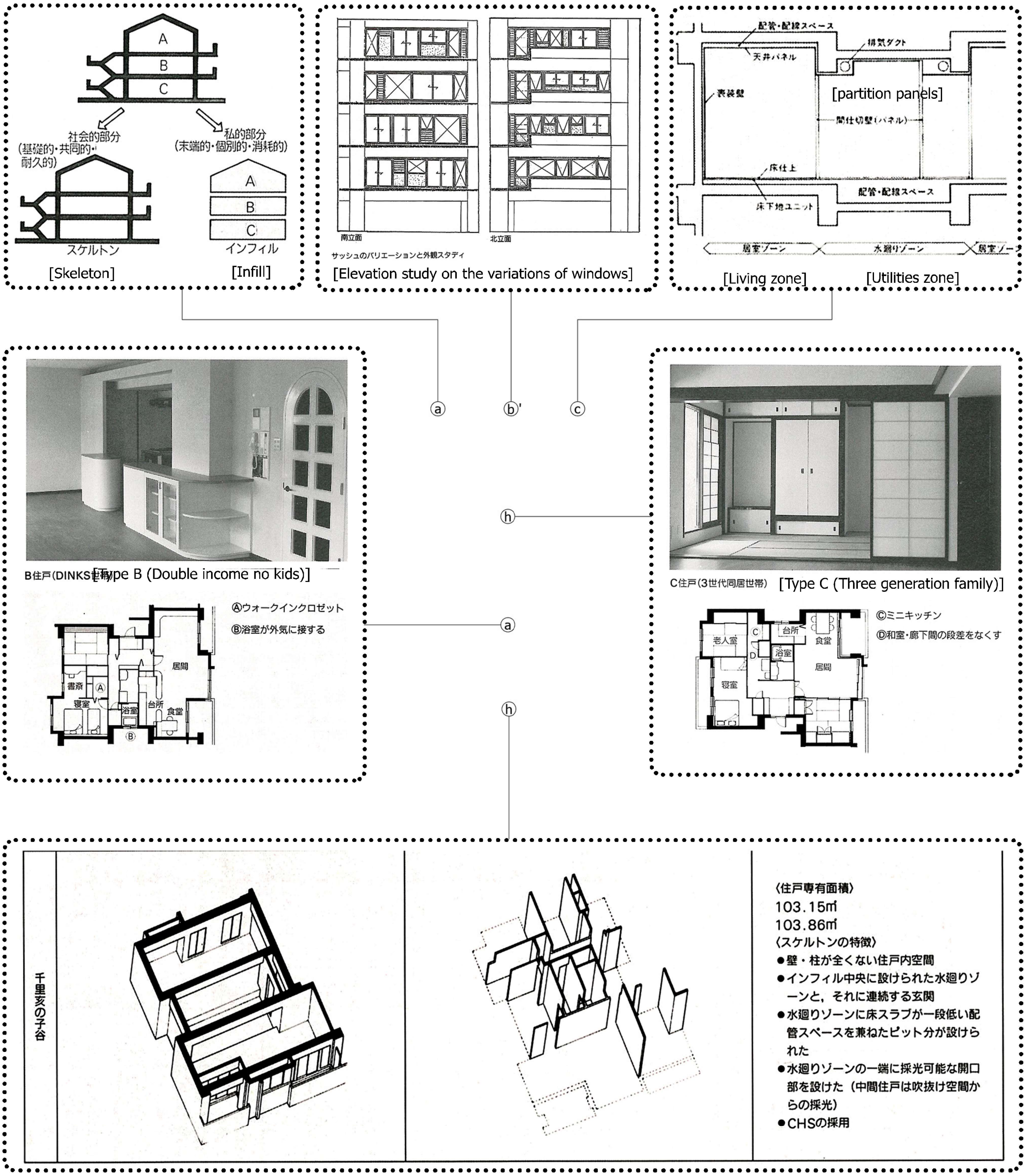


Fig.5-9 Figures from Original Materials[13] Explaining the Concept of ESS

[13] Pp. 102-04 in Ref.5-7

5.2.5 Estate Tsurumaki-3 [ETM]

Intended TP in case of ETM is evaluated based mostly on drawings observed in promo pamphlet and general characteristics of KEP building system[14]. In Fig.5-10 and Fig.5-11 it can be seen in the plans of Type B apartment that openings were incorporated in the load-bearing outer walls and so it is determined that **<DFT(FAÇADE)=1>**. Also, the usage of movable partitions and movable storage units that doubles as partitions can be observed **<DFT(Storage disp.)=6>**. At the same, there were two zones (northern and southern) which were intended for repartitioning, since possible positions of designated movable partitions and storage units were marked by dashed line (Fig.5-10), therefore **<DFT(No. of rooms, Ind. room size)=6>**.

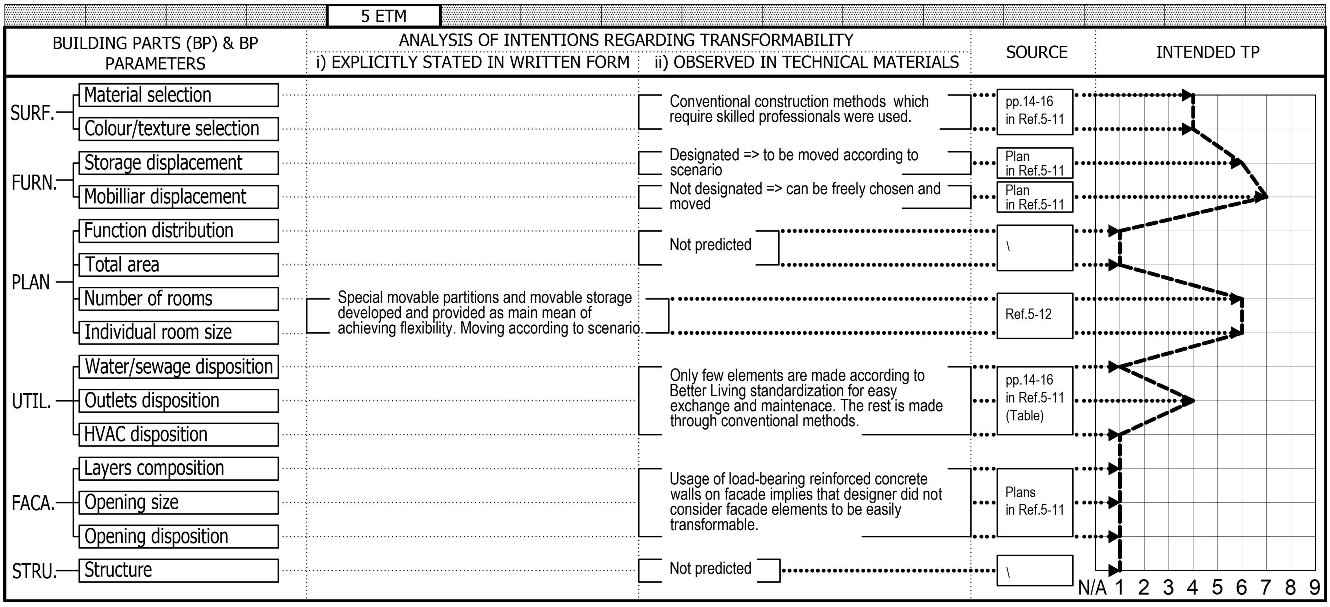


Fig.5-10 Analysis of Intentions Regarding Transformability – Estate Tsurumaki-3 [ETM]

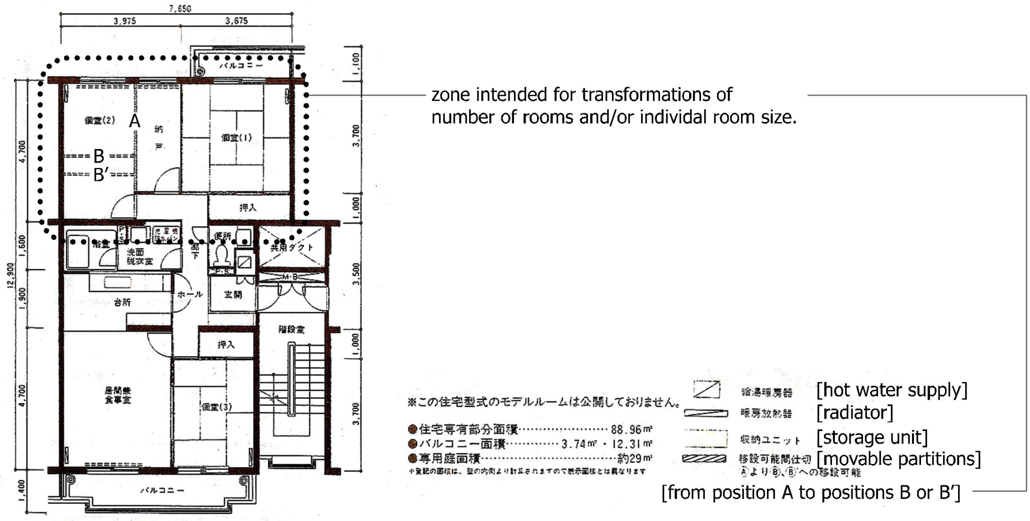


Fig.5-11 Figures from Original Materials[15] Explaining the Concept of ETM

14 Ref. 9 and Ref. 10

15 Pp. 102-04 in Ref.5-7

5.2.6 Flex Court Yoshida [FCY]

Designers of FCY showed many of their intentions explicitly through promotion pamphlet[16]. 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 3.3) it can be concluded that **<DFT Index (FACADE, UTILITIES, SURFACES)=1>**. Statement ⓓ shows designer's consideration for transformation that residents can execute alone (Q3), however, in manner designated by the designer (Q4), therefore: **<DFT Index(Number of rooms, Individual room size)=6>**. **DFT Index(Storage displacement, Mobilliar displacement)=6, 7**, respectively, were derived from looking up into plans and technical schemes, the findings are marked with ⓕ. The difference is that the mobiliar can be moved freely (Q4) by user himself (Q3).

In Fig.5-13 we can see that the Architect had clear intention about the relation between the User (tenant) and bodies envisioned to intermediate in the process of transformation. Also, the façade shows that fenestration is not a visual element in composition which is achieved by deep balconies and their shaping. Additionally, installations and their supposed variety is shown in innovative unconventional structural system.

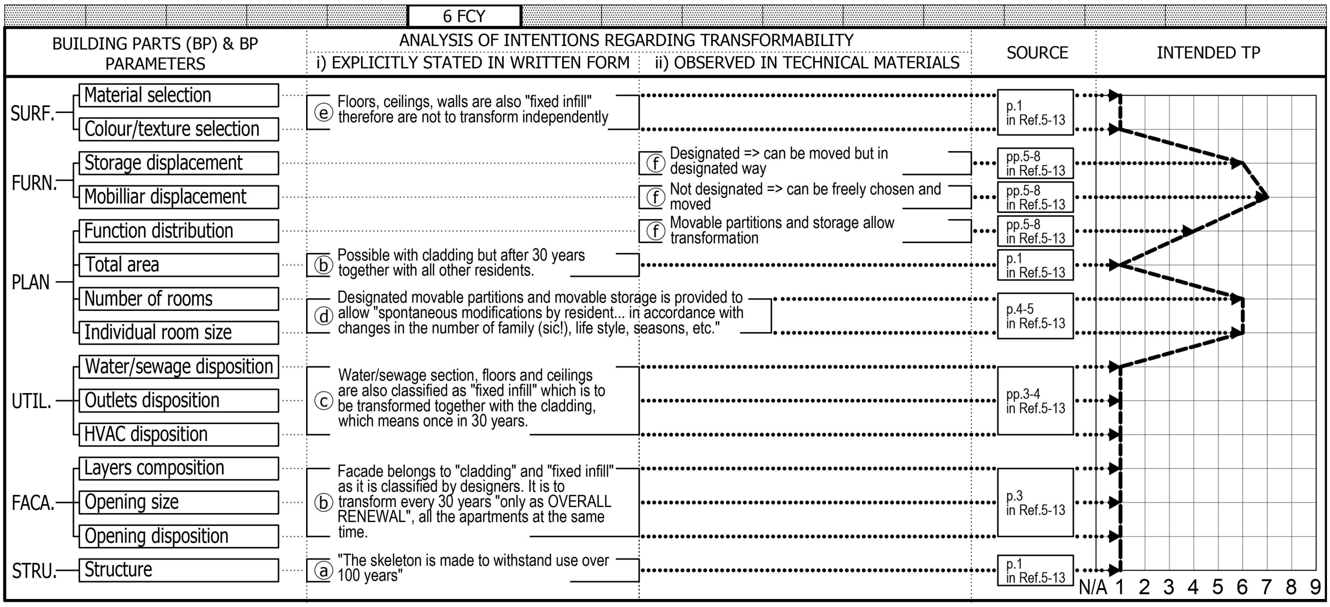
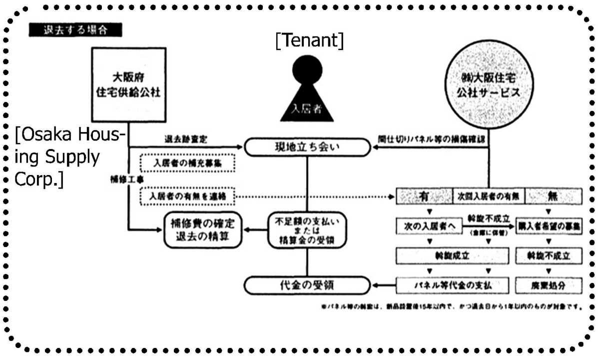


Fig.5-12 Analysis of Intentions Regarding Transformability – Flex Court Yoshida [FCY]

[16] Ref.5-13



Complex relationship between the tenant and public institutions when realizing certain transformations

Characteristic facade emphasizing "checkerboard" slab system

Explicitly stated separation of "Cladding", "Fixed Infill", and "Variable Infill" and when they can be transformed

ⓐⓑⓔ

ⓒ

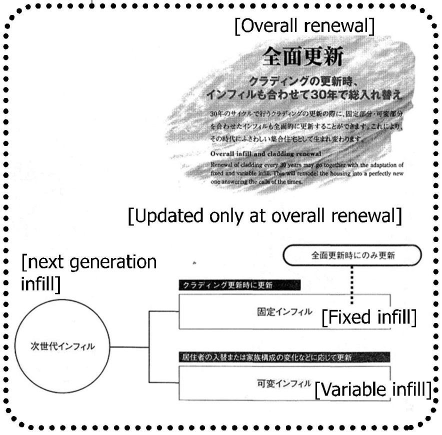


Fig.5-13 Figures from Original Materials[17] Explaining the Concept of FCY

[17] Ref.5-13

5.2.7 Flexsus House 22 [F22]

Since the project was very ambitious there were many follow up publications by its designers directly explaining the design[18]. The Architect considered skeleton in its original meaning – not as a skeleton, but as a support. However, its separation from infill and social context is even more emphasized as statements ⓐ illustrate **<DFTI(structure)=1>**. Under ⓑ it is shown in writing and drawing that the façade is open for transformations under certain rules (specially designed interface). For the purpose of maintaining of "visual integrity" of building special architect-coordinator was assigned, therefore **<DFTI(FAÇADE)=3>**. Items in ⓒ were mentioned in context of allowing flexible positioning of partitions and wall outlets. Two original advanced technologies for drainage mentioned in ⓓ were developed as the Architect considered this aspect of transformation important. However, the transformations remain to require skilled professionals to be performed, therefore, **<DFT(UTILITIES)=4>**. Transformability of infill is clear from ⓔ and ⓕ, but also from various infill designs for all dwelling units, including movable partitions and storage. Except for unit T-2, such transformations still require help of skilled professionals, **<DFTI(PLAN)=4>**. Custom (embedded) technologies always have implications to other elements **<DFT(SURFACES)=3>**.

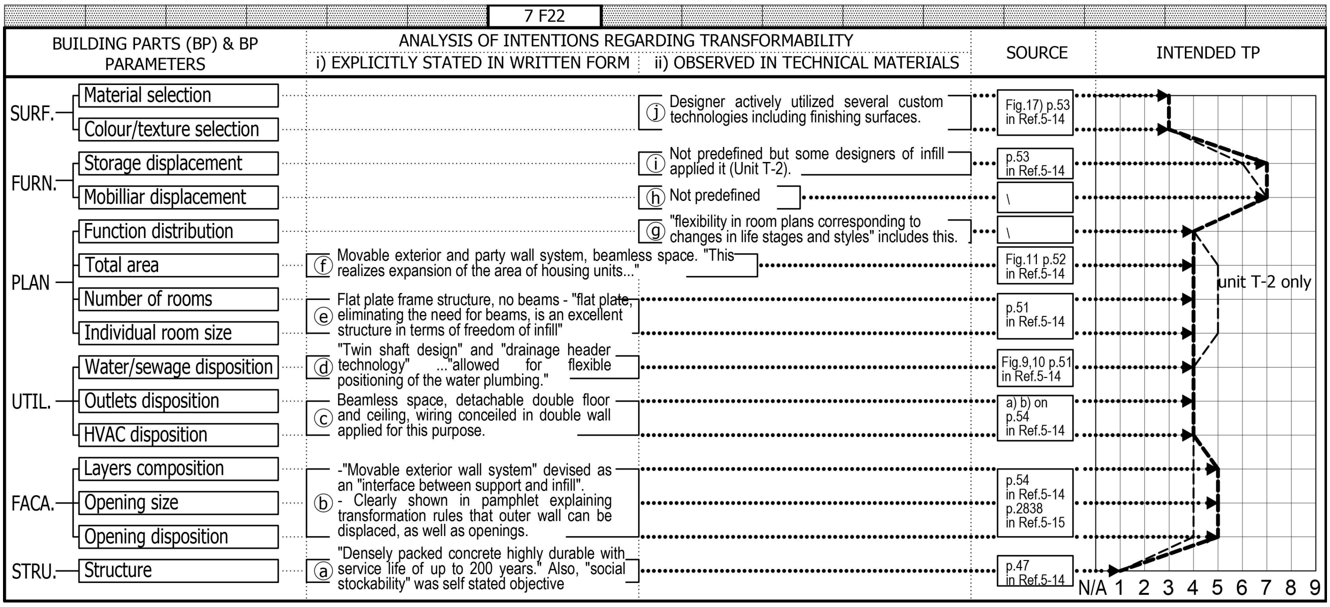


Fig.5-14 Analysis of Intentions Regarding Transformability – Flexsus House 22 [FH22]

[18] Ref.5-14, Ref.5-15, Ref.5-16

Interface for designing (or transformations)

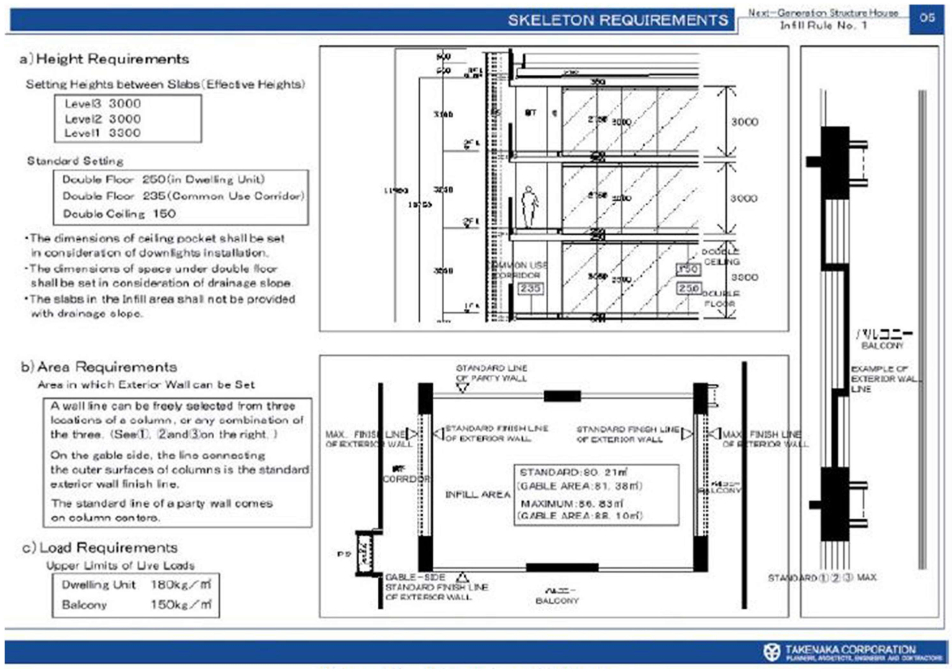


Figure 9 Example of infill rules

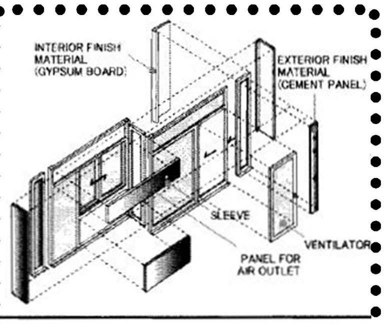
Variable position of outer wall

ⓑ

Modularly coordinated facade system

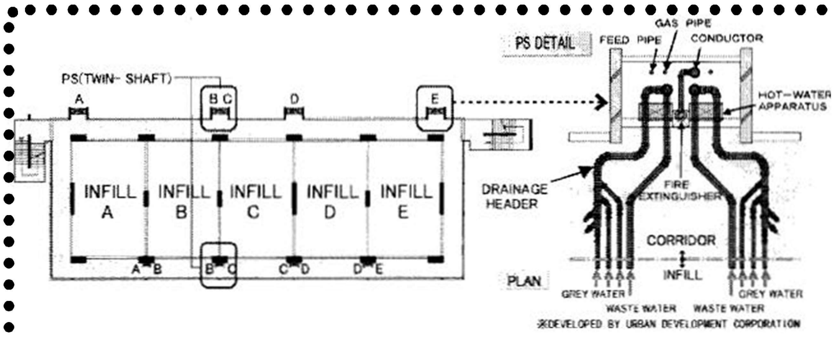
ⓓ

ⓕ

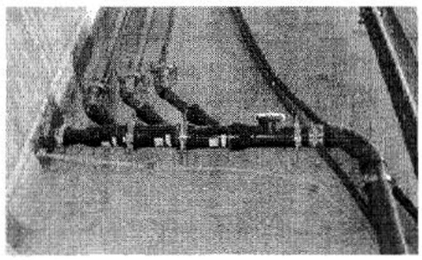


11) Movable exterior wall system

Drainage system on both sides of the building to shorten the path and reduce the necessary space for pipes.



