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Spatial Behavioral Model-Based Dynamic Data-Driven Diagram Information Model

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***Abstract*—**Diagram and drawing are important ways to communicate and the reproduce of architectural design, Due to the development of information and communication technology, the professional thinking of architecture and interior design are also change rapidly. In development process of design, diagram always play very important role. This study is based on diagram theories, observe and record interaction between man and objects, objects and space, and space and time in a modern nuclear family. Construct a method for diagram to systematically and visualized describe the space plan of a modern nuclear family toward an intelligent design, to assist designer to retrieve information and review event pattern of past and present.

***Keywords*—**Digital diagram, information model, context aware, data analysis.

I. Research Objectives and Background

LE Corbusier, a master in architecture in the 20th century, indicates that the issues with residence change with time. He believes that a new concept for residence is required to meet the needs from a new lifestyle in a new era; thus, designers must use new tool "in the new spirit of new era" to build a new residence [1]. With reference to the view of Le Corbusier, the new residence of the 21st century shall meet the needs present in the information age. The living environment thus shall be created by integrating popular computing tool available in the information age which is of the new spirit of new era. In the area of developing living environment for nuclear family a Smart Home fit for this new era shall be developed by integrating modern technologies such as information, communication, electronics, smart computing, etc., in the new spirit of new era.

Modern notion of a habitable space has evolved over time, which grew from the idea that a habitable space should serve as one for sleeping, cooking, and religious purpose with no other special purposes in mind in early human history. This idea did not change until 18th century where family life was kept at a distant from the society for the sake of privacy. Giddens [11] indicates that the rich sets up corridors that separate rooms for privacy and living rooms that are located outside of bed rooms, by following modern form of design notion. Such a concept becomes the primitive idea of interior design and initiates the development of various kinds of vital functions of life. Habitable space also evolves with the social development to meet the needs of modern life. It has included various living areas such as living room, dining room, bed room, kitchen, study room, rest room, etc., to meet various family needs such as leisure, life, and education.

According to Encyclopedia Britannica Online, a nuclear family is defined, according to the definition of sociology and anthropology, as a group of people who are bonded together through marriage or adoption, including one male, one female and their children who are socially recognized. In other words, nuclear family is one which is formed by two generations, i.e., parents and children. Anthropologist George Peter Murdock has created many databases, including Human Relations Area Files and Ethnographic Atlas [15], [16] and Standard Cross-Cultural Sample [17], [14], which receive wide academic acceptance. A series of arguments in his works mention nuclear family is the basic unit of family organization. Because a nuclear family has various form in each stage, the needs for residential environment also vary greatly accordingly. Proper residence and interior design must be selected to address practical issues, considering the residents, their ages and genders. If restrictions of the family and social conditions apply, the interior form of the existing residence should at least be adapted to the change of family pattern to best satisfy various needs of each family member in each phase of life.

The process of interior design of an architecture consists of four phases: Data Collection, Design Idea Generation, Detail Design, and Project Implementation [12]. However, the professional thinking in architecture and interior design is also transforming rapidly thanks to the development of information and communication technologies. "Diagram" has been playing a very important role in the development of interior design. It is an important media with which the instructors and students communicate and exchange design ideas in a design workshop. The progress of digital design tool has enabled the generations of many unprecedented digital diagrams. Although the term "Diagram" is still in use by most people, digital diagram differs from manual diagram in essence. In other words, digital diagram generates new meanings and concepts [29]. Certain 3D Computer Aided Design software has very complete data structure, such as SketchUP, AutoDesk Microstation, AutoCAD, 3D Max, etc. Such professional software can record the design in great details. However, the professional training offered in the departments of Architecture or Interior Design is not intended to train the students to be drafters. This study believes that said 3D Computer Aided Design software is suitable in the Design Development rather than Preliminary Design and it is not a suitable software for education of design thinking and design method. Moreover, design method and process must also be adjusted as spatial design proceeds with the help of digital intelligence and in consideration of human

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interaction.