9) Twin-Shaft / Drainage system



10) Drainage system

Fig.5-15 Figures from Original Materials[19] Explaining the Concept of F22

[19] Ref.5-13

5.2.8 Green Maison Tsurumaki-3 High-rise [GMT-H]

There were limited and only indirect clues about the design intentions of Green Maison Tsurumaki -3 housing complex. A research on its transformations, led by some of its designers (Prof. Seiichi Fukao et al.) was used as a source[20]. Figure 5-16 using drawings from this paper shows the outline of the apartment house. There are three structural fields but no strict zoning was designated. Room usage was initially designated, with living/dining/kitchen being integrated in a space in two structural fields, stressing the possibilities due to relatively small beams and columns. From statement ⓐ we conclude intention as **<DFT(UTIL.)=1>**, and from ⓑ **<DFT(FACA.)=1>**. On the other hand there is obvious effort to reduce the footprint of structural elements, especially between the three zones, and this was supported by ⓒ which suggests certain plan formation through removing or adding partitions, so **<DFT(No. of rooms, Ind. room size)=6>**. Movable partitions were used but movable storage units were not used, instead buil-in type storage was proposed **<DFT(Storage disp.)=4>** (ⓓ). There was no suggestion that unconventional finishing surfaces were used **<DFT(SURF.)=4>** (ⓔ).

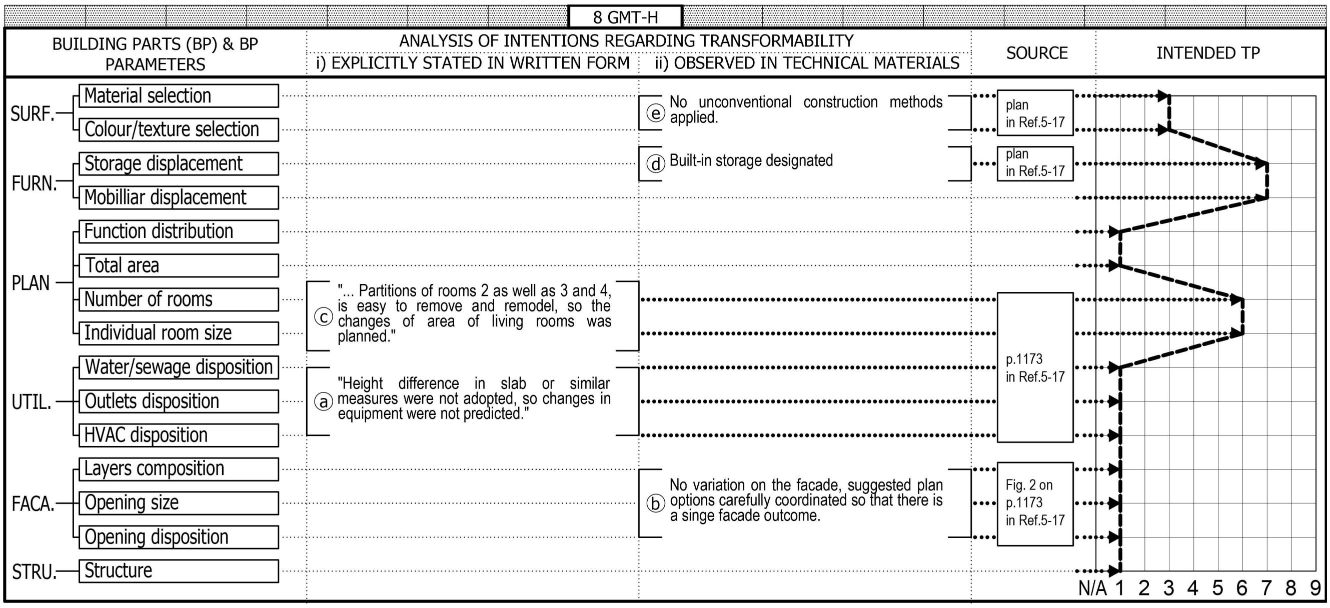


Fig.5-16 Analysis of Intentions Regarding Transformability – Green Maison Tsurumaki-3 High-Rise [GMT-H]

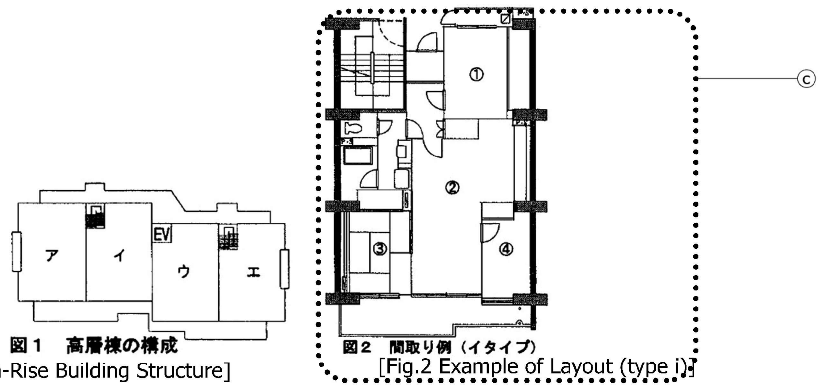


Fig.5-17 Figures from Original Materials Explaining the Concept of GMT-H

20 Ref.5-17

5.2.9 Green Maison Tsurumaki-3 Middle-rise [GMT-M]

There were limited and only indirect clues about the design intentions of Green Maison Tsurumaki -3 housing complex. A research on its transformations, led by some of its designers (Prof. Seiichi Fukao et al.) was used as a source[21]. Figure 5-18 was made using drawings from this paper, and it shows the outline of the apartment house. ⓐ We can see that zones and installation pit was used, however, in the menu plan there is no suggestion about the change of the middle zone, therefore we can conclude intention as **<DFT(UTIL.)=1>.** ⓑ Also, there was no variation on the façade, but menu plan variations were set in such a way that they form a single façade outcome, so **<DFT(FACA.)=1>**. ⓒ On the other hand there is obvious effort to reduce the footprint of structural elements, especially between the three zones, however, this was not supported by any suggestion of free plan formation in menu plans, so we may safely assume that the plan is supposed to be changed according to Architect envisioned menu plan **<DFT(No. of rooms, Ind. room size)=6>**. ⓓ Movable partitions and storage units were used **<DFT(Storage disp.)=6>**. ⓔ There was no suggestion that unconventional finishing surfaces were used **<DFT(SURF.)=4>**.

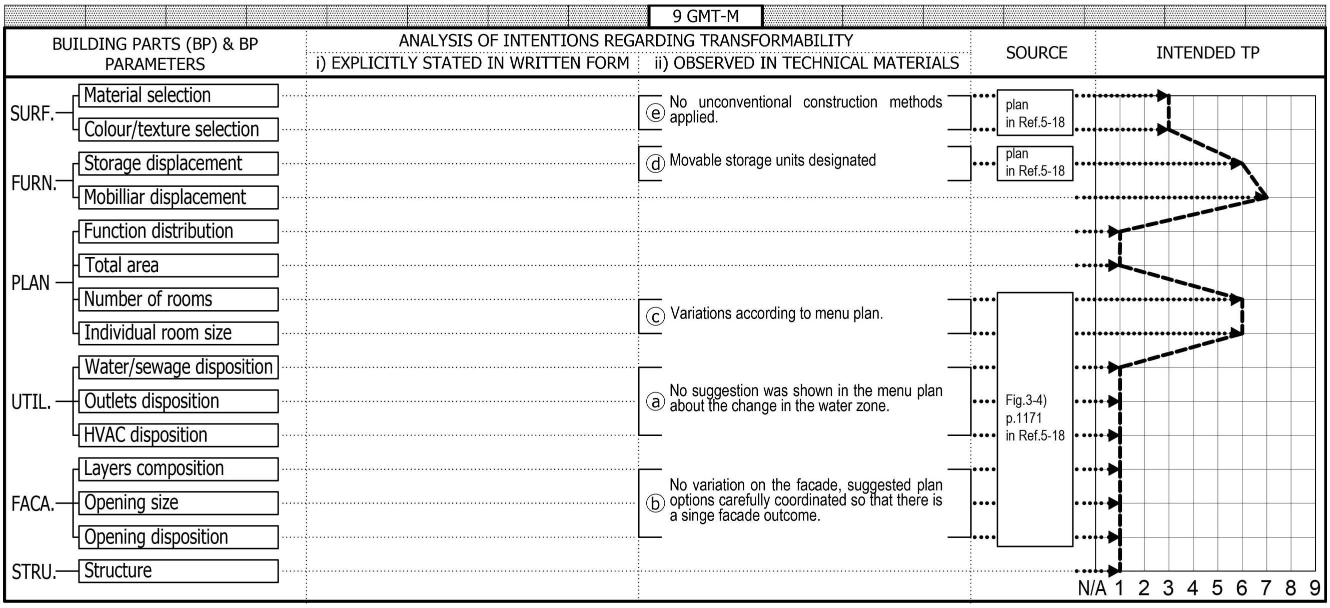


Fig.5-18 Analysis of Intentions Regarding Transformability – Green Maison Tsurumaki-3 High-rise [GMT-M]

[21] Ref.5-18

5.2.10 Green Village Utsugidai [GVU]

The example was excluded from INT TP analysis due to insufficient data available.

5.2.11 Hikarigaoka Parktown [HGP]

The example was excluded from INT TP analysis due to insufficient data available.

5.2.12 Momoyamadai-B Housing Complex [MDB]

Momoyamadai-B has an interesting and quite unusual approach to transformability among the examples cover in this paper. There are two structural bays separated by wall-frame. Since façade is completely integrated to RC structural walls, and water section is dedicated in the "fixed" area **<DFT(STRU., FACA., UTIL.)=1>** (ⓐ, ⓑ). No. of rooms was not fixed, and the way of partitioning and the partitions itself were not specifically designed, but rather zones and modular grid was proposed. Since professionals were required for editing of the partitions, **<DFT(No. of rooms, Ind. rooms size)=4>**.

The basic apartment organization (LDK area + sleeping rooms) can develop freely in the depth of the apartment, as well as around the entrance. Except for the kitchen and bathroom nothing is predetermined which resulted in a variety of floor plans in the initial phase.[22] In Fig.5-20 comprised of materials made by original designers[23] we can see an extensive study of possible layout organizations, as well as transformations of layouts in accordance to life stages (ⓒ,ⓓ).<Furniture> and <Surfaces> were also not designated, and the help of professionals is needed **<DFT=4>**, except for <Mobiliar> which is **<DFT=7>**.

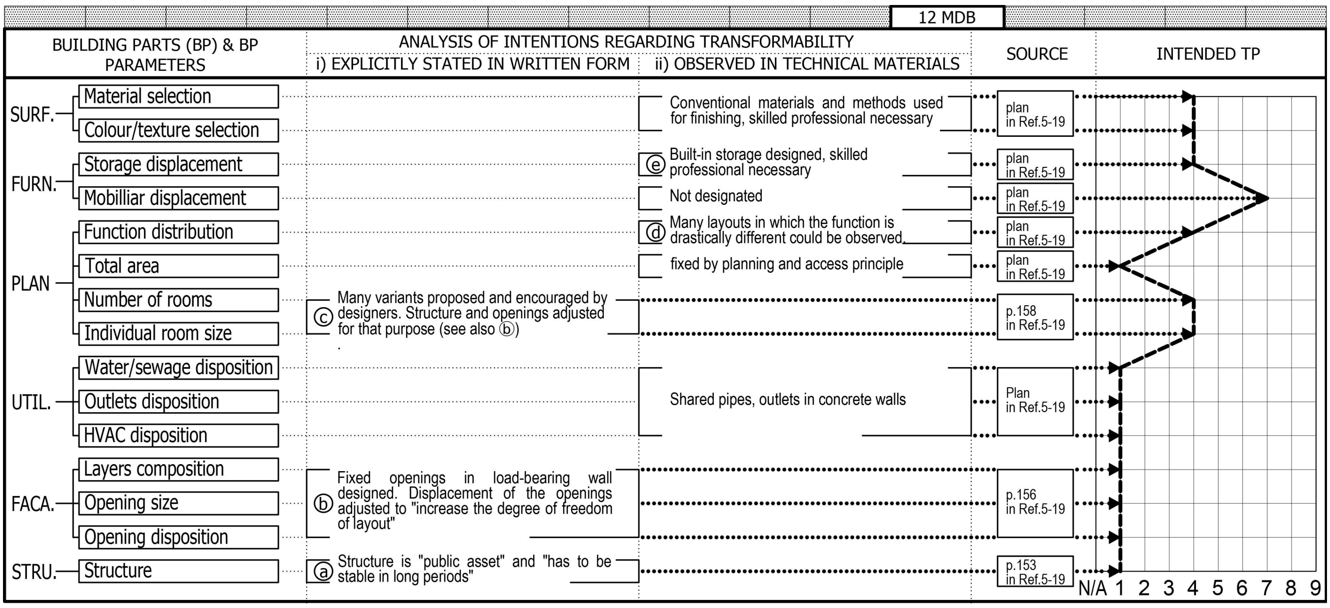


Fig.5-19 Analysis of Intentions Regarding Transformability – Momoyamadai-B Housing Complex [MDB]

[22] The involvement of Users in the design process was encouraged by designers.

[23] Ref.5-19 nad Ref.5-20

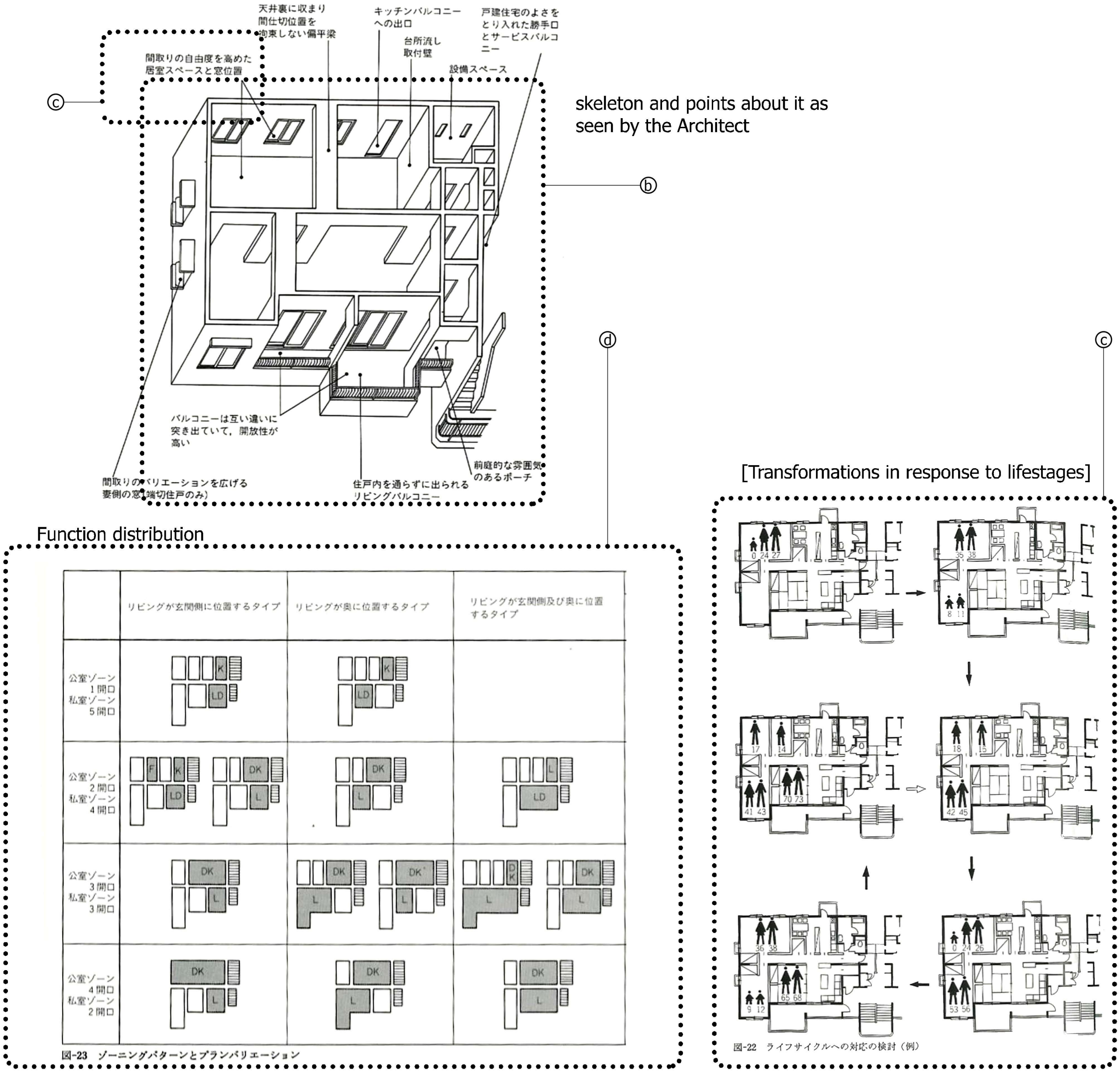


Fig.5-20 Figures from Original Materials Explaining the Concept of MDB

5.2.8 NEXT21 [N21]

NEXT21 is a joint experimental project where all the special design techniques developed over the course of time were applied. Its skeleton is custom shaped to allow easy supply of utilities from various access points **<DFT$_{(UTIL.)}$=4>** (ⓒ). Façade is composed of specially developed modularly coordinated system of façade elements so that it can be changed but the identity and the general appearance of the building preserved (ⓑ). This can be performed by skilled professionals, according to the rule book, therefore: **<DFT$_{(FACA.)}$=4>**.

Large column-free spaces were achieved by large spans of the custom skeleton in order to allow transformations and variations of plan. Although various movable partitions were applied, it is not a general rule, so we can say that **<DFT(PLAN)=4-6>** (ⓓ).

Especially is interesting that the building allows transformation of unit sizes, due to the design moat around the main structural bays in which utilities equipment is laid. When there is no common outer wall this kind of transformation belongs to User's discretion zone, which should significantly improve the chances of transformation.

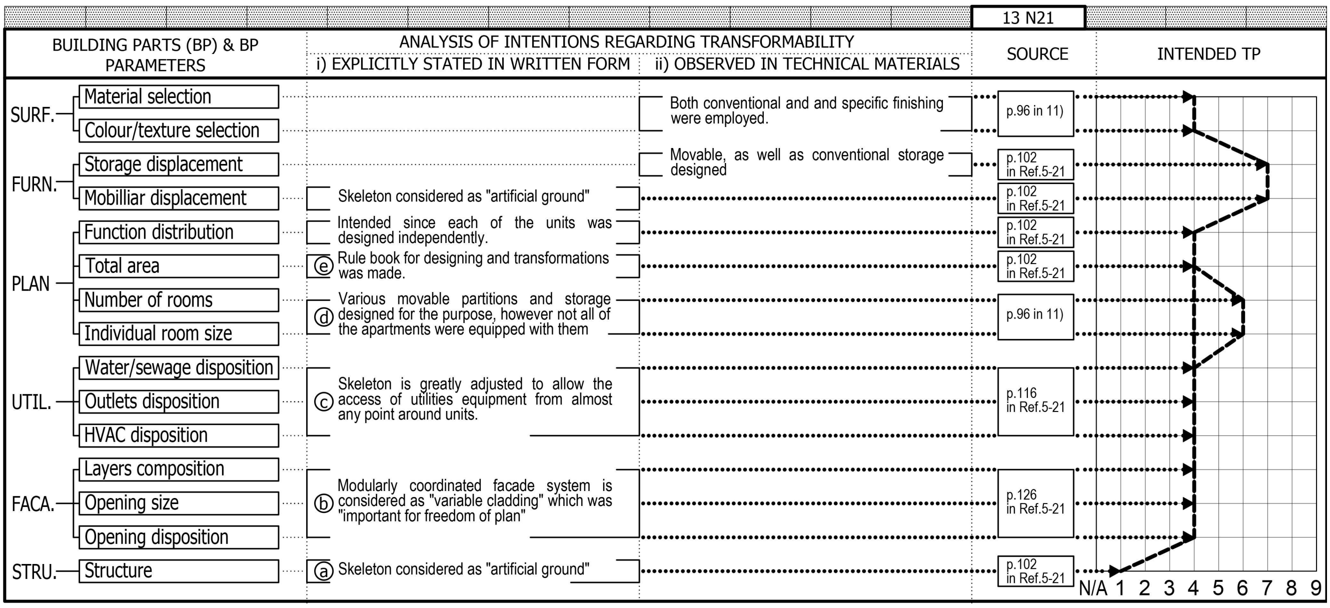


Fig.5-21 Analysis of Intentions Regarding Transformability – NEXT21 [N21]

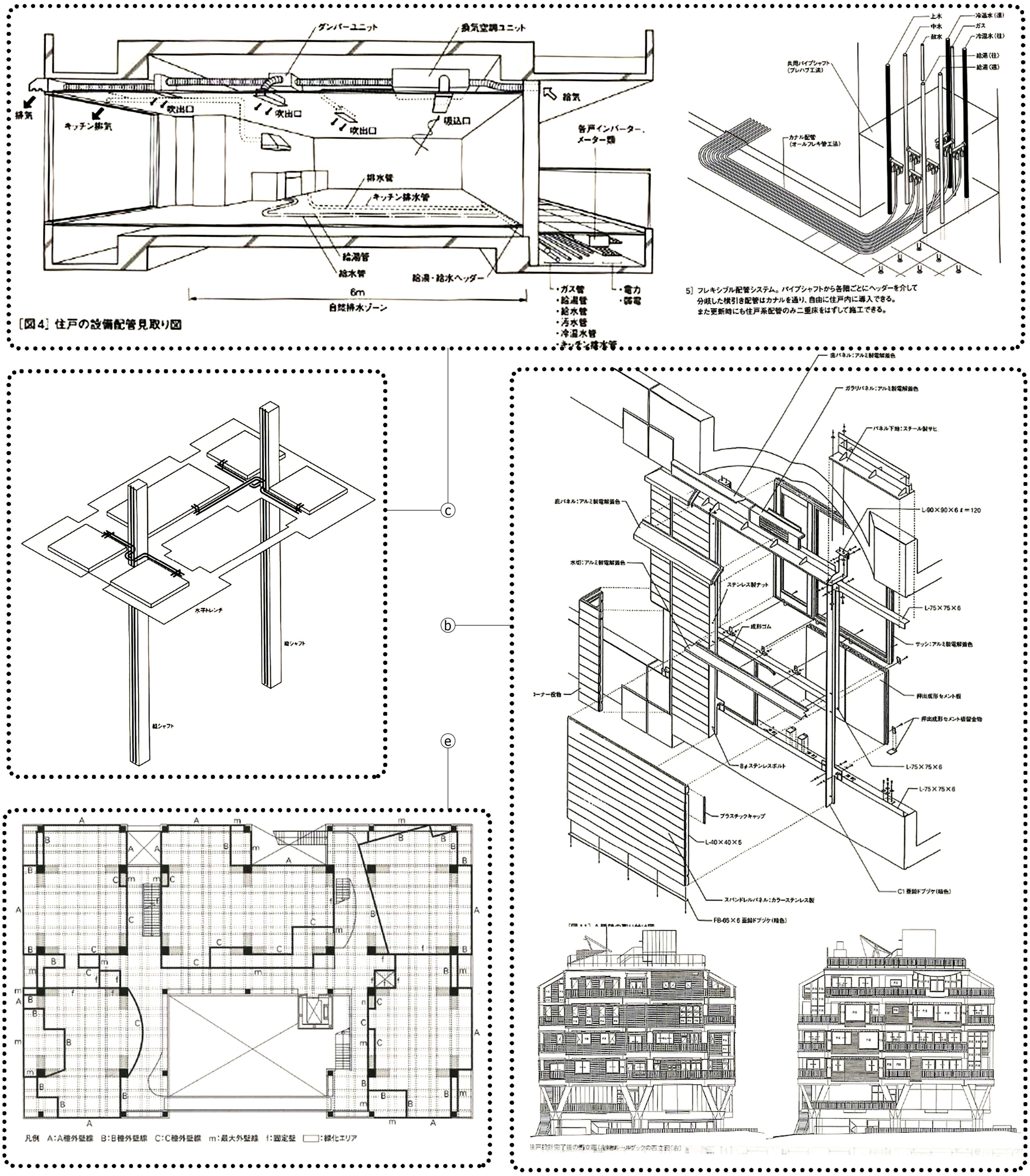


Fig.5-22 Figures from Original Materials Explaining the Concept of N21

5.2.14 San Life Sanda (Hyogo Century Housing) [SLS]

San Life Sanda is very similar in its design concept and transformability approach to FCY (5.2.6), but implements somewhat different technical solutions to achieve it. The team of designers published a paper in which they explained the concept behind the design[24]. Instead of "checker-board slab", there was "inverted slab" with sleeves for the piping. But, the important thing is that the installations were classified as "secondary skeleton" and therefore scheduled to be replaced at larger timespans[25], therefore **<DFT(UTIL.)=1>**. Spans were shorter, more rational, but still large at 6m. Given that there were no beams in the space we can say that the effect of clear uninterrupted space of 6 by 12 m is achieved in a similar way as in FCY. Also, the planning and access principles were the same too, so was the TP.

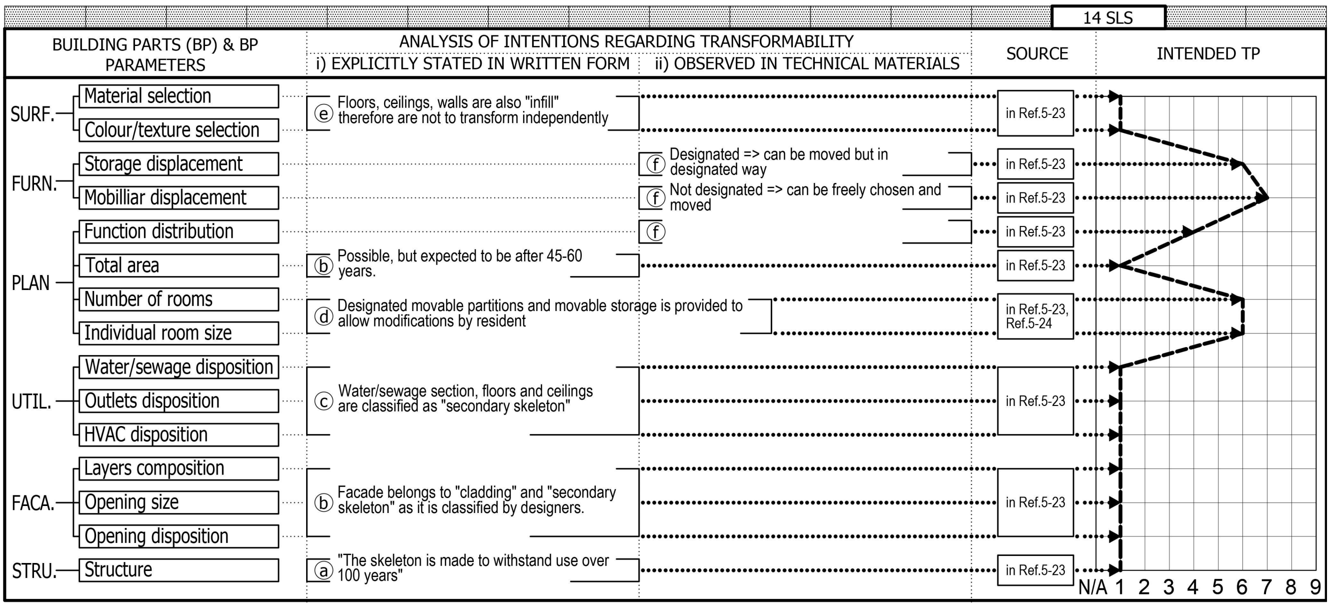
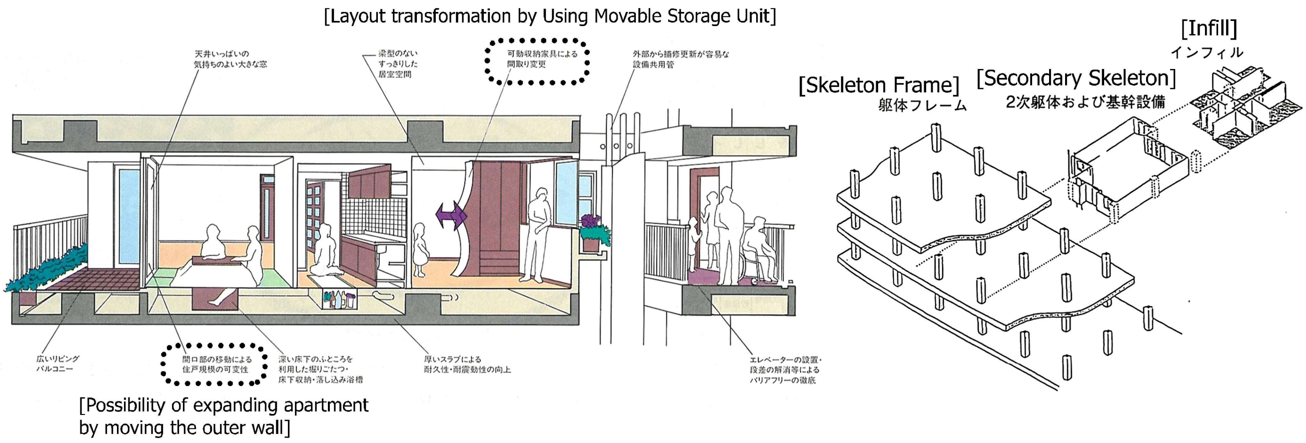


Fig.5-23 Analysis of Intentions Regarding Transformability – San Life Sanda (Hyogo Century Housing) [SLS]



ひょうご100年住宅の概念図 [The Concept of Hyogo Century Housing] 住宅の基本構成図 [Basic Structure of the Building]

Fig.5-24 Figures from Original Materials Explaining the Concept of SLS

24 Ref.5-23

25 Fig.5 in the original paper in Ref.5-23

5.2.15 Toyogaoka Tama New Town [TGT]

Due to the lack of reliable material this example was excluded from this analysis.

5.2.16 Town Estate Tsurumaki-3 Low-rise [TET]

Town Estate Tsurumaki-3 is significant example since it stands on the border of single and multi-family housing. The Architect secured obstacle free space of 5.4m by 8m and south-north orientation just as most of the slab-type examples. The apartments were not stuck one above the other, but rather turned into maisonnette type apartments[26].

Fig.5-33 Analysis of Intentions Regarding Transformability – Town Estate Tsurumaki-3 Low-rise [TET]

[26] Ref.5-25, Ref.5-26

5.3 Results Summary

Through this chapter, a systematical extraction of Intended TP from design related materials was demonstrated.

Despite the examples representing only one type of housing, and sharing a significant amount of common concepts and ideas, a variety of TPs could be observed which is a good opportunity to examine them in the next chapters for the common and/or different points.

There were examples where two examples share (almost) identical Intended TP (FCY and SLS; CHK and CHM[27]), but slightly different skeletons which point out to how much is the "width" of possible solutions inside certain TP.

Also, it is noticeable that the Architects paid a lot of attention to the technical aspect of the solution to the problem of transformability, especially for the water section zone, and through application of movable partitions and furniture, so the efficiency of these efforts should be examined with care in respect to the actually experienced transformations.

The most advanced example of all, N21, does not differ much in actual INT TP. Its advanced technical and technological solutions do not mean that the Architect could bring much improvement in <UTILITIES>, <PLAN>, <FURNITURE>, and <SURFACES>, however they do improve significantly the <FAÇADE>. Similar can be seen in case of FH22.

27 In case of CHK/CHM there is only one slight difference.

5.4 References

5-1) [Ichiura Architects], センチューリ始良、住戸・住棟計画 [*Century Aira, Apartment/Building Plan*], (n.p.: n.p., n.d.) 15-19.

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5-4) [Ichiura Architects], センチュリーハイツ健軍：パンフ（コンセプト）[*Cherry Heights Kengun: Pamphlet (Concept)*]. (In Japanese).

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6. EXPERIENCED TP ANALYSIS

In this chapter, actually experienced transformations for each building/housing complex of the Example Set presented in Chapter 4 were analyzed. The objectives of this analysis were three-fold:

1) Confirming the applicability of DFTIDP to analyzing actually experienced transformations.

2) Confirming whether Intended TP is achieved or not, and if it is, how long after the completion that happened.

3) Investigating the accumulation of transformations over the time for units of the same type[1] as a way to overcome lack of surveyed examples[2].

Experienced transformations are the most objective facts about buildings' transformability. While intentions may be miss-communicated or miss-interpreted, the transformations can be tracked down to how and when they exactly occurred. However, similar to Chapter 5 where the intentions confined in the materials were formulated in different manner or depth of detail, in this chapter there were surveys of actual transformability with slightly, but still significantly different focus and/or depth of detail of recorded transformations. On top of that, not all of the examples from the Example Set were surveyed, and though the intentions for designing highly transformable buildings were clearly stated by their designers, the extracted Intended TPs could not be confirmed.

By doing a cross analysis rather than a new survey, the intention of the Author is to try to connect past long-term efforts, to overcome the insufficiencies of partial or individual analyses, and to shed some light to directions in which future POE surveys regarding transformability should go.

6.1 Method and Materials

DFT Index Determination Protocol (DFTIDP) was used to analyze actually occurred transformations and determine DFT Index for each of the related BPs on which the transformation has influence. The information about transformations does not ideally match to BPs and BP parameters, however, the effects on each of it can be observed precisely enough. Also, there may be some changes recorded that does not produce any effect to any of the BP parameters. Such changes were not considered transformations in sense of this work.

Description of transformation, when identified to which BP parameter(s) it has influence, were filtered through DFTIDP question sequence. However, the Q1-Q4 were adjusted for the past tense, so instead of "Who initiates transformation?" it is rather "Who initiated the transformation?" Most of the steps (especially Q1-Q3) of the protocol are indeed trivial and the answers are in most of the cases self-evident so in this paper we will mention and discuss only those that were more ambiguous, rather than presenting the whole step-

[1] Only minor differences between the unit types will be ignored. This mostly refers to some units which have additional windows as they were being placed at the end of the housing blocks. These units were appropriately marked in the analysis.

[2] The Author finds the efforts of the researchers to record these transformations extraordinary, however they were facing many difficulties as the collection of private data is always very sensitive.

by-step analysis.

The materials used in this research were outlined in Table 6-1. First, materials which contain any information about past transformations, for each example of the Example Set, were collected. The most informative data for this analysis were multiple continual surveys about any transformations that occurred after completion, which also include layouts' and other transformations' transition over the time, presented in graphical form (CHA/SHK, CHM, ESS, ETM-A/B, HGP-A,B/C, MDB, TGT, and TET). If that was not available, any detailed summary of transformations of units of same type was used, however, in that case the transition over the years could not be fully estimated. When both data were available, but not all of the surveyed units were published (CHM, ESS, MDB), the transition of achieved DFT Index of transformation over the time were taken from the published information, and the ultimate accumulated Experienced TP was evaluated from the overall data.

Table 6-1 Outline of the Surveys about Transformations of Buildings of the Example Set

Table 6-1 Outline of the Surveys about Transformability of the Example Set of Buildings

	1	2	3	4	5		6	7	8	9	10	11		12	13	14	15	16
	CHA/ SHK	CHK	CHM (D)	ESS	ETM - A	ETM - B	FCY	F22	GMT- H	GMT- M	GVU	HGP - AB	HGP - C	MDB	N21	SLS	TGT	TET
Any survey about transformations	○	○	○	○	○	○	○	×	○	○	×	○	○	○	△	×	○	○
Years elapsed after completion at the moment of survey	14	16	15	11	12/23 /31	12/23	3	/	25	25	/	8/25	8/25	18	/	/	8/25	12/23 /31
No. of units surveyed	77	118	36	24*	63*	6	19	/	65*	16*	/	5	3	84	/	/	17	26
No. of units surveyed in detail (any transformations)** including those without layout transition	/	/	36	13	3	1	/	/	/	/	/	4	3	25	/	/	2	26
No. of units surveyed in detail (any transformations)** with layout transition	/	/	2	3	2	1	/	/	/	/	/	4	3	25	/	/	2	7
No. of units surveyed partially (only specific transformations), including those without layout transition **	38	/	/	/	/	/	19	/	21	10	/	/	/	/	/	/	/	/
No. of units surveyed partially (only specific transformations recorded), with layout transition	11	/	/	/	/	/	19	/	3	2	/	/	/	/	/	/	/	/
Exact years of transformations recorded	○	△	○	○	○	△	○	/	○	○	/	○	○	○	○	/	○	○
Transformability evaluation	○	△	○	○	○	○	△	/	△	△	/	○	○	○	×	/	○	○
User satisfaction/opinion about transformability surveys	○	△	○	○	○	○	△	/	×	×	/	○	○	○	×	/	○	○
Source (Reference)	6-1	6-2	6-3, 6-4, 6-5	6-1	6-6/7,8,9	4	6-10/11	/	6-12	6-12	/	6-14/15	1	1		/	1	

*not clear how many of which type
** only published or available for analysis

If there were surveys about specific transformations, for example: a study on the transformations of movable partitions and storage (FCY, GMT-H/M), Experienced TP could not be evaluated for all of the BPs. This leads to an important point - evaluated Experienced TPs shows only the Experience that could be confirmed, which is not necessarily identical to a truly and fully achieved experienced transformability! Some units that has not been surveyed (for various possible reasons) might actually had another transformation which could increase the accumulated Experienced TP of the whole unit type. This has been kept in mind when specific conclusions were made and especially when Substantial TPs were estimated in Chapter 8.

Finally, if the survey had its own evaluation of transformability those were discussed to see if they are in line with the conclusions of this analysis.

The reliability of the DFT Index values determination relies on the level of details of the description of transformation in original surveys and may vary from case to case, or among BP parameters. Nevertheless, the underlying logic of analysis and reasoning remains unaffected, as long as this is taken into account when conclusions are made.

6.2 Analysis of Experienced Transformability of SI Apartment Houses Example Set

The example of analysis procedure and presentation of results is shown in Fig. 6-1 on a fictive example with fictive DFT Index values. The example has three units of the same fictive type – type A, which were an object of three surveys occurred in the past.

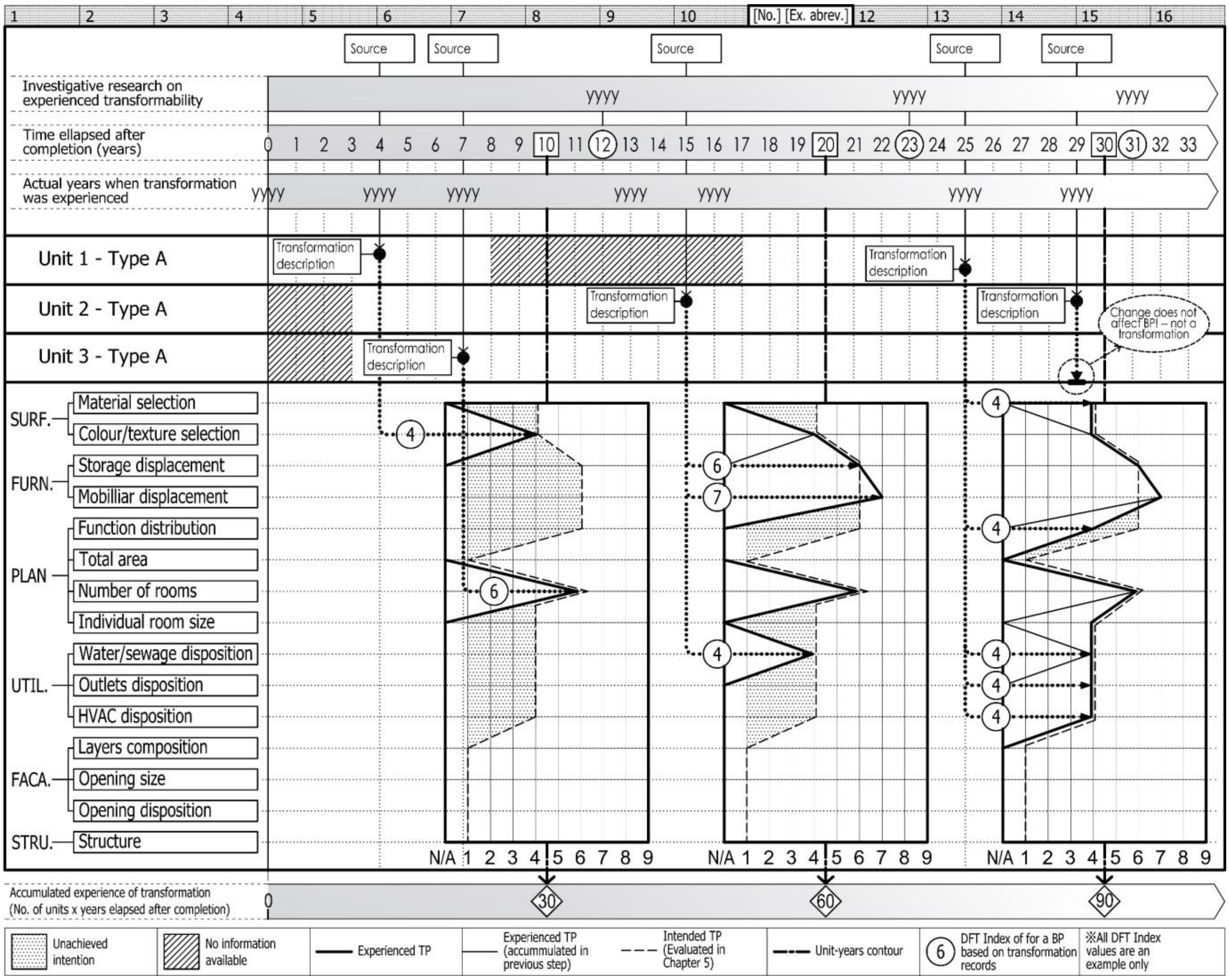

Fig.6-1 Accumulated Experience of Transformation – Analysis Procedure and Presentation of Results

On top of the figure there are three time scales, each starting at the moment of completion of building. The years of surveys and a reference to it will be given for each covered example, above the indicated year on the top time scale. Also, encircled values on the middle time scale (unit: one year) show how many years past since the building was completed, at the moment of survey (from this point "after completion" was abbreviated to "a.c.") Values in squares indicate the year after completion for which the accumulated experience of transformation is evaluated. In this work values of 10, 20, 25 and 30 years will be used[3] when there Is not enough examples with known year of transformation. Years of actual transformations were indicated on the lowest of the three upper time scales.