Considering above factors, this study focuses on issues of knowledge reuse and sharing that will appear in the field of architecture and interior design in the age of information technology and knowledge-based economy. The possibility of the description of design analysis must be explored. Description, rather than drafting, is more important. The methods adopted by these analysis tools must be included in the content of the context of the design itself. So, furtherer speaking, what we need is a suitable tool that designers may use to enhance their abilities in exploration and expression. With this in mind, this study attempts to propose an Information Open Source Platform of Dynamic Data-Driven Diagram with Dynamic Data-Driven Diagram as its core content. The theoretical framework of this platform is shown in Fig. 1 By using systematic diagram analysis, a set of methods of recording data, and describing and reflecting modern nuclear family's home activities may be created with a series of created illustrations that show the relationships between People and Object, Object and Space, and Space and Time. Moreover, experiments on real cases are conducted and the result, discussed in an attempt to understand the fitness of this method. Meanwhile, how digital diagram enables a designer to describe the survey reading of the past and current event models systematically is also investigated.

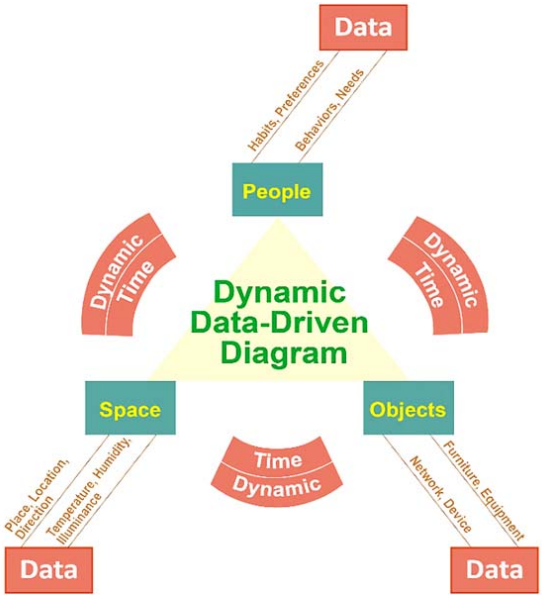

Fig. 1 Dynamic Data-Driven Diagram

II. Relevant Studies

In this section, relevant theories and technical discussions are explored with respect to targeted needs, based on the proposed Information Open Source Platform of Dynamic Data-Driven Diagram with Dynamic Data-Driven Diagram as its core content. The meaning and technology of Digital Diagram, the information and context-awareness of Dynamic Data-Driven Diagram, and the network-based interactive visualization platform technology are discussed below.

A. The Meaning and Technology of Digital Diagram

1) Diagram of Architecture and Interior Design

According to Oxford Dictionary, "Diagram" is defined as a simple sketch representing the appearance, structure, and operation of something, while its verb form is defined as an act of expressing the process of something in drawing, marked with lines for representation. Diagram plays a significant role as a set of communication language, which facilitates the understanding of the logic of thinking behind the space and architecture system. Generally speaking, in order to express the function and purpose of communication we can divide a diagram into three stages according to the design process: (1) Initial stage of design - a stage in which certain characteristics are expressed based on spatial environment, experience, and other factors; (2) Mid stage of design - a stage in which the system and the logic of design is sought by using diagram for the advancement of design work; (3) Late stage of design - a stage in which the thinking, decision making, and concluding of a design are expressed in intuitive and clear diagrams. The two-volume series of The Autopoiesis of Architecture- a New Framework of Architecture written by Schumacher [26], [27] indicate that diagram and drawing are means of representation for architectural communication. The process of architecture design can be seen as one that produces diagrams and drawings. Schumacher further divides the diagram into four different kinds in his book:

1. Metric-Ordinary Diagram - an orthogonal diagram of Architectural Typology Diagram and Modernism, which is good for the discussion of composition of basic design elements
2. Metric-Extraordinary Diagram - deconstructive architecture diagram between mid-1980's and late 1990's, a kind of so-called open diagram by the philosopher Gilles Deleuze, which utilizes deconstructed diagram elements to create a special space form.
3. Parametric-Extraordinary Diagram - a diagram generated for computer animation software in mid, an open diagram that manages architecture exterior with metamorphic kinematics and dynamics of topology for the purpose of form-finding.
4. Parametric-Ordinary Diagram-a diagram resulting from a gradual transformation from Metric-Extraordinary Diagram to Metric-Ordinary Diagram post year 2000, which is presented in program script or visualized network language for the benefit of discussing associative networks among design parameters.

2) Definition of Digital Diagram

Different from traditional diagram, digital diagram emerges due to the following three important developments in information technology:

1. Computer graphic algorithms. The development of computer graphics relies on complex geometry and graphic algorithms. The user can save time by shortening lengthy drawing process. The analysis and result presentation can

be completed rapidly, yielding more effective graphic illustration for the benefit of visual communication, revision and interpretation.