In the bottom of the figure there is another time scale which measures accumulated experience of transformations by multiplying number of units with number of years after completion. In this example 10, 20 and 30 years for which the accumulated experienced transformations were evaluated were multiplied by 3 which is the number of units analyzed, so the values became 30, 60, and 90, respectively (enclosed in rhombs). The unit for this scale is unit-year which will be explained in detail in Chapter 7.

On the left side of the figure are BPs and its parameters, and above it the names (or codes, when applicable) of the actual units from surveys.

The analysis is performed by following procedure:

1) The recorded transformations for each unit is plotted horizontally to correspond to the year in which it occurred. Beside each transformation there is a text box in which will be given short description of recorded transformation, and effect to BP parameter.
2) The effect was then analyzed with DFTIDP and the DFT Index value was determined. Thick dotted line will point to a part of TP where such confirmed DFT Index value will be plotted, expanding TP from its original N/A value. Transformations can have impact on more than one BP parameter, and can also have no impact on any of them. In that case, the thick dotted line will end like it is shown in case of second transformation of Unit 2 (29 years a.c.).
3) All the transformations that occurred between 0 and 10 years a.c. will be accumulated in a single TP – $TP_{(10)}$. In this fictive example there were two such transformations, first transformation of Unit 1 (4 years a.c.), and the only transformation of Unit 3 (7 years a.c.). In one the wallpapers were replaced with another one, with a different pattern, and the transformation was performed by skilled professionals, therefore, <DFT Index$_{(SURFACES: Color/texture)}$=4>. The TP expanded for four fields to the right. In Unit 3, a fictive transformation considered addition of a new room by subdividing of the existing by utilizing existing movable partition provided by the Designer in which case the answer to a Q3 is "User himself", and to Q4: "in designated way", which determines <DFT Index$_{(PLAN: Number of Rooms)}$=6>. Since there were no other recorded transformations inside the period of 10 years a.c. we can say that the accumulated experienced transformability for that period is as shown in $TP_{(10)}$. The TP keeps expanding with each new confirmed transformation which is shown in $TP_{(20)}$ and $TP_{(30)}$. $TP_{(10)}$ is shown with thin continuous line in $TP_{(20)}$, and $TP_{(20)}$ is shown the same way in $TP_{(30)}$, while the full Experienced TP for each period is shown with thick continuous line.
4) Intended TP, previously evaluated in Chapter 5 is plotted on each EXP TP and is represented by thin dashed line. The difference between the two is indicated with dotted hatch pattern. That difference gets smaller as the time passes and the actually experienced and confirmed transformations accumulate. When EXP TP reaches INT TP (or exceeds it!) the hatch is no more.

[3] The interval depends on the focus of researcher, and the "resolution" of available data. Since many examples has only a couple of units covered in full detail the Author thought that the 10 year intervals were most appropriate at this time.

6.2.1 Century Heights Aira/Station Heights Kinko [CHA/SHK]

Century Heights Aira and Station Heights Kinko were surveyed in February and March 2001, 14 years after completion (12 in case of SHK) by a group of researchers and published as part of subsequent report[4]. The focus of this investigation was the effectiveness of the Architect-provided set of movable partitions, storage units, and door units, therefore this was a partial survey of transformation[5].

123 apartments were surveyed by questionnaire, 77 of which also included interviews with the residents. The questionnaire consisted of five parts asking for information about: A) the year of moving-in and reason, B) the type of layout and way of using movable storage units and movable partitions over the years (including drawing a sketch of layout if outside the designated 5 types), C) Users' opinion about the movable storage and partitions, D) User's satisfaction with the housing, and E) family structure and age/sex of family members. Eleven transitions of layouts were published in the subsequent report, as well as "present" (as of year 2001) conditions of additional 38 apartments, which were not set up as one of the original 5 types of layout. The later does not indicate information about previous conditions and transformations, but some of them can be deduced from the layouts.

In Figure 6-2 the accumulation of actually experienced transformations was presented. For the clarity of explanation only type A apartments were shown[6], but the results of type B and type C apartments gave the identical results. This is because the differences between the types were minor, and there were no significant differences in the transformable part of the apartments. Among 13 apartments of type A, three units had transition of layout published, and the rest contains only information on the conditions of the layouts at the moment of survey (2001). Therefore, two accumulation axes had to be made. In the first one, the development of accumulation of transformation experience can be observed, so EXP $TP_{(10)}$, and EXP $TP_{(14)}$ were made. Three units and 14 years give 3x14=42 unit-years of transformation experience. Analogically, 13 units and 14 years give 13x14=182 unit-years of transformation experience, however, only for all 13 units only EXP $TP_{(14)}$ could be estimated, since the exact transformations for each apartment and point in time at which they happened were not disclosed. This is also valuable information since looking up into those conditions from 2001 no additional accumulation of TP was found. This means that at 42 unit-years the apartment unit has already reached its full transformability potential, even exceeding INT TP.

In case of Unit 1 we can see transition of layouts over 14 years (from moving-in in 1987 until survey in 2001). Over the course of time Architect-designated layout (5 types) as well as freely arranged layouts were recorded. Four panels, two door panels, and two movable storage units were reportedly manipulated by users

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[4] Ref. 6-1 pp. 54-75; 157-62; 179-83; 224-28. The group was called 可変型集合住宅に関する調査ワーキンググループ（可変調査 WG）[Working Group for Investigation of Transformable-type Apartment Houses (Transformability Investigation WG)]. It consisted of scholars from Kyoto U (Takada Mitsuo), Mie U (Takai Hiroyuki), Japanese Ministry of Land, Transportation and Infrastructure (Kato Shuichi), Ichiura Architects, and several public corporations. Some of the most detailed transformation investigations were published by the group in 2001 in the report.

[5] There was a few information about transformations other than movable elements inserted as a side comments, and that information was used when possible.

[6] Type A' included (see 4.2.1).

themselves[7]. When panels were rearranged in designated way, effectively creating additional room (or merging more rooms into one) or changing the size of the existing rooms, **<DFT(No. of rooms, Ind. room size.)=6>** was evaluated. When they were manipulated in a way that was not suggested by Architect DFT=7 was assigned. In observed examples, transformation of number of rooms was always achieved in a way that architect designated (three possibilities). However, Storage displacement and Individual room size were transformed in different ways, as shown in year 1994 and 2001. In 1994 storage room is made using one partition panel and door panel, however, the depth of the storage was 600mm (aligned with side of movable storage unit, not the 900mm back).

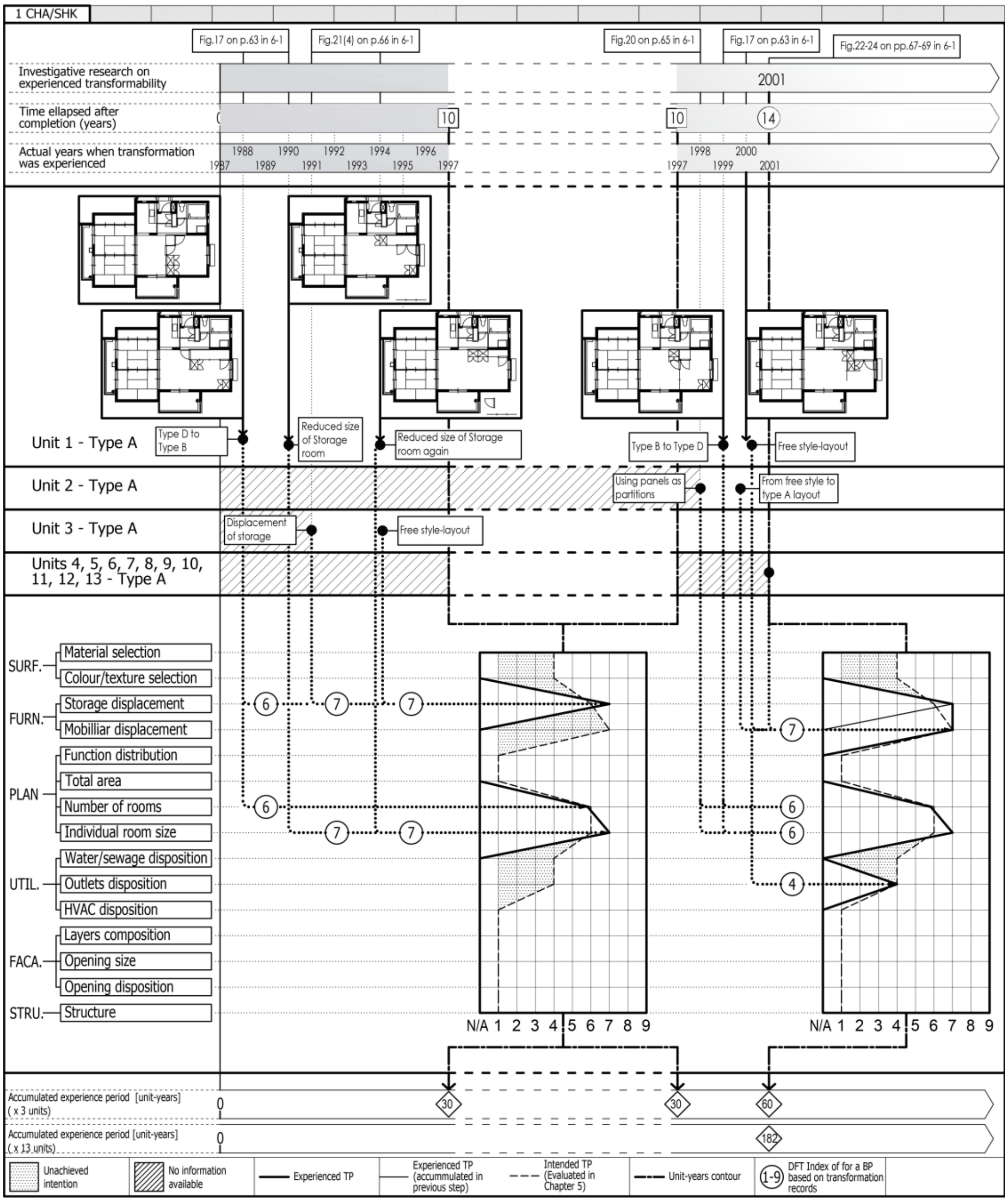

Fig.6-2 Analysis of Actually Experienced Transformability – Century Heights Aira/Staiton Heights Kinko

7 Some users hired professionals for the job, however, a majority of users did it by themselves. Ref. 6-1 Table 39, p.70

6.2.2 Cherry Heights Kengun

Cherry Height Kengun was surveyed by Yoshio Wakiyama, Makoto Tsunoda, and Shuichi Matsumura in 2000 [8], 16 years after completion, for the purpose of evaluating the effectiveness of CHS as a way to achieve long lasting apartment house. A part of the questionnaire was about the transformations after moving-in and the general outline of the transformations was published. In Figure 6-3 those data were used to evaluate Experienced TP.

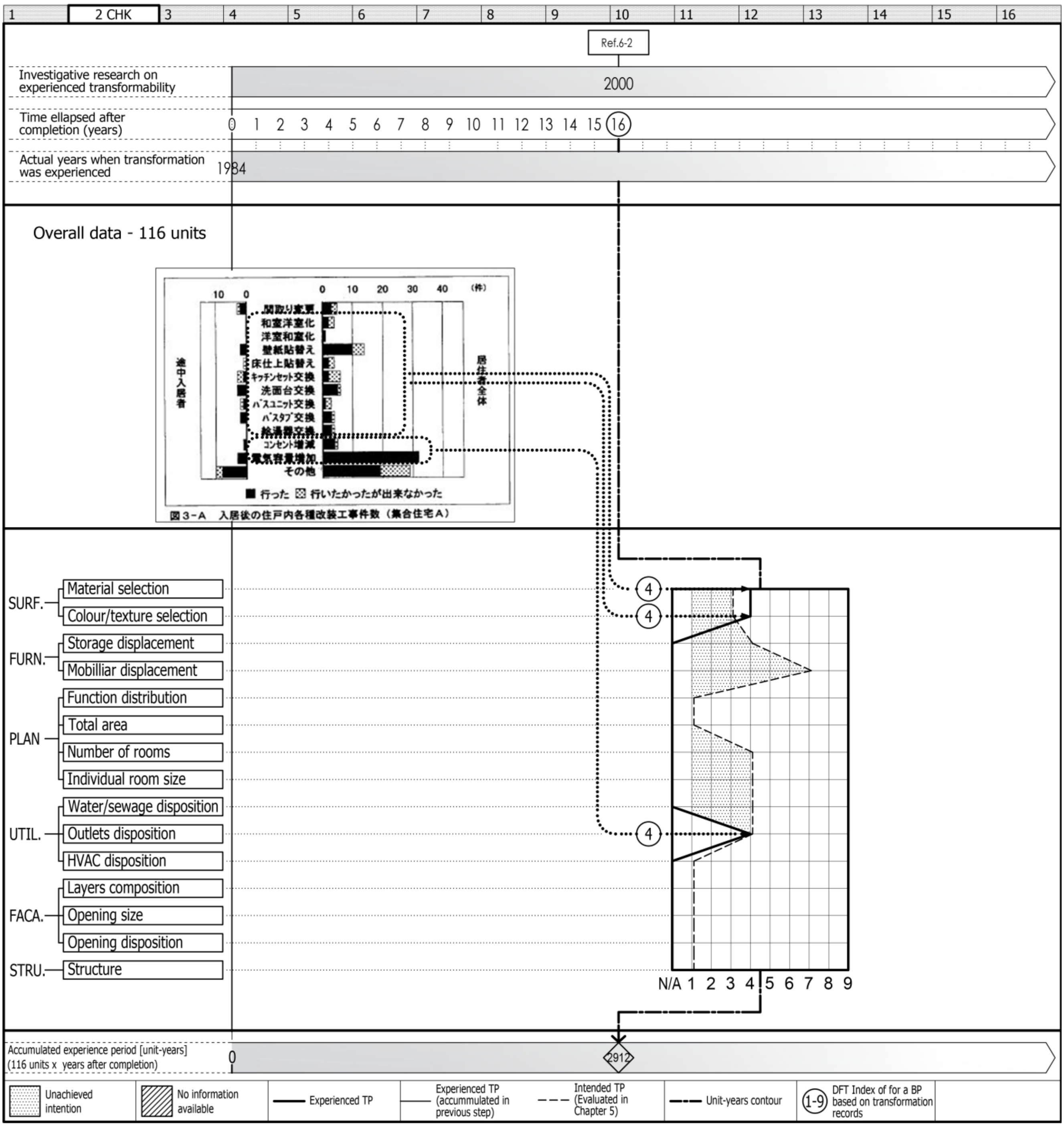

Fig.6-3 Analysis of Actually Experienced Transformability – Cherry Heights Kengun [CHK]

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[8] Ref. 6-2, p.201, Fig. 3-A

Since the survey entries does not entirely match Building Parts and its parameters only partial TP could be developed. Also, since there was no information about the exact year at which certain transformations occurred, only EXP $TP_{(16)}$ could be evaluated.

Most of the surveyed items described the transformation of Surfaces – changes from Japanese style room to Western style room and vice versa, as well as replacement of wall/floor/ceiling finishing, and finally the replacement of fixed appliances such as kitchen set, bath tube, toilet etc. should all be treated as surfaces transformation. There is also entry "layout changes" which is too vague to be used for this analysis. Also there is a "addition of consents" item which corresponds to <UTILITIES: Outlets Disposition>.

All of the above mentioned items are normally a subject of transformation by skilled professionals, therefore <$DFT_{(SURFACES,\ Outlets\ disposition)}$=4>.

The excessive number of surveyed units and fairly long period after completion adds to 2912 unit-years of transformation experience, however, the EXP $TP_{(16)}$ shows that all the surveyed items reached or exceeded INT TP.

6.2.3 CI Heights Machida [CHM]

Second phase of development of CI Heights Machida housing complex, was surveyed by Hiroyuki Takai et al. in December 2001[9], 15 years after completion of the building complex. A questionnaire is distributed to 226 units from which 84 replied. Since the building complex consist of four main types of apartments here is presented only type D apartment which had the most questionnaires filled (36 out of 84). The questionnaire consisted of 8 parts (A to H). In part C, information about renovations were asked. The list of surveyed items was the same as in previous example CHK (6.2.2), however the overall information about the layout changes were more detailed and also included layout transition (initial condition and "present" condition), which revealed more information about the related Building Parts, as shown in Fig.6-4. For instance, there were information about increasing and decreasing number of rooms of the apartment (Units 3-36 in Fig. 6-4), and the layout changes indicated some changes in function (concretely, new walk-in closet and "family-room" were made in case of Unit 1).

EXP $TP_{(15)}$ is determined based on this data. Thirty-six units 15 years after completion, represents 540 years of transformation experience. We can see that in this case EXP TP and INT TP are almost matching in all the BP parameters that surveyed items from the questionnaire were related to.

[9] As reported in Ref. 6-3 and 6-4. However, for the EXP TP evaluation, more detailed data of the same survey were used from a graduation thesis from Mie U to which the Author had access (See 6-5).

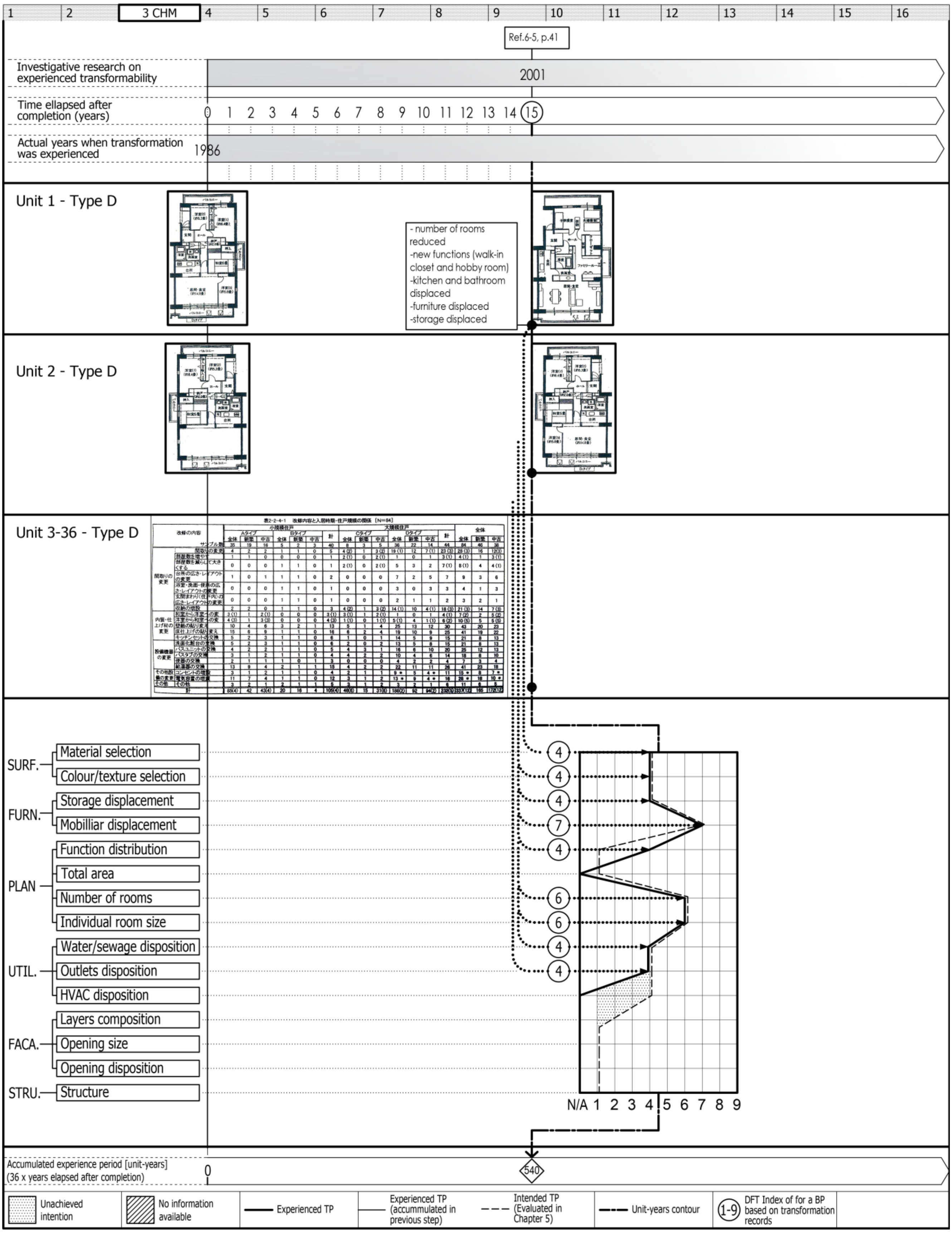

Fig.6-4 Analysis of Actually Experienced Transformability –CI Heights Machida [CHM]

6.2.4 Estate South Senri (Inokodani) [ESS]

ESS is surveyed by the same group of researchers that surveyed CHA/SHK (6.2.1), using the similar questionnaire, and the results were published in the same report[10]. Total of 26 units were surveyed 11 years after completion, 24 of them of the A and B type. Three layout transitions were available for the analysis.

Part C of the questionnaire that is inquiring about the actually occurred transformations had more developed list of options (19 items) which were shown in Table 6-2, along with how they correspond to BPs and DFT Index values. When there was no specific data about who performed these transformations, assumptions had to be made based on logic and experience. Now, logic implies that if there was no movable partitions or storage (which could have a role of partition, too), then there is almost no chances that User himself can change the number of room, and/or their size. So this must be done by skilled professionals, therefore **<DFT$_{(PLAN)}$=4>**. With the changes in layout of kitchen, bathroom, and washbasin zone one has to be more cautious since not all of the changes lead to effective transformation, in sense of this work. For instance, moving certain elements of kitchen on the adjacent wall but keeping the elements that require piping in the same spot is simply a mobiliar displacement. When there are such changes that faucets, bath tube, toilet has to change their position that is a transformation of Utility. This normally can be done only by someone qualified – skilled professionals. When there is no information whether kitchen layout led to transformation of Utilities **<DFT=N/A>** had to be used

Table 6-2 Surveyed Changes (Concrete Items) and its correspondence to BP and DFT Index

Surveyed changes categories	Mark	Surveyed changes - concrete items	Correspondence to Building Parts	DFT Index	Explanation
Layout changes	1	No. of rooms increased	PLAN: No. of rooms, Individual room size	4	Fixed partitions designed
	2	No. of rooms decreased and room enlarged			
	3	Kitchen area/layout changes	Util.: Water/sewage disposition	N/A or 4	Not all kitchen changes lead to transformation of Util.
	4	Bathroom/toilet/wasbasin space area/layout changes		N/A or 4	Not all changes lead to transformation of Util.
	5	Entrance (genkan) area/layout changes		N/A or 4	Not all changes lead to transformation of Util.
	6	Added storage	FURN.: Storage displacement	N/A or 4	
Interior/ finishing materials changes	7	Change from Japanese style room into Western style room	SURF.: Material selection & Color/texture selection	4	Any of these changes normally require professionals' help to connect . Although the possibility of user himself performing these transformations cannot be ruled out entirely, the survey data does not provide enough information to conclude DFT Index higher than 4.
	8	Change from Western style room into Japanese style room		4	
	9	Displacement of built-in furniture		4	
	10	Wallpapers replaced		4	
	11	Flooring replaced		4	
	12	Kitchen set replaced		4	
	13	Washbasin/make-up unit replaced	SURF.: Material selection	7	This can be done by user himself.
	14	Bath tube replaced		4	Professionals' help needed
	15	Toilet bowl replaced		4	
	16	Water-heater replaced	/	/	Not a transformation in sense of this work (at the resolution at which transformability is investigated in this work).
Changes toward "barrier-free" living environment	17	Handrails displaced	/	/	
	18	Floor height difference eliminated	/	/	
Other	19	Other	Decided from case to case		

In Figure 6-5 EXP TP was evaluated based on these transformation records. Again, we can look separately on the data based on three detailed examples, and overall data for all 24 apartments. Three units over 11 years makes 33 unit-years of transformation experience. On the other hand, all 24 units make 264 unit-years of transformation experience. There is very little difference between the recorded transformations of the three exampled units and all 24 units, which suggest that the full transformability was achieved early (at least the BPs that were surveyed).

[10] Ref. 6-1) pp. 1-21; 50-53; 151-56; 174-78

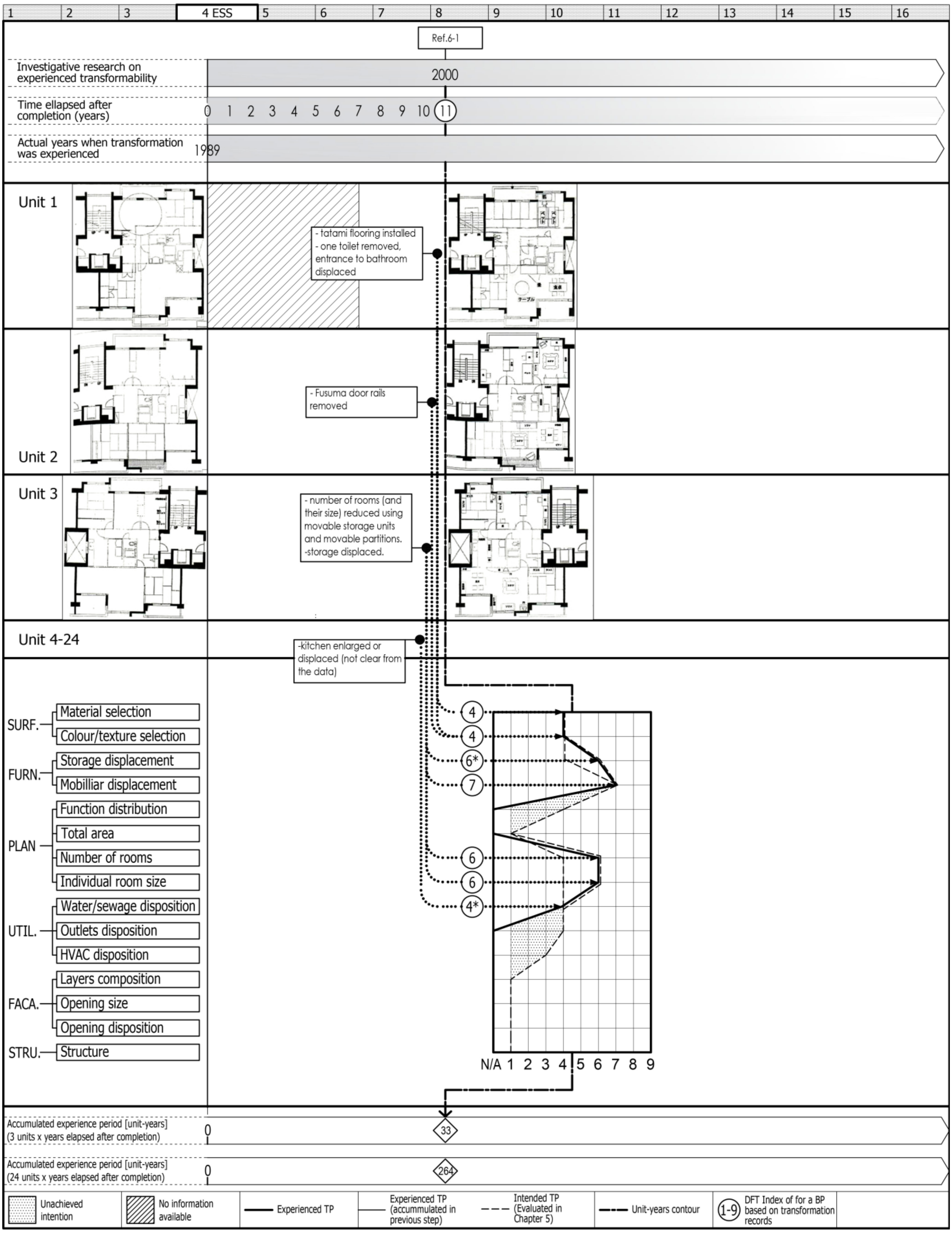

Fig.6-5 Analysis of Actually Experinced Transformability – Estate South Senri (Inokodani) [ESS]

6.2.5 Estate Tsurumaki-3 [ETM]

Estate Tsurumaki-3 is one of the best documented housing complexes in terms of recording transformations over the time. The research was started by Manabu Hatsumi in 1995, and then continued by Kazunobu Minami who recorded and compared the transformations in 2005 and 2014. So there were three surveys, at 13, 23, and 31 years after completion[11]. The researchers were making an effort to survey the units by entering and taking pictures, although they were primarily relying on questionnaires.

Based on this data EXP $TP_{(13)}$, EXP $TP_{(23)}$, and EXP $TP_{(31)}$ could be evaluated (Fig. 6-6)without interpolating the results from one survey, like in most other examples (except for Town Estate Tsurumaki-3 [TET], Hikarigaoka Parktown [HGP], and Toyogaoka New Town[TGT]). Since the results for all of the unit types (A, B, C) were bundled together, the analysis is based on the three units of type B which detailed layout transitions were published. Three units and the intervals at which the surveys were performed make 39, 69 and 93 unit-years of transformation experience.

Unit 1 transformed in 1990 when the special movable partition (Ⓐ in Fig.7) was moved to a new position Ⓐ' transforming at the same time the sizes of two rooms, but not the number of rooms. It was moved in designated way, therefore: **<DFT(Room size)=6>**. Storage and movable furniture were relocated to a new position, however this was done freely, therefore: **<DFT(Storage displacement)=7>**. The accumulated TP expanded accordingly. In 2013 another partition provided by architect was removed: Ⓑ⇢Ⓑ', thus the living room became larger and the number of rooms changed: **<DFT(Number of rooms)=6>**. 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 (Mat. selection, Color/texture selection)=4>**.
We can see the detailed developing of accumulated EXP TP as the transformation experience was growing (unit-years) until all BPs reached or exceeded INT TP.

[11] Ref. 6-6, 6-7, 6-8, 6-9

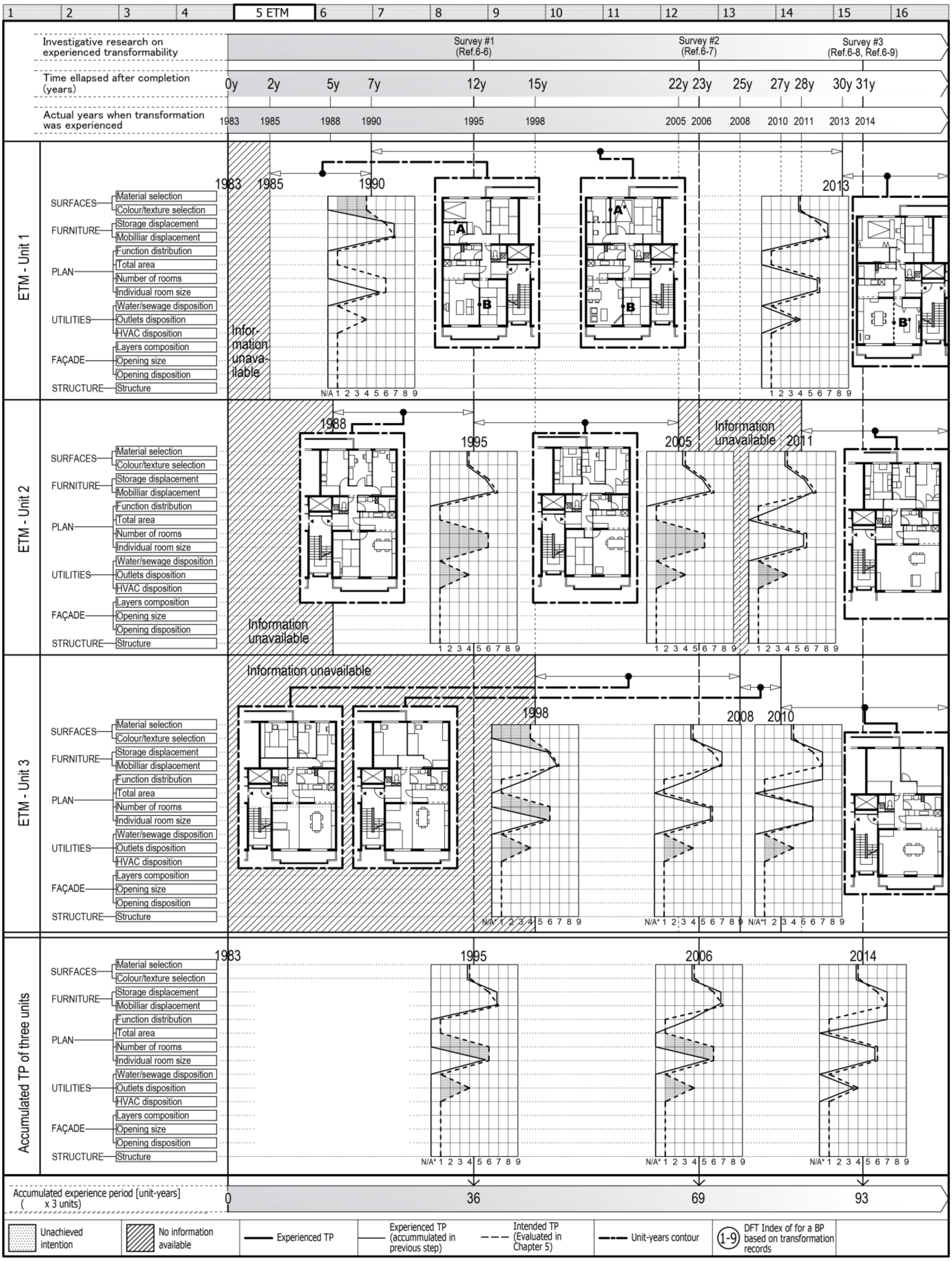

Fig.6-6 Analysis of Intentions Regarding Transformability – Estate Tsurumaki-3 [ETM]

6.2.6 Flex Court Yoshida [FCY]

Flex Court Yoshida incorporated a number of very bold structural and construction methods in order to achieve high transformability so it was intended to be surveyed and evaluated after completion[12]. The first survey occurred only three years after completion, however it had a purpose of evaluating various movable partition produced by different manufacturers, which was presumed to be frequently moved by residents. The research was led by Mitsuo Takada, and the results were published in detail[13].

Total of 19 layout transitions were presented. In this work only a unit type with higher number of surveyed units (type A) was showed. There are 13 type A units surveyed in 1999 immediately after completion, and in 2002, after three years of use. EXP $TP_{(3)}$ was evaluated and shown in Fig.6-7. The thirteen units were arranged by original researchers in four groups based on the transformation pattern[14], which is also adopted here to avoid redundancy of explanations.

By manipulating movable storage units which can have a double role of being a partition walls one can subdivide a room, or changing the size of the existing rooms without affecting their number. Logically, moving storage affects its displacement, and may affect the displacement of mobiliar through apartment. So EXP TP was sensitive to these four parameters. Since all the transformations were done by users himself **<DFT(No. of rooms, Ind. room size, FURNITURE)=7>**.

Even if the period of use was so short (only three years), EXP TP achieved its full potential, and even exceeded it. Researchers reported that the achieved combinations exceeded the variations envisioned and proposed by architects.

[12] One of the main members of design committee of the housing complex, Mitsuo Takada, is also active researcher and theorist in the field of transformability.

[13] Ref. 6-10. Subsequent analysis was a subject of doctoral dissertation by Yongkyu Yi in 2006 – Ref. 6-11

[14] Ref. 6-10, p.86, Table 4.

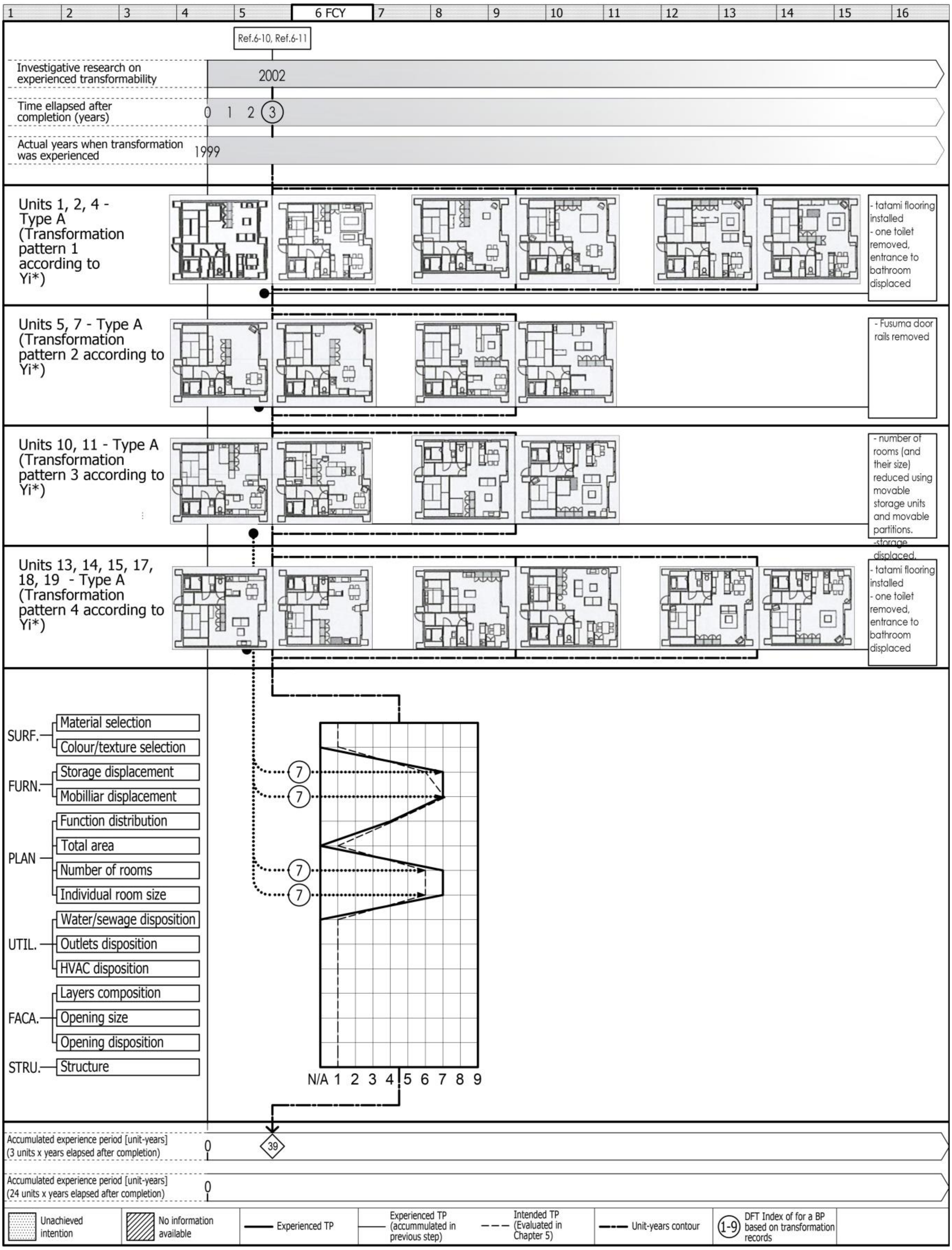

Fig.6-7 Analysis of Intentions Regarding Transformability – Flex Court Yoshida [FCY]

6.2.7 Flexsus House 22 [F22]

Flexsus House 22 has no recorded transformations. The approach to investigating transformability of that building was little different – many infill design teams were asked to provide the infill for one apartment, and each of the apartments were slightly different in size. However, by doing so, it is more about flexibility of designing than transformability after the building is built.

Now, since already 16 years has past since its completion it would be very interesting to see were there any spontaneous changes initiated by Users, and not by researchers.

6.2.8 Green Maison Tsurumaki-3 High-rise [GMT-H]

Green Maison Tsurumaki is one of the housing complexes which transformations were studied in detail. Seiichi Fukao, Kazunobu Minami, Kozo Kadowaki et al. have performed an investigation about the present condition of the apartments in 2009, 25 years after they were built, recording the transformations chronologically[15]. They inquired the previous conditions of the layouts and reconstructed layout transitions for the whole period for three units, two of them of the same A type.[16] We used this data to reconstruct the transition of the EXP TP over the time so EXP $TP_{(10)}$, EXP $TP_{(20)}$ and EXP $TP_{(25)}$ were shown in Figure 6-8.

Two units over the 25 years give a total transformation experience of 50 unit-years[17]. The survey was concentrated on layout changes and the usage of movable partitions, which is reflected in the EXP TP shape.

It is interesting that movable partitions and storage transformations could not be noticed, and that the change of kitchen layout did not had the effect of transformation of water/sewage.

15 Ref.6-12

16 Actually, Japanese katakana letter ア was used.

17 Here, we have to be very careful when making conclusions, since the small number of either number of units or number of years past completion can significantly skew the results because there is high possibility that there was not enough variety of use cases of the apartment unit.