2. Parametric design. Digital diagram is not merely an act of combining elements of graphic illustration, it requires a huge database. Moreover, all diagram elements are correlated among themselves. Such correlations form digital models such as data flow, semantic network, open source database, etc.
3. Visualization of data model. Data algorithm is one of the very important functions of computer science. However, the complex data generated by algorithms must be interpreted through imaging and visualization for better illustration of data and persuasion. Take Mathematica software as an example. It can not only visualize formula, functions and geometry, but also image economics and sociology models, thus enhancing the dimension and meaning of illustrations.

3) Visualization of Dynamic Data-Driven Diagram Information

According to NOX International Design Team, students today own a variety of computer tools which can integrate data analysis software, imaging software, and 3D creation software. The 2D and 3D images generated by them are then integrated to form a series of diagram concept map. Design visualization can be even achieved to an unprecedented level by the further use of dynamic visualization simulation like dynamical system and particle system [28]. MVRDV is one of the leading and most influential architecture offices in the world. Founded in 1991, MVRDV design team is led by three Dutch architects Winy Maas, Jacob van Rijs, and Nathalie de Vries. MVRDV pays much attention to the social development trends of Netherlands, including those of urban design, interior and architecture design, and landscape architecture in an attempt to express the understanding of and the care for the society. In the process of the practice, MVRDV presents collective use behavior of a city and the stats in a visualized concept map, transforming various constraints to various parametric and variable factors, and then further to data generated in a computer process. A diagram is thus drawn to allow architects to understand and process each factor that may have influence to the final result of the architecture. This is the so-called Data-Scape concept [19], [20]. This concept proposed by MVRDV explores the potential of design and provides a very new and effective digital design method. On the other hand, UNStudio also employs quantitative and statistical analysis in their design process to develop their digital diagram system by employing computer graphics and referencing knowledge of other disciplines such as Genetic Engineering and Complexity Theory [32]. Furthermore, they also form usable architectural space by employing Mobius Ring in Algebra and non-Euclidean geometry with the help of computer graphics. It is quite obvious that many leading design teams are promoting the practice of design method that integrates design with research, analysis, and experiment.

B. Dynamic Data-Driven Diagram Information and Context-Awareness

1) Dynamic Time and Diagram

The diagram is best known by the general public in the form of musical notation. In addition, dance notation, electronic schematic, map and so forth are diagrams systematically recorded. Diagram is a convenient tool for man to not only read activities of creation, but also to participate, give feedback and document experience from past events [7]. Continuous time factor connects a series of experiences from events in the order of time, thus combining the interactions in time and space. Therefore, diagram is related to time factor. "Time" is an integral part in human society. Individuals schedule their daily lives with respect to time. For groups in a society, the changes in culture and living environments are all documented and expressed in terms of time. In other words, due to the characteristic of time we are able to understand and express the changes of all things. Many characteristics of time are often conceptualized into a Timeline in which time always advances forward. Such is called a Linear Time. However, linear time is not the best way of expressing cyclic activities, such as those of daily and weekly life patterns. Thus, Cyclic Time becomes another way of expressing time. Furthermore, various assumptions often appear in a long term study and plan. In such a case, Branching Time is required to handle different tracks of segment. The three characteristics of time are shown in Fig. 2.

Fig. 2 Three characteristics of time

Tufte [31] proposed six conclusions and arguments for the space and time characteristics of a diagram: Escaping Flatland, Micro/Macro Reading, Layering and Separation, Small Multiples, Color and Information, and Narratives of Space and Time. Moreover, several models have been proposed for the study based on time reasoning expression in the field of artificial intelligence. Among them, Allen's Interval Algebra proposed by Allen [2], [3] is one of the most well known in the handling of logical relation with respect to time. According to a series of studies by Allen, et al. [4]-[6] there can be seven kinds of relationship between two time intervals: Before/After, Meet, Overlap, Start, During, Finish, and Equal. When treating the change of object interaction between user and space in this study, these methods of time recording provide the needed support. In general, change relationships can be categorized as Continual Change (such as user's movement in space) and Discrete Change (changes that happen suddenly, i.e., change of space's temperature).

2) Connotation of "People-Object-Space" Diagram Information

Schmidt and Aidoo [24] defined the comprising elements of "context" as three dimensions - Self, Environment, and

Activity. He believed the environment should deliver the information required by users to the place where it can be used by them, in accordance with various places in space or context. In order for the environment to perceive the information required by users, current statuses of each context must be considered, including essential entities within contexts such as location, user identity, status of activity, essential object, or information object. Schmidt [25] further categorized context perception into two categories: Human Factor and Physical Environment. There are three major categories among elements of human factor: 1. User information (perceiving user habit, mood, and physiological condition); 2. Users' social interactions (perceiving user's partner, social interaction, groups, etc.); and 3. Tasks users intend to complete. There are also three major categories among elements of physical environment: 1. Spatial location; 2. Infrastructure of surroundings (perceiving the strength of wireless signal, base station, etc.); and 3. Actual factors of environment (perceiving noise, temperature, humidity, illumination, etc.)

The platform of context-awareness is mainly about perceiving or memorizing information about actual contexts such as people and environment. Schilit, et al. [23] proposed three major concepts of context-awareness: Where, Who, and What. Korea-aho [13] suggested to consider the effective information content in dimensions of 6 W's, building a framework model for user-oriented context-awareness function. In the design of a context-awareness platform six dimensions, called in short "6 W's," should be considered. They are shown, respectively, in Table I, Purpose of platform design (Why); Procedures and methods of applying awareness information (How); and awareness information of people, events, time, and location: Users and groups (Who); Relevant facility and equipment (What); Time and timing (When); and Environment and quality of environment (Where).

TABLE I
CONTEXT-AWARENESS DIMENSIONS, 6 W'S

6 W's	Context
Why	Purpose of platform design
How	Procedures and methods of applying awareness information
Who	1. User identity: gender, age, feature, occupation 2. Physiological measurements: blood pressure, heart beat, breathing rate, tone 3. Psychological preferences: likes, dislikes, happiness, anger 4. Types of activities: conversation, reading, walking, jogging 5. Social contexts: company, group, social status, privilege
What	1. Variable factors to be adjusted in platform test and assessment 2. Equipment, device, console and space which are relevant to platform 3. Effective resources: demo, network, bandwidth
When	1. Temporarily stored information: daily, quarterly, annually, or over a period of time 2. Appointment: Agenda, schedule 3. Timing for triggering events, duration of events, repeated cycles of events
Where	1. Spatial information: location, orientation, direction, movement 2. Quality of environment: Temperature, humidity, illumination, air quality, wind direction, noise, etc.

C. Technology of Network-Based Interactive Visualization Platform

3D drawing software like AutoLISP of AutoCAD, Ruby of SketchUp, MEL of MAYA (combining UNIX and Java language), MaxScript of 3DMax, VB Script of Rhinoceros, or Grasshooper developed for users unfamiliar with programming, provides script compiling function. Moreover, ActionScript and Processing can also be programmed to produce image. As far as the structure of database is concerned, Microsoft Excel employs Relational Database while Grasshopper adopts Hierarchical Database in combination of Network Database. This study does not purpose to discuss how to produce complicated forms, but how to create digital diagram information and use it for the analysis of spatial behavior. Two proven open source library programming languages, D3 and Processing, are listed for targeted demands, and their pros and cons, detailed below.

1) D3 (Data-Driven Documents)

Browsers of interactive network are running is faster, and their functions are more complete. Information visualization has also adapted accordingly recently, focusing more on integration of HTML, JavaScript and CSS code to allow running directly in a browser. In the past, interactive information was carried out by ActionScript while static data graphs were stored in the format of image. Today, there exist more than one option when it comes to cross-platform integration collaboration. Some robust libraries can help us create interactive or static visualized images and provide many options for data customizations.

D3.js (Data-Driven Documents) [8] was released by Visualization Team of Stanford University and was used to create data visualized image. D3 is an open source visualization library which provides a series of open source open-box visualization tools. It imposes no restriction in the creation of geometry. The greatest advantage of this library is that it integrates the collaboration among HTML, JavaScript and CSS (Cascading Style Sheets) by acting as a driver which connects data and files [30]. Today, there are many network application-based visualization tools available, such as Processing which is very popular. Though they increase the efficiency of visualization, these tools have increased the complexity and difficulty in learning how to perform Document Object Model (DOM) encapsulation and optimization-based work flow. Moreover, the methods used by these tools do not allow collaboration with other tool such as CSS, making the use of them very tedious. Therefore, compared to the problems found in the old fashion interactive visualization tool, D3 has advantages such as high compatibility, very fluent dynamic execution, and ease of learning and development [9].