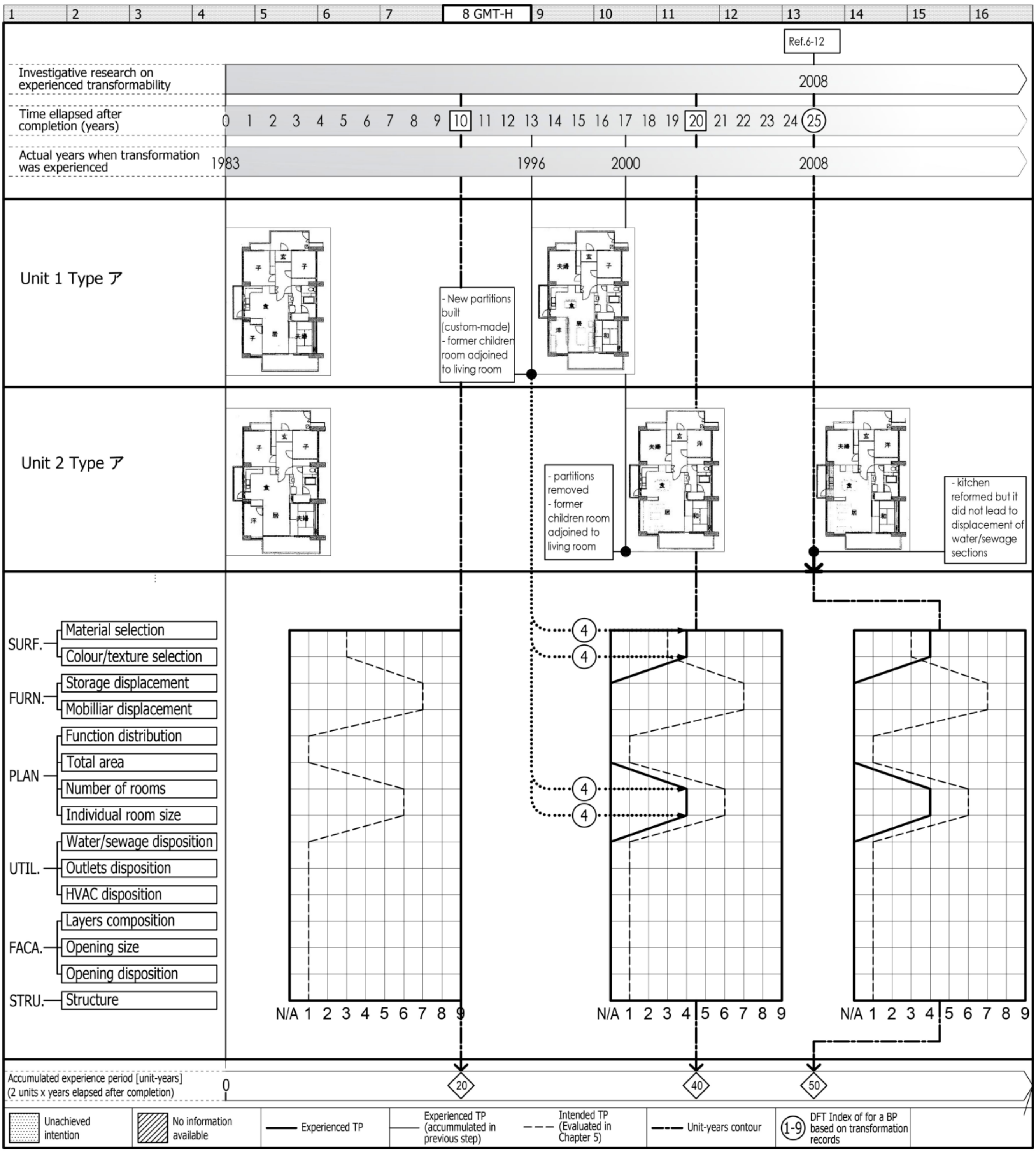

Fig.6-9 Analysis of Intentions Regarding Transformability – Green Maison Tsurumaki-3 High-rise [GMT-H]

6.2.9 Green Maison Tsurumaki-3 Middle-rise [GMT-M]

Green Maison Tsurumaki-3 complex has another, middle rise type of apartment houses. The same survey from previous subchapter contains information about transformation records of four units of middle-rise apartments as well. Here, displacement of movable partitions and storage units in accordance with Architect-designated system could be noticed, so the EXP TP grew to **<DFT(No. of rooms, Ind. room size)=6>**. However, In Unit 2 in 2007, partitions in south zone in living room were changed with foldable ones, rendering the room easily transformable by user into one large or two smaller rooms. So **<DFT(No. of rooms, Ind. room size)=7>** does not apply to replacement of partitions (which is certainly done by some skilled professionals), but to the subsequent occasional transformations.

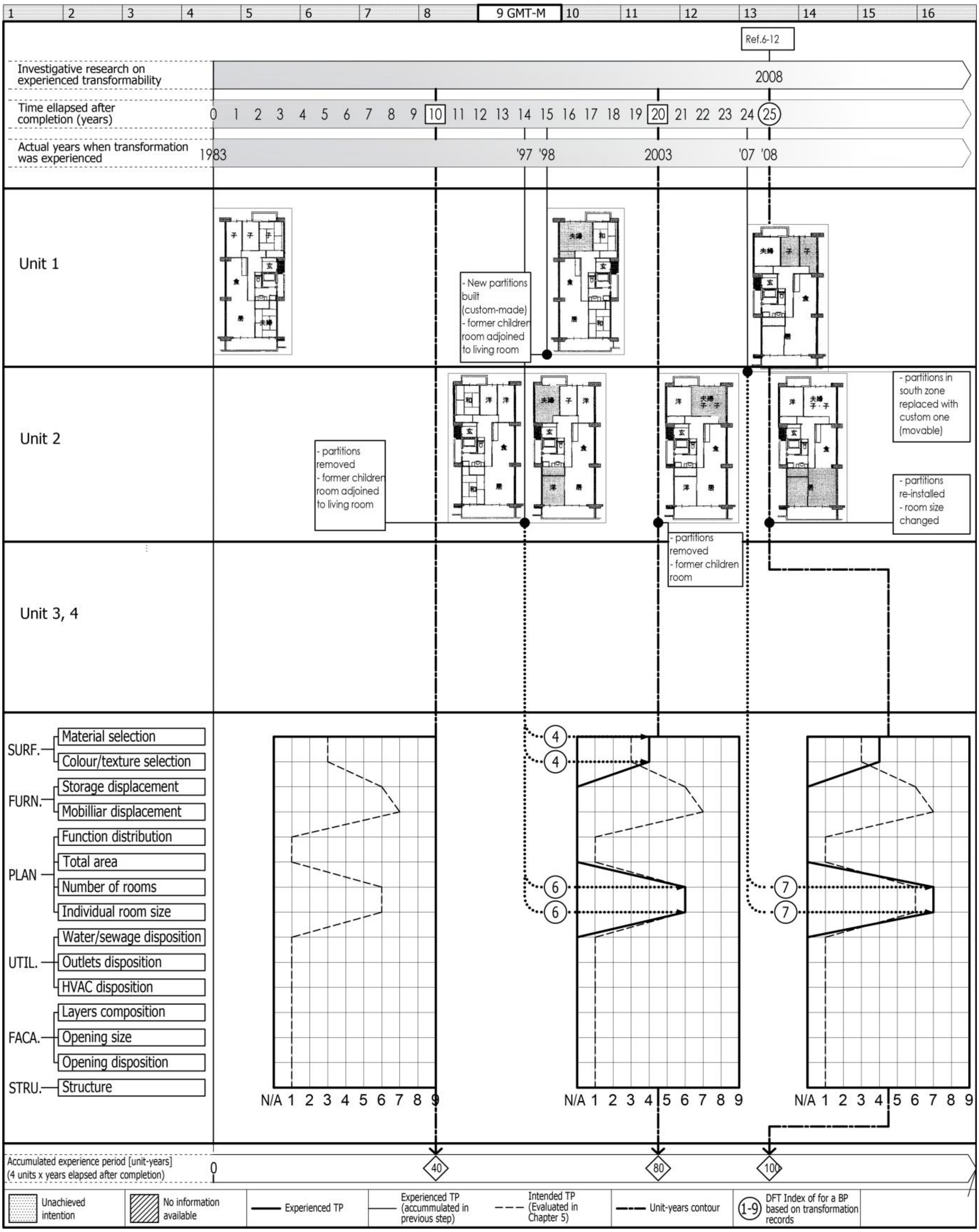

Fig.6.10 Analysis of Intentions Regarding Transformability – Green Maison Tsurumaki-3 High-rise [GMT-M]

6.2.10 Green Village Utugidai [GVU]

Certain Post-Occupancy Evaluation of Green Village Utsugidai was performed by Kaoru Nozaki, however, the survey concentrated on the Users' satisfaction by the dwelling and their involvement in the process of design[18]. We will just use this example to stress the importance of differentiating the "flexibility of design", and transformability, for the word "flexibility" has often been used in the past for both meanings.

6.2.11 Hikarigaoka Parktown [HGP]

Hikarigaoka parktown post-occupancy transformations were recorded in detail by Tomoko Sawada et al.[19] The building has been investigated since moving-in, first by KODAN in 1986, then by Sawada et al. in 1994, and again in 2011. There are four units that has been surveyed all three times (two of type A and two of type C), and additional five that has been surveyed two times.[20]

Type A and B are almost identical, and Type C is quite different (see 4.2.11) so we will cover only type A/B, since there were more units to analyze.

Unit 3 experienced large transformations – from SOHO apartment to regular housing unit when the business and children were growing, and then back to SOHO apartment when children became independent. Mostly thanks to this unit EXP TP grew significantly. After 20 years transformations were not leading to higher degree of freedom, therefore EXP $TP_{(20)}$ and EXP $TP_{(25)}$ were the same.

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[18] Ref.6-13

[19] Ref.6-14, Ref. 6-15

[20] The information about transformation were related to the year at which it occurred, so these examples carry almost as equal amount of information about transformations as the units surveyed three times, although the data itself is less reliable.

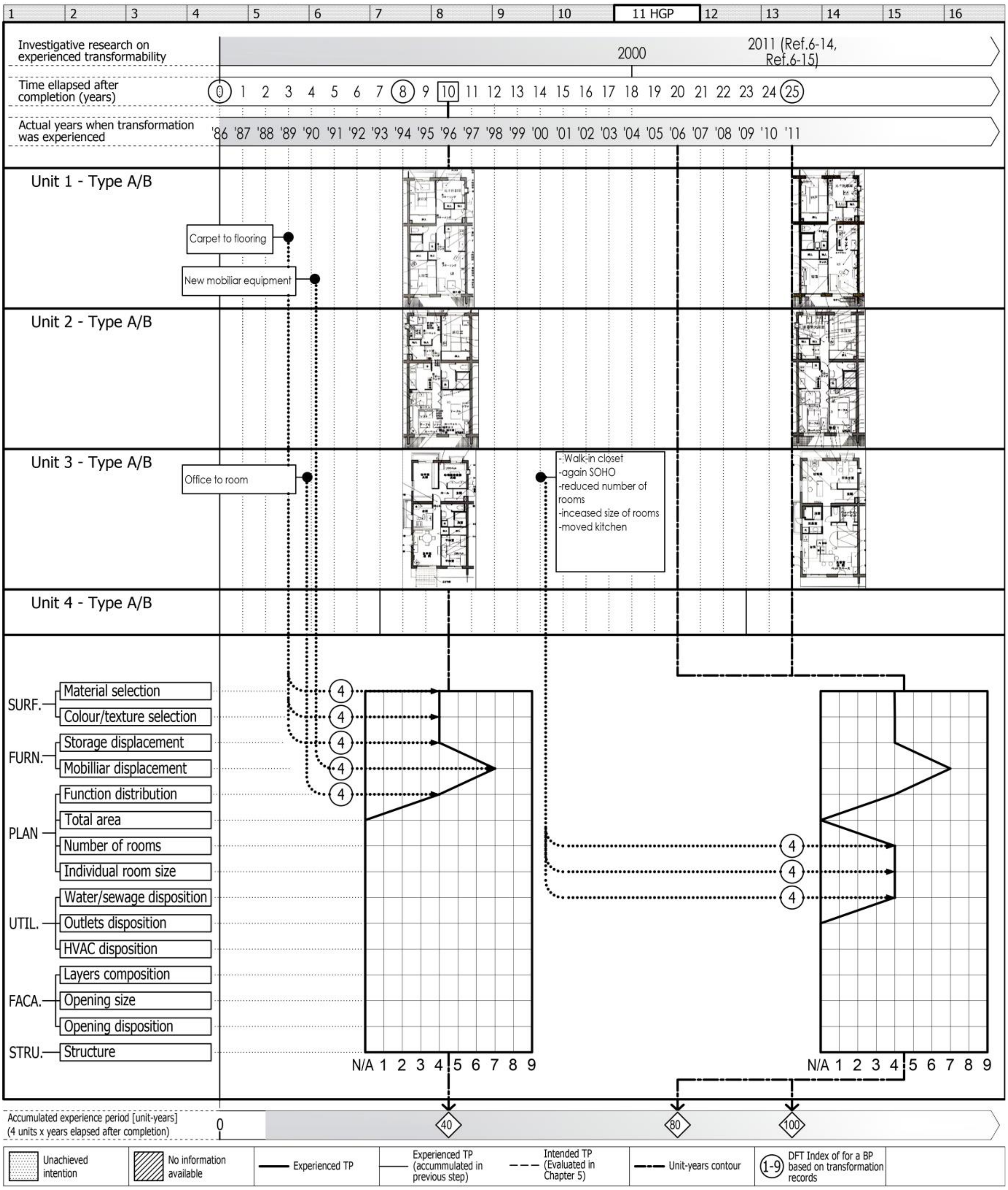

Fig.6-11 Analysis of Intentions Regarding Transformability – Hikarigaoka Parktown [HGP]

6.2.12 Momoyamadai-B Housing Complex [MDB]

Momoyamadai-B housing complex was surveyed at the same time when ESS (6.2.4) was surveyed, by the same method and same researchers).[21] So the evaluation of DFT was done in the same manner (see Table 6-2 in 6.2.4 again).

There is large number of units with recorded transformations and layout transitions over the period of 18 years, so quite large transformation experience was accumulated (450 unit-years. In such case the variety of users should be well enough to be excluded as a skewing factor of transformation tendencies.

<Note to reviewers: at this moment the DFT is not fully determined but this data will be inserted soon>

[21] Ref 6-1

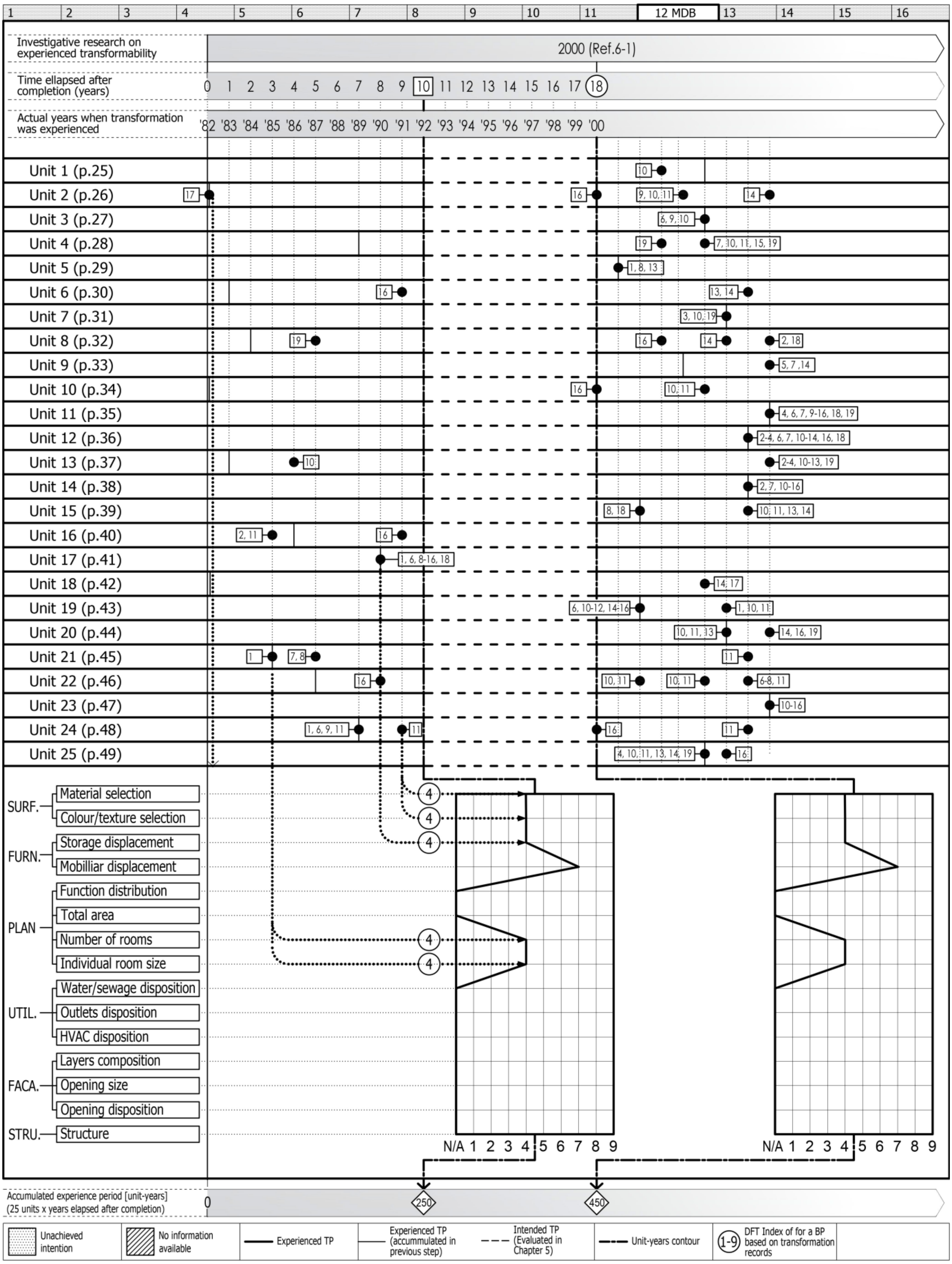

Fig.6-12 Analysis of Intentions Regarding Transformability – Momoyamadai-B Housing Complex [MDB]

6.2.13 NEXT21 [N21]

Next21 is an experimental housing, so its Users (residents) were picked by researchers and given incentives to live in settings provided by Architects, therefore its actual transformations were also imposed from the outside, and as such were not suitable for EXP TP analysis. However, its significance is in state of the art technical solutions that were applied which implications were covered in Chapter 8.

6.2.14 San Life Sanda (Hyogo Century Housing) [SLS]

Similarly to NEXT21, San Life Sanda has no recorded transformations, although the intention for such design is well stated.

6.2.15 Toyogaoka Tama New Town [TGT]

Toyogaoka apartments were surveyed at the same tame and by the same researchers and methods as Hikarigaoka Parktown (6.2.11). Although large number of units were surveyed, only two of them were surveyed all three times (immediately after completion, after 8 and after 25 years).

In Figure 6-13 those two apartments in their changes were shown, however, none of them qualifies to be transoformation, but mere maintenance.

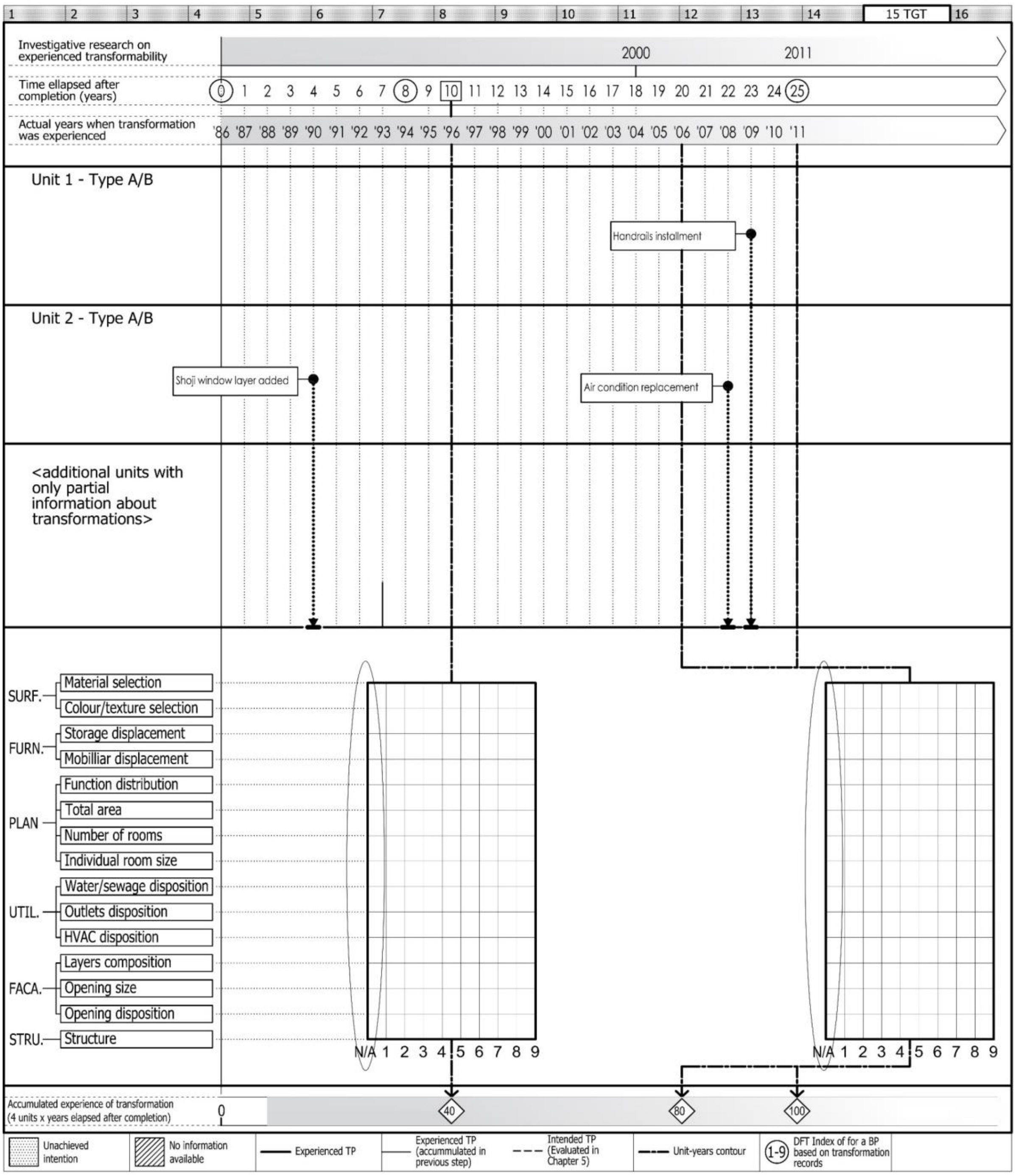

Fig.6-13 Analysis of Intentions Regarding Transformability - Toyogaoka Tama New Town [TGT]

6.2.16 Town Estate Tsurumaki-3 Low-rise [TET]

Town Estate Tsurumaki was surveyed several times at the same time and by same researchers and methods as Estate Tsurumaki-3 (6.2.5). Since the unit type is significantly different from any other analyzed type it was included in the Example Set.