Information is structured data, which reflects certain facts. In the context of visualization programming, data are stored in digitalized files, which are generally in the forms of text or binary digits. Things that are qualified as "data" are not limited to text and digit. Digital data such as image, database and model, can be classified as data [33]. Data that are saved as a text file named as "**.txt" or Comma-Separated Values uploaded in the form of file named as "xx.csv," can be driven and visualized by D3. In other words, interactive visualization over network usually requires the use of multiple technologies -

HTML for display of page content; CSS for style design; JavaScript for interaction; SVG (Scalable Vector Graphics), a vector-based graphics library, for drawing with advantage in zooming; and DOM for display of page content in layered structure - making possible the collaboration of said technologies. However, current visualization tool over-performs autonomous encapsulation on visualization tool, causing them to score poorly in Accessibility and Expressiveness in general [18]. However, the releases of D3 for JavaScript and Java languages can run across platforms. Their greatest advantage is that users can use SVG more directly, especially in dynamic performance, thanks mainly to the fact that only varying properties are locally rendered instead of the whole scene being re-drawn [22].

2) Processing

Processing (https://www.processing.org), mainly used in art, image, and the design and process of audio and video materials, was released jointly by Ben Fry (Broad Institute) and Casey Reas (UCLA Design| Media Arts) in 2001; and its updated version was developed by Aesthetics and Computation Group under MIT Media Lab. When Processing was first released, it was intended for designers and artists; thus it was an open source language fit for designers and digital artists. Processing is a tool that emphasizes the creativity of visual thinking. It allows the creation of graphs with dynamic and interactive functions with just a few lines of script. Today, its open source library has more varieties, allowing users to use various libraries to improve diversity. Processing is an environment built on Java language, so programs written in Processing will be translated into Java language and executed as a Java program.

However, one of the disadvantages with Processing is its dependence on Java application which slows down the loading of Processing onto a computer. Furthermore, Java is not used by all users. To address these issues, a JavaScript version of Processing was also released, a very suitable tool for beginners. It enables users who have no programming experience to create interesting interactive designs. The greatest advantages with Processing are its unique image library and simplified language. Developing a platform or creating interactive design does not require a preliminary understanding of advanced concepts such as Classes, Objects, Animation, and Double-Buffering. Processing also gives advanced users more freedom in use even though programming in Java language is required to address the technical details of advanced uses. Such a feature has been integrated into the environment of Processing, allowing the creation of more streamlined programs that are easy to understand [10].

As stated above, though with a very useful Application Programming Interface (API), Processing is much inferior to HTML in compatibility. The variety of today's hardware products and interactive devices poses a new technical challenge to visualization design tool [21]. Ideally, visualization tool needs to support applications in the environments from desktop to network, plus multi-touch mobile device. It also needs to follow closely the trend of hardware development like multi-core computing and special graphic hardware. By contrast, D3, being built on standard HTML, can be integrated to and collaborate with other technologies. For example, D3 can use external Style Sheets as its style, and even CSS for animation. Meanwhile HTML pages generated on a server can then be displayed on a client through data conversion by D3 or used with other JavaScript tools together. Thus, compared to D3, Processing is a less open system.

III. Methodology

Based upon said major literature and the objective of this study, the methods employed in this study are ordered in four major steps: 1. Capture of client's user experience; 2. Establishment of algorithm; 3. Information platform interface of Dynamic Data-Driven Diagram; and 4. Output of information model for designers' reference and assessment. The flow chart of the four major steps is shown in Fig. 3. The methods of implementation and their content are detailed as below.

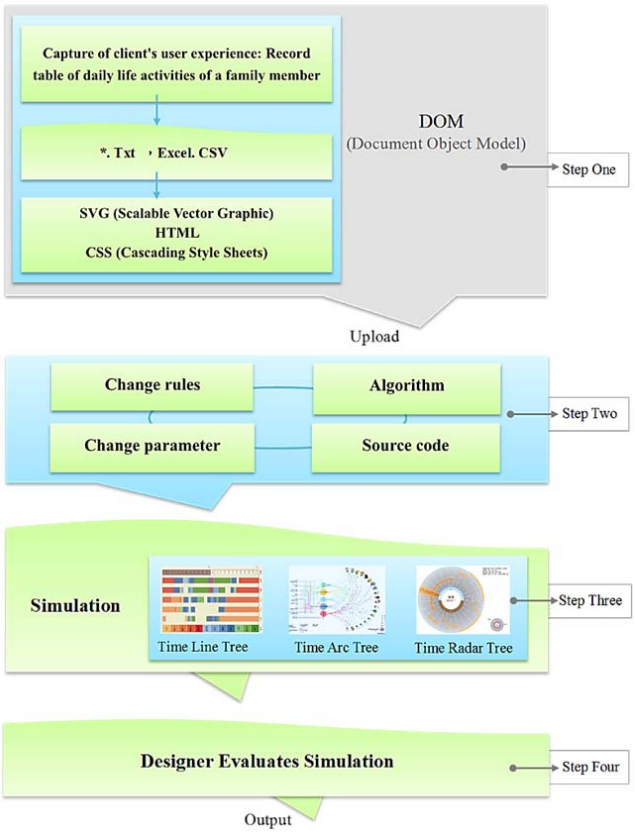

Fig. 3 Flow chart of the four major steps

A. Capture of Client's User Experience

A nuclear family of today is observed by recording daily living contexts of family member. A family of the Lin's in Changhwa county of Taiwan R.O.C. is the subject of the case study. Information of the client's user experience and status of

interactive context were captured. Time series and status of spatial context, the relationships between people and the time of use, and between space and time of use are recorded.

B. Establishment of Algorithm

Time is not independent from various change factors in a real world. In other words, time, spatial location and activities produced are not completely independent. With the records of time, relationships between events may be compared with respect to time. The methods of recording, generated as a result of three characteristics of time (Linear Time, Cyclic Time, and Branching Time) as mentioned in referenced literature, are employed in this study. The forms of time analysis with this platform are thus Time Line Tree, Time Arc Tree, and Time Radar Tree, integrating dimensions of People, Object and Space. The algorithm must also follow the seven logical relationships among time intervals, as shown in Table II. User-oriented model, i.e., Time(T) ∈ Event(E), is shown in (1).

$$\text{Time(T)}\begin{cases}\text{Time Line Tree}\\ \text{Time Arc Tree}\\ \text{Time Radar Tree}\end{cases} \in \text{Event(E)}\begin{cases}\text{People}\\ \text{Object}\\ \text{Space}\end{cases} \quad (1)$$

TABLE II
THE SEVEN LOGICAL RELATIONSHIPS AMONG TIME INTERVALS

	Logical relationships
1	Event A before Event B (before), Event B after Event A (after)
2	Event A meets with Event B (meet)
3	Event A overlaps with Event B (overlap)
4	Event A starts with Event B simultaneously (start)
5	Event A happens during Event B (during)
6	Event A finishes with Event B (finish)
7	Event A finishes with Event B simultaneously (finish)

C. Information Platform Interface of Dynamic Data-Driven Diagram

The interface of information platform of Dynamic Data-Driven Diagram in this study is featured by a structural concept simulating associative thinking of the brain in organizing and connecting information, thus forming mesh network of information brain structure. Designers can obtain required information by clicking at the information point in the information brain structure. More than anything else, the concept of mesh networked information structure resembles the model of human ability of thinking and organizing information. It presents associatively diagram information in visualization and allows designers to read and analyze the associative characteristics implicit in the information.

D. Output of Information Model for Designers' Reference and Assessment

The ease of use and fitness are assessed by two experts of different disciplines - interior designer (industry) and professor of design (academia). The information output models of Dynamic Data-Driven Diagram are exemplified in the time intervals, the relationship analysis of privacy level between spaces, the frequency of use of each space, time ratio of a user's continual use of each space are output visually, by capturing certain space user's order of event (before and after), or the start and finish of certain event.

IV. CONCLUSION AND SUBSEQUENT STUDIES

Overall speaking, mass information content may be converted to meaningful design model through Dynamic Data-Driven Diagram. Compared to the pure digital display used in the past, Dynamic Data-Driven Diagram is more intuitive and easy for designer to quickly understand and use information. With the improvement brought about by new technologies and algorithms, the data dimension and width that information visualization can present today are more diversified and interactive. The models that observe and record people-object, object-space, and space-time interactions based on the theory of diagram have been completed so far, thus establishing a set of space planning method that allows diagram to systematically and visually describe intelligent design of today's nuclear family. Subsequent studies shall create an open source visualized network platform, consisting of information model of Dynamic Data-Driven Diagram in three forms - Time Line Tree, Time Arc Tree and Time Radar Tree - by following the mechanism of this method. The interior designers may record interaction information visually through network and output analysis model in visualized result; thus they are enabled to capture information and describe the survey reading of the past and current event models more effectively.

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