There are 6 units (of 29 overal) surveyed fully by Minami et al. and their layout transitions and detailed transformation information were published.[22]

[22] Ref. 6-16, 6-17, and 6-18.

In Fig.6-14 EXP TP of TET is shown. Two units were shown in detail, while for the other 6 overall data is given. Layout transition figures were taken from the source material with minimal editing so the original marks (encircled numbers) remained.

In case of Unit 1, Water/section is significantly transformed in 2004 and 2006. The works had to be done by skilled professionals, therefore DFT=4. In case of Unit 2, we can see changes in function recorded in 2006, where new study room was introduced in the layout. At the same time designated partition was used to increase number of rooms and change the size of existing rooms, therefore **<DFT(No. of rooms, Ind. room size)=6>**.

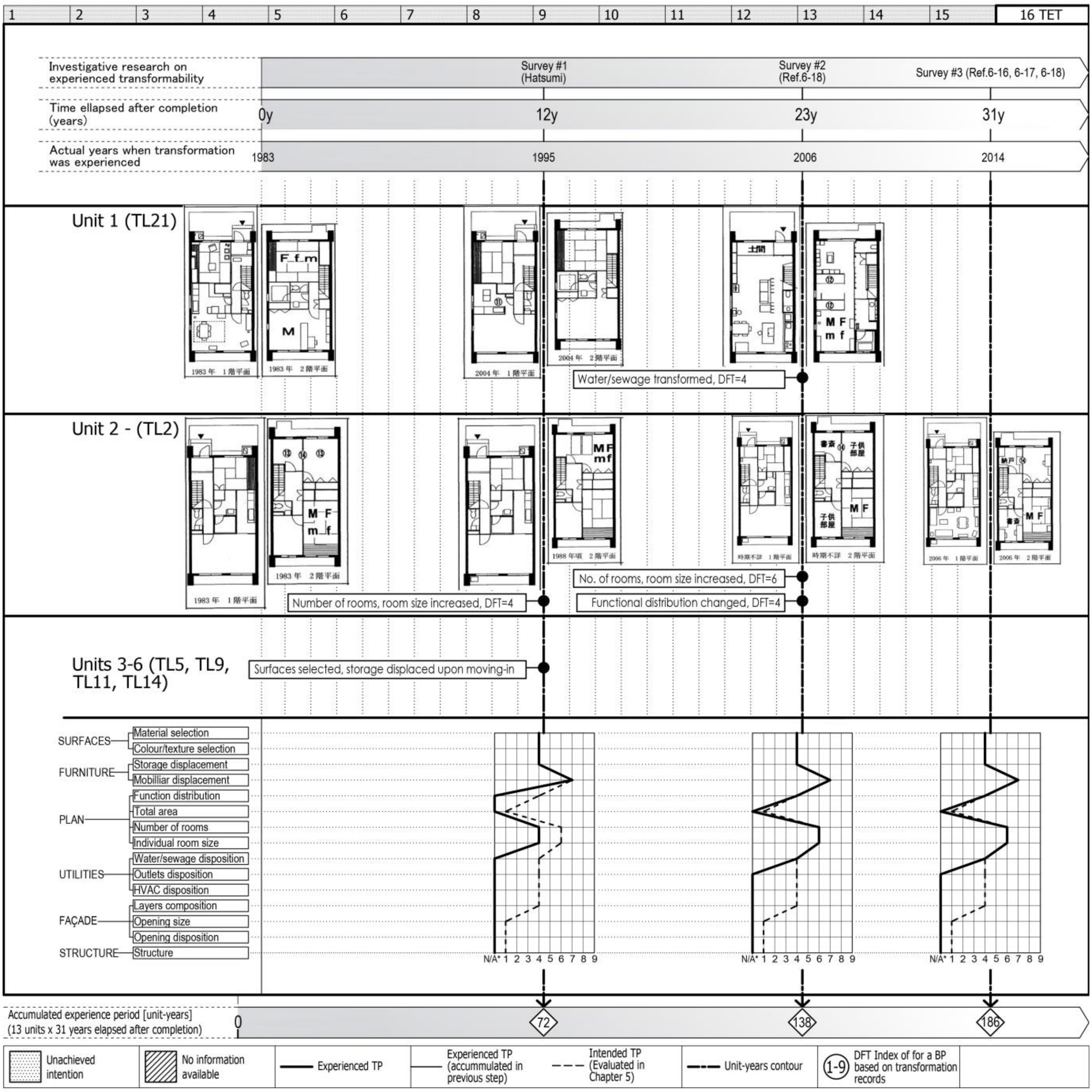

Fig.6-14 Analysis of Intentions Regarding Transformability - Town Estate Tsurumaki-3 [TET]

6.3 Results Summary

In this chapter, it was demonstrated how the information about the post-occupancy transformations can be used to evaluate partial or full EXP TP and represent the accumulation of the transformations over the time.

It is obvious from the results that significant increase of the unit-years is not necessary for full evaluation of transformability, or, in other words, building reaching its full transformability potential when EXP TP stops the “growth”. Also, there could be noticed that certain intended transformation never occurred, and that certain transformations exceeded the intended degree of freedom.

These slight discrepancies between INT TP and EXP TP are a basis for deeper analysis about the exact period of transformation experience at which the building reaches its full transformability potential and about the technical characteristics of the buildings which might be a cause for these discrepancies. These analyses were shown in Chapter 7 and 8.

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7. COMPARISON OF INTENDED TP AND EXPERIENCED TP

In Chapters 5 and 6, each apartment unit from the Example Set was analyzed, and as a result Transformability Profiles for each apartment unit were evaluated. In Chapter 7, these TPs will be taken as objects of analysis which will show the implications of the specific discrepancies between the two, and how they can be interpreted.

Since the TPs were evaluated from different input materials (different design of survey, number of units surveyed, different periods after completion at the time of investigation, etc.), in order to be effectively compared to each other and among themselves, an additional, mediating measurement – unit-year-- was necessary which will also be explained in this chapter.

7.1 Accumulated Experience Period as a Conversion Method

Evaluating the experiences from the investigative researches, we dealt with different number of units investigated at different points after completion. To overcome these differences and to convert the experienced transformability of the examples into comparable format, the period of accumulation of experience – a mediating scalar measurement-- was introduced.

The "width" of the experienced transformations that was gathered from several examples and those gathered from tens of examples, is nominally different. Also, the experience gathered from a survey conducted ten years after completion and the one that covers 30 years of use of the apartment are different, too. However, if we assume that the families that occupy the apartments were in –to put it simply-- different "life-stages", then we can imagine that their needs for transformations were different to each other at the same time. We can further simplify this logic like in the Ex.1 shown below.

Ex.1

IF there were three families in three different stages of life:

a) a young couple with small kids,
b) a couple with middle school kids and
c) a middle aged couple whose kids already got independent,

AND

IF the transformations in the ***three*** apartment units of the very same type, were recorded for ***ten years***,

THEN we can say that the apartment type has been in a *same*[1] *"pressure for transformation"* as yet another unit of the same type that was continuously occupied by ***one*** family for ***thirty years*** who also got through the same three stages of life during that time.

If a significant number of same type of units who covers the wide palette of residents and their needs were surveyed for the period of time shorter than one generation lifecycle, the actually occurred transformations may be combined to represent the total transformation experience of that type of unit as if

[1] For the sake of the argument, other differences between families were excluded from consideration for the moment.

the full lifecycle elapsed. Similarly, a longer period of time can overcome the insufficiencies born due to small number of units available for analysis.

The accumulated experience period stands for the measurement of width of experience after completion. Its value is determined when number of years after completion is multiplied by the number of investigated units. In this work it was represented as a contour line (thick dashed line, variable length of dashes) connecting the TPs of same width of experience.

7.2 Approaching behavior of EXP TP toward INT TP

Using accumulated experience period as mediators and plotting the transition of EXP TP over the years for each apartment, the points at which experienced transformations matched or exceeded the intended, or just stopped changing, can be observed and compared among the apartment units of the Example Set. There are a few significant reasoning patterns that could be derived from such information:

1) If EXP TP stopped growing at some number of unit-years for all of the examples, that value of unit-years may represent enough experience for assessing the transformability of any apartment.

2) If EXP TP exceeds INT TP and then stop growing even if the new transformations are being accumulated, it means that the full potential of EXP TP is achieved, and the reason for exceeding the Designer' intention in reality can be examined with greater reliability (without moving target).

3) If EXP TP does not reach INT TP fully, but it stops growing even if the accumulation of experienced transformations continued, then similarly to 2) it may be considered that the apartment reached its full potential of transformability, but then the reason for the failed prediction of the Designer can be examined with greater reliability.

4) In all the cases, DFT Index value at which the EXP TP of some BP is maturing implies the full potential of transformability of that BP of that apartment and becomes an object of further analysis whether the applied design techniques hold the same substantial transformability, which will be further discussed in Chapter 8.

7.2.1 Analysis of the Approaching Behavior of EXP TP toward INT TP - Detailed Transformations

In Fig.7-2 EXP TP accumulation of seven examples that were surveyed for detailed transformations, were compared to their respective INT TPs, and the approaching behavior was examined. EXP TPs for each of the example were plotted horizontally relatively to the year of completion. When there were enough surveys, the exact years of surveys were used for the year of accumulation, but when one survey covered a period of time much longer than ten years, the estimated EXP TPs for 10, 15, 20, or 25 years were plotted as well. The number of units shown in the left is multiplied by the years of accumulated EXP TP and the unit-year contours were drawn. The order of the examples is from the one with most unit years to those with least unit-years of experience in order to avoid overlapping of the contours

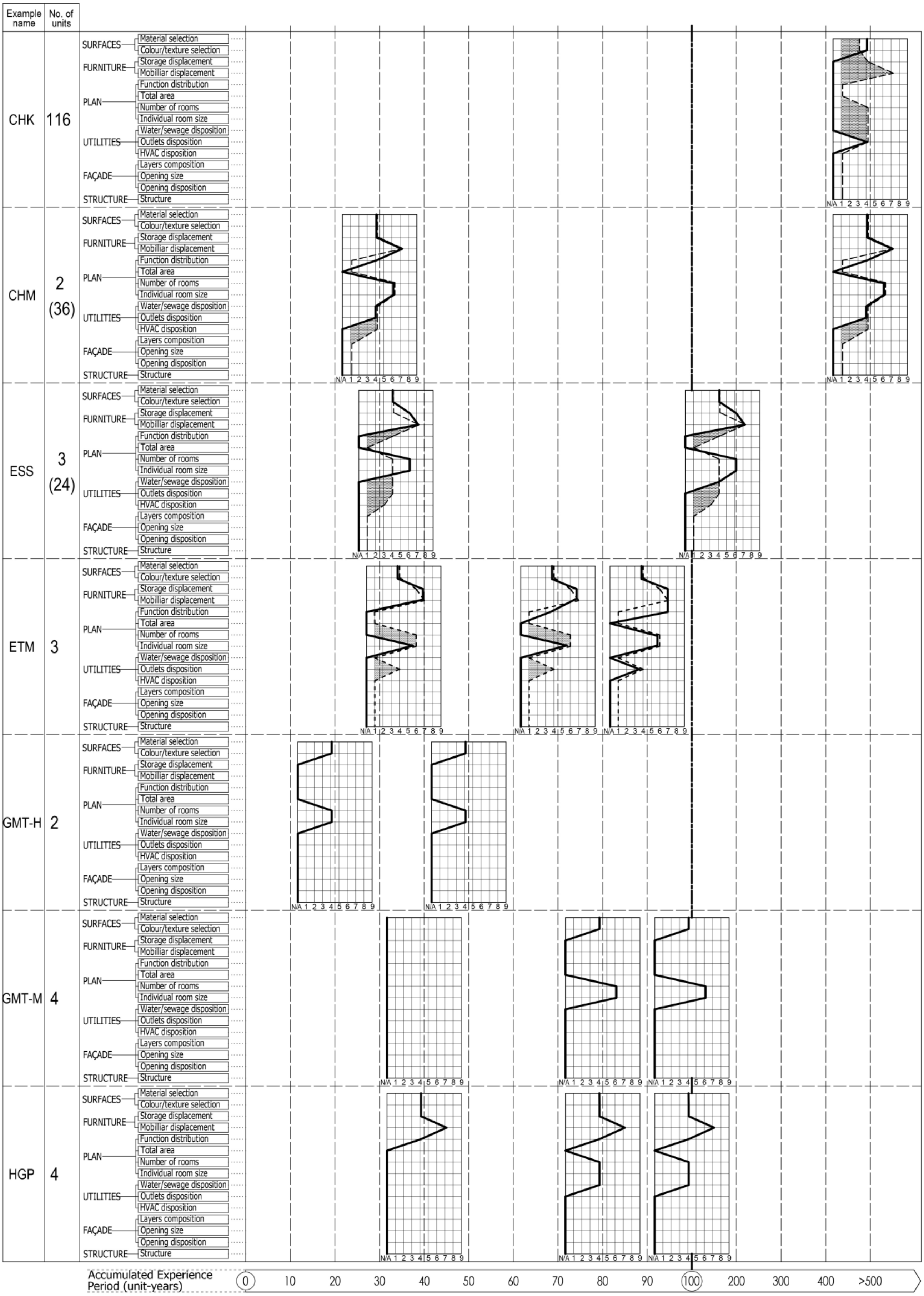


Fig.7-2 Analysis of Approaching Behavior of Experienced TP toward Intended TP

The results were as follows:

1) the lowest value of unit-year at which all of the examples reached its full maturity (stopped growing) was between 90 and 120.

2) Inside that interval the examples that have not reached the full INT TP were (for each BP parameter),

3) The examples that exceeded their INT TP were (for each BP parameter).

Based on this, the new hypothesis can be made that the transformation experience of approximately 100 unit-years might be enough for the full and reliable assessment of transformability of apartment houses.

7.2.2 Transformation Timespan for the Apartments Surveyed for the Effectiveness of Movable Partition and Storage Units

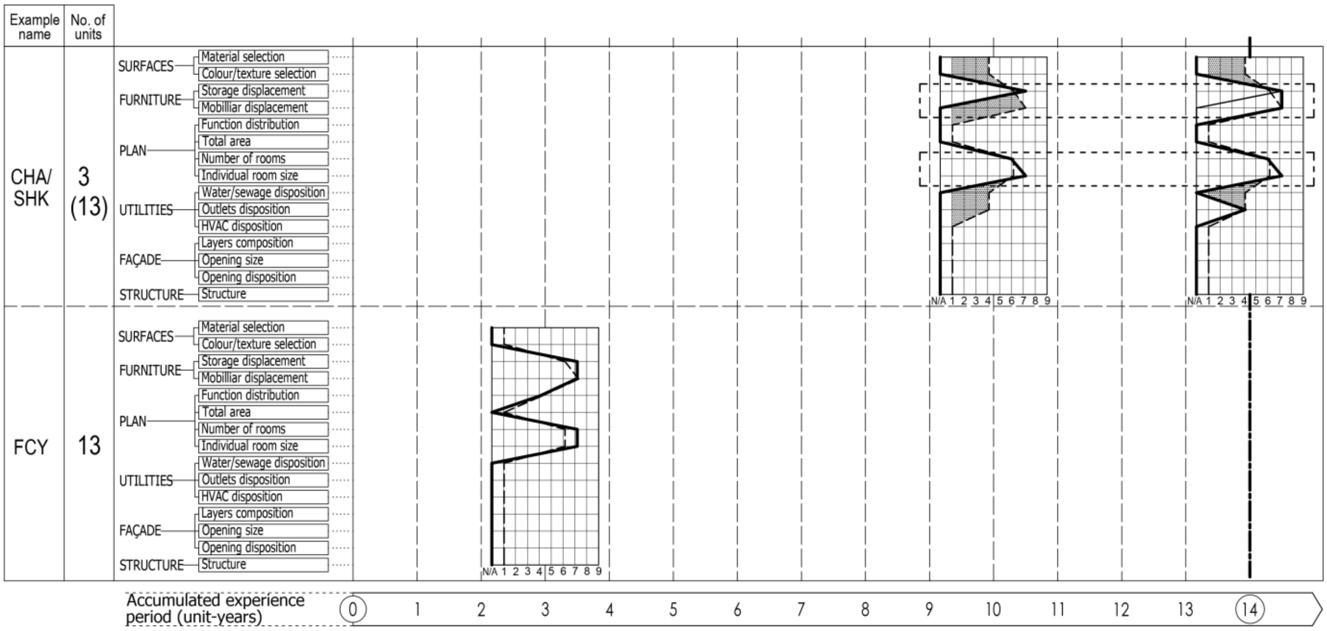


Fig.7-3 Analysis of Approaching Behavior of Experienced TP toward Intended TP – Movable Partitions/Storage

Based on the limited data it may be noticed that the parts of TP affected by movable partitions and movable storage <PLAN$_{\text{(No. of rooms, Ind. room size)}}$> and <FURNITURE> reached the INT TP at 14 unit-years, which is much faster than 100 unit-years for the total TP. This also implies that certain parts of TP may be assessed earlier, and that certain DFT values need less transformation experience to be assessed. These observations can be formulated as hypothesis and tested on the entire Example Set.

7.3 Possibilities and Limitations of Accumulated Experience Period Analysis

Here, accumulated experience period was used to make the general transformability of the buildings comparable. However, a potential of this analysis is larger than that. It can be used for analysis on individual Building Parts, or Building Parts Parameter, on any building sub-system, depending on the focus of inquiry. In those cases, there could be larger all smaller "resolution" of the transformation records (i.e. daily, monthly, or again - measured in decades). For each of the building parts there could be possible to determine at what value of unit-years the DFT Index stops growing, or, in other words, when the BP reaches its full transformability.

It has to be stressed that the conclusions made in this paper based on the unit-years analysis were quite conditional, and 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, a careful consideration on the dispersion of dwellers has to be recommended.

8. SUBSTANTIAL TP

8.1 Reasoning for Determining of Substantial TP

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.

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,

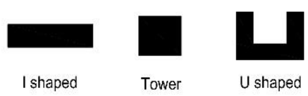
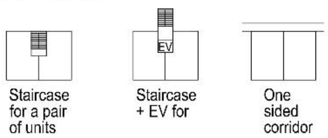
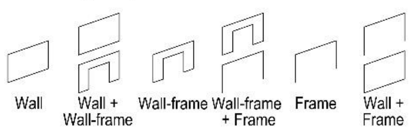
ii) and if the intentions were proven by Experienced TP of each,

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.

8.2 Design Specifications Classification

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 spatial, planar and sectional form and their dimensions, and c) partial techniques such as movable partitions applied in the certain parts in a unit. A number of examples is shown in Table 8-1.

Table 8-1 Design Specification Overview and Basic Classification

DESIGN SPECIFICATIONS CLASSIFICATION		
a) Design principles (whole building)	b) Form and dimensions (dwelling unit)	c) Design techniques applied partially
Planning principles 	Spatial - Number of cells - Shape of cells - Method of combining cells - Main spans - Floor height	Equipment - Multiple access points for pipes/wires/ducts - Securing sleeves in beams in advance - Double floor/wall/ceiling
Access principles 	Plannar - Facade plan (opening width) - Structural elements - Balcony depth	Layout - Dry construction methods of partitions - Movable partitions - Movable storage
Structural principles 	Sectional - Facade section (opening height) - Slab type (flat, regular, inverted, stepped) - Beam type (conventional, hidden, reduced height)	Surfaces - Modularly coordinated facade elements - Modularly coordinated interior finishing elements

8.3 Experimental Application of the Logic to the Example Set

Previously mentioned building elements' INT TP and EXP TP as well as the converted experience of observed transformations (number of unit-years at which certain transformation has been recorded) were analyzed for building parts that can possibly affect building's transformations and the results were shown in Table 8-2. Based on these results, two discussions can be made, as follows:

1) SUB TP and the implications to the Architects when considering implementation of certain design principles, techniques and features can be discussed, as follows:

a) As for the design principles, I-shaped buildings as the most numerous among examples was analyzed for all of the building parts, except for <FURNITURE> and <SURFACES> as it is fair to assume that planning principles, no matter how applied, can hardly determine these building parts. Conditions that suggest causal relationship were met in case of <Individual room size> and <Number of rooms> that belong to <PLAN>. There, the data suggest that DFT=6 is achieved when it was intended. When it was not intended (when the Architect did not design devices that enables it, such as movable partitions and movable storage), then at least DFT=4 was achieved. However, there is an interesting case of [GMT-H] when DFT=6 was not intended but movable partitions were anyway installed afterwards and the transformation was achieved anyway. The limited data and unavailability of comparison to buildings of different planning principles does not allow concluding that the effect is exclusive to I-shaped buildings, however it can be argued that the correlation is achieved due to planning of "flexible zones" in north and south of the unit, which is, again, possible for I-shaped buildings, especially those where access to dwelling units is through staircase or EV cores. These zones have continual span and the light source from only one side so the partitions are constrained to one direction (normal to façade=in direction of the main span) and to fixed dimensions (floor height x main span) which, arguably, makes the sliding of the partitions very logical and technically simple.

b) Two characteristics of form and dimensions of the dwelling units were analyzed – number of cells and installation pit (as sectional characteristic of slab) – for their possible influence to <function distribution>. The data consistently suggest that in case of dwelling units composed of two space cells there is DFT=4 for both intended and experienced transformability so the Substantial TP of this part should be the same, DFT=4. It is interesting that all three cases were quite different in a way that the two cell organization was achieved. [FCY] has two identical cells oriented toward the north and south of the building connected by their longer sides, [HGP] has two cells of different size and side ratio oriented toward opposite sides of buildings facades, and [TET] dwelling unit is a maisonette, so its identical cells are stacked one on top of the other. To make sense of this it is necessary to pay attention to three-cell dwelling units and notice that in that case the INT TP for function distribution is generally low - DFT=1. In these apartment units the function is more determined (hence "zones" which also double as structural bays). In two cell units, the function is not determined, but rather suggested, so the subsequent transformations were both expected and experienced more.

When it comes to installation pit, no implications could be found regarding it influence to <UTILITIES> where it was supposed to have influence. This, however, comes from a very limited data on actual transformations of utilities, so there is need for more investigation.

Table 8-2 SUB TP Estimation Chart

				Structure	Openings disposition	Opening size	Layers composition	HVAC disposition	Individualk room size	Number of rooms	Total area	Function distribution	Mobiliar displacement	Storage displacement	Colour/texture selection	Material selection	Outlets disposition	Water/sewage disp.
				not significant					Ⓑ						Ⓒ			
Ⓐ	I-shaped slab type	2 [CHK]	INT TP	1	1	1	1	1	4	4	1	1	7	4	3	3	4	4
			EXP TP												4	4	4	
			Unit-years												2912	2912	2912	
		3 [CHM]	INT TP	1	1	1	1	4	6	6	1	1	7	4	4	4	4	4
			EXP TP						6	6		4	7	4	4	4	4	4
			Unit-years						540	540		540	540	540	540	540	540	540
		4 [ESS]	INT TP	1	1	1	1	3	4	4	1	4	7	4	4	4	4	4
			EXP TP						6	6			7	6	4	4		4
			Unit-years						33	33			33	33	33	33		33
		5 [ETM]	INT TP	1	1	1	1	1	6	6	1	1	7	6	4	4	4	1
			EXP TP						6			4 and 7	7	7			4	
			Unit-years						36			69 and 93	36	36			93	
		6 [FCY]	INT TP	1	1	1	1	1	6	6	1	4	7	6	1	1	1	1
			EXP TP						7	7			7	7				
			Unit-years						39	39			39	39				
		7 [F22]	INT TP	1	4	4	4	4	4	4	4	4	7	7	3	3	4	4
			EXP TP															
			Unit-years															
		9 [GMT-M]	INT TP	1	1	1	1	1	6	6	1	1	7	6	3	3	1	1
			EXP TP						6	6					4	4		
			Unit-years						80	80					80	80		
		10 [GVU]	INT TP	1	3	3	3	1	4	4	4	4	4	4	3	3	4	4
			EXP TP															
			Unit-years															
		11 [HGP]	INT TP	1	1	1	1	1	4	4	1	4	7	4	4	4	1	4
			EXP TP						4	4		4	7	4	4	4		4
			Unit-years						80	80		40	40	40	40	40		80
		12 [MDB]	INT TP	1	1	1	1	1	4	4	1	4	7	4	4	4	1	1
			EXP TP						4	4			7	4	4	4		
			Unit-years						250	250			250	250	250	250		
		14 [SLS]	INT TP	1	1	1	1	1	6	6	1	4	7	6	1	1	1	1
			EXP TP															
			Unit-years															
		15 [TGT]	INT TP	1	1	1	1	1	4	4	1	4	7	4	4	4	1	4
			EXP TP															
			Unit-years															
		16 [TET]	INT TP	1	1	1	4	4	6	6	1	4	7	4	4	4	4	4
			EXP TP						6	6		4	7	4	4	4		4
			Unit-years						93	93		93	93	93	93	93		93
	U-shaped	[CHA/SHK	INT TP	1	1	1	1	1	6	6	1	1	7	6	4	4	4	4
			EXP TP						7	6			7	7			4	
			Unit-years						30	30			60	30			60	
		13 [N21]	INT TP	1	4	4	4	4	6	6	4	4	7	7	4	4	4	4
			EXP TP															
			Unit-years															
	Tower	8 [GMT-H]	INT TP	1	1	1	1	1	6	6	1	1	7	3	3	3	1	1
			EXP TP						4	4					4	4		
			Unit-years						40	40					40	40		
		SUB TP							4~6*	4~6*		4	7	4~7*	4	4	4	4
		accu.exp. period [unit-years]	minimum						30	30		40	33	30	40	33	60	33
			maximum						540	540		540	540	540	2912	2912	2912	540

*with movable partitions

c) Movable partitions, movable storage units and double ceiling/floor/wall were common techniques for addressing transformability that can be seen through the Example Set, so they were analyzed for their assumed influence to corresponding building parts. Movable partitions have its role in transforming the <PLAN>, Movable storage units in <Storage displacement> and double ceiling/floor/wall to <UTILITIES>.
As for movable partitions, SUB TP could be concluded for <Individual room size> and <Number of rooms> to be DFT=6, but no correlation for <Total area> and <Function distribution> could be found. It has to be said that SUB $TP_{\text{(ind. room size, no. of rooms)}}=7$ is also possible in case of [FCY]. This might be due to very detailed survey that was concentrated specifically to transformations of movable partitions, or due to specific design of the partitions, which indicate the direction in which the deeper analysis should go. In either way, even under the constraints of the present limited data, it can be said that the effectiveness of movable partitions is confirmed.
The same can be concluded for movable storage in terms of <storage displacement>. Additionally, here the intentions were more often exceeded so the SUB TP=7 was concluded instead of intended DFT=6.
As for the double ceiling/floor/wall, the analysis suggest that it only has noticeable influence to water/sewage type of installations indicating SUB $TP_{\text{(water/sewage distribution)}}=4$. Now, one can try to evaluate the use of such extensive and expensive design technique for achieving DFT=4, which does not reward user with much more options for transformation, as skilled professionals would be needed even in case of conventionally distributed water and sewage pipes.

2) Second discussion is concerned with unit-years. In order to have even better information about certain design principles, techniques, and features, beside the expected SUB TP (DFT Index for the appropriate building parts) it is useful to know when the transformation can be expected to occur. In the bottom of the Table 8-2, and based on the accumulated experience of transformation for each estimated SUB TP, a range of unit-years inside which the transformations were recorded, as well as the average value of unit-years was shown. Due to the limited available data, these periods are quite large, and the averages are thus cannot be taken as reliable enough. Therefore, the number of unit-years at which any transformation occurs can be seen as a value of probability density function that can be described by its domain (minimum and maximum number of years on horizontal axis; number of units on vertical axis), and by its peak (ideally, but not necessarily average number of years), under the condition that minimum and maximum fall into the sufficient probability range (Fig. 8-1).

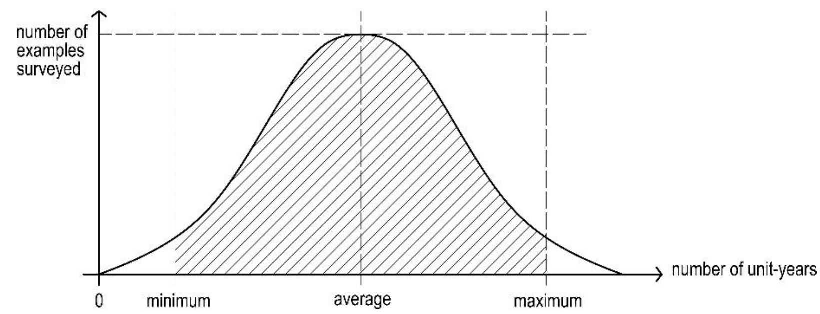


Fig. 8-1 Model of Probability-Density Function Distribution of Unit-Years

8.4 Frequency of Transformation

In order to make some general assumptions which can be useful in early stages of design (i.e conceptual/shematic phase) and for planning it is important to try to generalize the differences in frequency of transformation of certain building parts, as well as generalize the differences in necessary experience for achieving each DFT Index value. To do so, the following was investigated:

1) How much transformation experience is necessary for certain groups of building parts to transform.
2) How much experience is necessary for certain DFT index to be achieved by experience.

8.4.1 Shearing Layers of Change vs.Transformation Timespan

The frequency of transformation of building parts was already mention in this paper when Steward Brand's Shearing Layers of Change were taken as a base for dividing the building into smaller sub-systems. Shearing Layers of Change were developed on the observation proposed earlier by Frank Duffy which says "a building properly conceived is several layers of longevity of built components"[1]. This claim, however, has never been tested systematically.

The analysis of converted transformation experience and its accumulation is, however, an independent analysis based on actual transformation experience, and if the claim is true it should be possible to notice differences in the amount of necessary experience for assessment among different Building Parts.

Based on the above Hypothesis 1 was formulated as following:

H1) Shearing Layers of Change have different transformation timespan.

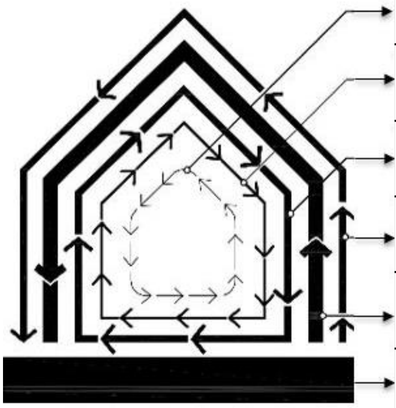
According to Brand's proposition, each layer has different frequency of transformation ("pace of change") with the difference in frequency indicated by the thickness of the line in diagram (Fig. 3.2-X)[2].

To test the hypothesis, the information confined in Approaching Behavior of EXP TP toward INT TP was extracted and associated with the appropriate Layer. Concretely, number of unit-years at the moment of EXP TP reaching its maximum (which is a point where the assessment of intentions becomes possible) was calculated.

Only examples with multiple surveys, and the examples which transformation records could be broken down into periods were selected.

The results were shown in Figure 8-2.

[1] Reference 8-1; Duffy actually coined "4S", four layers of change Shell, Service, Scenery and Set, which Brand later developed into "Shearing Layers of Change" or "6S".
[2] Estimated periods in years were also argued (Ref. 8-1 p.13)



SHEARING LAYERS OF CHANGE (in order of frequency of transformation)	BUILDING PARTS	Building Parts Parameters	EXAMPLES						
			1 [CHA]	5 [ETM]	8[GMT-H]	9[GMT-M]	11 [HGP]	12 [MDB]	16 [TET]
STUFF	SURFACES	Material Selection	N/A	36	40	80	40	250	N/A
		Colour/Texture Selection	N/A	36	40	80	40	250	N/A
	FURNITURE	Storage Displacement	30	36	N/A	N/A	40	250	156
		Mobiliar displacement	60	36	N/A	N/A	40	250	156
SPACE PLAN	PLAN	Function Distribution	N/A	69	N/A	N/A	40	250	N/A
		Total Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Number of rooms	30	36	40	80	N/A	250	156
		Individual room size	30	36	40	80	80	250	156
SERVICES	UTILITIES	Water/sewage disposition	N/A	N/A	N/A	N/A	80	N/A	N/A
		Outlets disposition	60	93	N/A	N/A	80	N/A	N/A
		HVAC disposition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SKIN	FAÇADE	Layers Composition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Opening Size	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Opening Disposition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
STRUCTURE	STRUCTURE		N/A	N/A	N/A	N/A	N/A	N/A	N/A
SITE	*DISCARDED*		N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure 8-2 Shearing Layers of Change and Transformation Timespan

The partial data presented in Figure 8-2 supports the Hypothesis 1 as the following could be observed:

1) There were examples in which differences in frequency of transformation were recorded.
2) There were no such differences to negate the proposed order of Shearing Layers of Change.
3) No noticed differences in some examples such as, [TET] can be explained by low number of surveyed units, not enough variations of their inhabitants [GMT-H] and [GMT-M], or lack of data about the actual time of transformation [MDB].

In order to confirm that the actual frequency of transformations corresponds fully with the Shearing Layers of Change, enrichment of the Example Set is necessary. The additional examples should include buildings of different type, not only SI housing, and not only multi-family apartment buildings.

8.4.2 DFT Index vs. Transformation Timespan

In order to more effectively predict the transformations and apply the most appropriate design techniques it is useful to have a general feedback about the pace at which those transformations come to realization.

DFT Index is based on the assumption that higher frequency of transformation indicates higher degree of freedom of transformation. There is gradation of transformation frequency, from the lowest value 1 toward the highest value 9. On the other hand, there is transformation experience upon which this assumption can be tested, trough analyzing the necessary experience for achieving certain DFT Index value. Based on this, another hypothesis, Hypothesis 2), was made, as follows:

H2) Higher DFT value implies less necessary transformation experience for confirming whether INT TP was achieved or not.

To test the hypothesis, from the information confined in Approaching Behavior of EXP TP toward INT TP of each example, for each DFT value that was achieved a minimum number of unit-years was extracted. To prove the hypothesis, it should be possible to notice the trend of decreasing of the number of necessary unit-years from DFT Index=1 toward DFT Index=9.

There are such cases where intention was not realized beside large transformation experience and in such cases number of unit-years could converge toward infinity, so it is not possible to calculate exact arithmetical average. However, since we need just to estimate these numbers and simply compare their values and see if there are differences among DFT Index values, a protocol is devised to make the calculation of the estimated average possible. The procedure is as follows:

If DFT(INT)=X, and DFT(EXP)≥X ⇒ minimum number of unit-years for DFT(INT)=DFT(EXP) is taken.

If DFT(INT)=X, and DFT(EXP)<X ⇒ maximum recorded number of unit-years for DFT(INT)≠DFT(EXP) is taken with the regard that the DFT=X is not yet achieved, so a "+" is added after the number.

If a part has no information on the transformation due to not being surveyed, that part was excluded from analysis.

If a survey data could not be broken down into separate periods but shown only cumulatively, the example is excluded from the analysis.

The results were organized and presented in table 8-4.

Table 8-4 DFT Index vs Converted Experience Period of Observed Transformation (unit-years)

DFT INDEX	Accumulated experience of transformation for each example [unit-years]						
	4 [ESS]	5 [ETM]	8 [GMT-H]	9 [GMT-M]	11 [HGP]	12 [MDB]	16 [TET]
1	264	93	50	80	100	450	403
	264	93	50	80	100	450	403
	264	93	50	80	100	450	403
	264	93	50	80	100	450	403
	264	93	50	80	100	450	
		93	50	80		450	
		93	50	80		450	
			50	80		450	
			50	80			
2							
3	264		20	80			
			20	80			
4	264	36			40	250	403
	264	36			40	250	403
	33	93			40	250	403
	33				40	250	403
	33				80	250	403
	33				80	250	403
	33				80	250	403
					100		
					100		
5							
6	33	33	20	80			156
	33	33	20	80			156
		93					
7	33	33			40		156
							156
8							
9							

The results presented in Table 8-4 support the Hypothesis 2 as following could be observed:

1) There is general trend among the examples of lower necessary unit-years for confirming the achievements of higher DFT Index.
2) There were no results showing the opposite trend.

It has to be emphasized that values of converted experience are based on accumulated observed transformations data, which places some limitations for drawing conclusions which has to be discussed. First, the "resolution" of unit-years is affected by cumulative data, so in case of very large number of surveyed units, large number of years past after completion at the moment of survey, or both, value of converted experince is too large and not very informative, since the transformations could have occurred long before. Second, there are differences in the approach to the survey among the researchers so some transformations can be recorded for their exact year of actualization, and some may be just generalized representing the "present state" of the dwelling unit at the moment of survey (and not necessarily at the year of transformation). If more precise times of transformation were available there should be possible to see more nuanced differences in unit-years values for each DFT Index value.

8.5 Application of Substantial TP in Design Phase

SUB TP can be consulted in various phases of design.

In conceptual phase, the Architect may analyze or look up into basic parameters to check what kind of transformability he may expect for the intended design. The opposite is possible as well, so the Architect may start the design with the desired type of transformability, and choose the appropriate means to achieve it.

Secondly, it may be used when the schematic design is advancing to deriving plans and sections.

Further, when it comes to details and designing the joints, specific construction methods and its SUB TP would be useful.

Aside from Architect and other designers, the DFT Index and TP can be used to better estimated the effects of the intended legislation in field of multi-family housing standards, and as an indicator for real estate companies, so that they can more precisely estimate the long term price of the real estate.

9. CONCLUSIONS AND FUTURE PROSPECTS

9.1 Concluding Remarks

With this thesis, three major goals were achieved.

First, a new, general, reliable and inclusive transformability assessment method was proposed (Ch. 3) based on crossing the Building Parts (WHAT) and DFT Index (HOW EASILY) and its applicability was proven through analyses of 16 examples of SI apartment buildings.

Second, the relevant examples of realized SI apartment buildings were collected and the method was applied for observing and comparing intended and experienced transformability. Through analyses in Ch. 5 and Ch. 6, the practical application of the method was demonstrated and the reasoning procedure for determining DFT Index was made clear, through following:

a) extracting of the Architects' intentions regarding transformability of SI apartment buildings (INT TP) from both primary and secondary materials.

b) extracting of the transformation experience and its accumulation over time from the most reliable data (EXP TP).

Third, through additional analyses of INT TP and EXP TP more specific inquiries were possible, as follows:

a) conversion of transformation experience for comparison of different transformation experience records was performed through introducing unit-years (Ch. 7). From here, it could be concluded that:

  i) *approximately 100 unit-years of transformation experience could be sufficient for judging whether the design intentions regarding transformability were actualized, and*

  ii) *that approximately 14 unit-years could be sufficient for judging the same about movable partitions and/or movable storage units.*

b) a logical procedure for determining SUB TP directly from building characteristics based on INT TP and EXP TP of the same design characteristics, was derived (Ch. 8.1). Some basic design characteristics were investigated and presented in Table 8-2 (Ch. 8.2) upon which further conclusions were made, as follows:

  i) partial SUB TP was determined for the following design characteristics

    I- shaped buildings – DFT $_{\text{(water/sewage)}}$=4; DFT $_{\text{(Ind. room size, number of rooms)}}$=6(4 if not intended)

    II- two-cell apartment units: DFT $_{\text{(Function distribution)}}$=4

III- Movable partitions: DFT $_{\text{(Ind. room size, number of rooms)}}$=6

IV- Movable storage: DFT $_{\text{(Storage displacement)}}$=6

V- Double ceiling/floor/wall: DFT $_{\text{(water/sewage distribution)}}$=4

ii) Expected period of time after which certain transformations should be expected was defined as a probability density function which domains are minimum and maximum recorded unit-year values. More precise data would narrow down the domain allowing for more realistic predictions.

c) two hypotheses about the general character of SI apartment buildings transformability were tested (Ch. 8.2), through which the following was concluded:

i) *Shearing Layers of Change indeed have different frequency of transformation (H1).*

ii) *Higher DFT value implies less necessary transformation experience for confirming whether INT TP was achieved or not (H2).*

9.2 Future Prospects of the Research

By applying the proposed assessment method of transformability, determination protocols and logical procedures, the research topic has potential for long term investigation and can be expanded such as in the following manner:

1) POE methods can be improved to be more consistent and informative.

2) Number of examples can be enriched, both domestically and internationally.

3) Different types of housing and buildings at large can be investigated.

4) Predictions can be made in advance and tested subsequently.

5) The set of design characteristics list and its SUB TP can be enriched together with enhanced resolution of analysis (more precise years of transformation and description of transformation), creating a usable index of available methods for architect to consult in different stages of design process.

6) Experimental development of construction methods and techniques can be tested in reality.

7) Comparative analysis with other transformability assessments methods may be performed in order to test the theory.