デザインの形式表現への BDI フレームワークの適用
デザインにおける思考過程の計算モデルに向けて
Application of the Belief-Desire-Intention Framework to Formal Representation of Designing
Towards a computational model of thought process in designing

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1. Introduction

The objectives of this study are to enrich Belief-Desire-Intention, or BDI in short, framework [5] so as to be employed in design research and computing and to create a method of extracting the rationale of actions in designing from narratives about designing. The rationale is composed of propositional attitudes, which are categorized as belief, desire, or intention. Since designing is a purposive activity, a designer has desire to provide a particular functionality and intention to make something to fulfill the desire. Formal representation of a processes of designing and its product or a part of them is helpful to computer aided design research and design computing, as well as to design science. This does not mean that we intend to let a computer replace a human designer. We can leave what can be done by computation with a computer and leave what a computer cannot do and what is fun to do for human with a human designer.

Various means to describe states of affairs concerning architecture and architectural spaces exist and are being improved. Formal models of designing were proposed as well [1][2]. Gero [1] proposes to represent an artifact from three different kinds of aspects, i.e., function, behavior, and structure. He models a process of designing as a sequential cycle of transformations among the representations from the aspect of function, behavior, or structure. This framework for describing designing is called Function – Behavior - Structure framework, or FBS framework. Gero and Kannengiesser [2] sophisticate the FBS framework to deal with situatedness in designing. It is assumed that actions in designing are situated in the sense that a course of actions is determined by an interaction between external factors, i.e., the environment where it is performed, and internal factors of the designer, i.e., some goals, beliefs, etc. The framework is called as the situated FBS framework. However, to our knowledge, formal representation of cognitive processes in designing, which is promising for making a computational model of architectural design process, is not sufficiently proposed [3][4]. Akin [3] proposed a model of information processing in designing on the basis of the protocols in designing. Gero and Fujii [4] proposed a cognitive framework of a situated design agent.

The original contribution is to construct the theoretical and computational foundations of normative study on designing and building. In this context, our naïve research question is: how does the BDI framework help us to explain the transitions of residential houses from past to present, and to generate trajectories towards their preferable future?
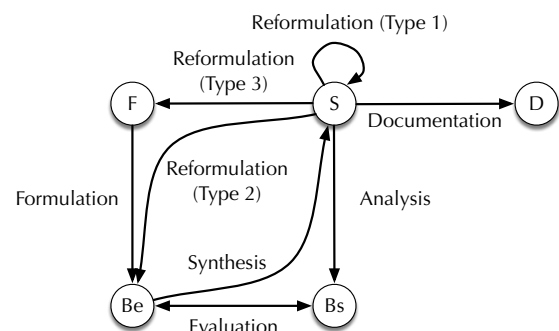

Figure 1. Model of Design Process with FBS Framework.

2. The BDI Framework

The primary reason of an action is explained in terms of propositional attitudes. The notion of a *propositional attitude* [7] refers to a mental structure composed of a content of an agent's cognition or opinion and a mental state held by the agent toward the content [8]. The content is expressed as a proposition whose truth value can be assigned. Specifically, the primary reason of an action is explained by combining desire and belief, which are propositional attitudes. An action is regarded as the emergence of a bodily movement toward a certain matter X, of agent A's desire – agent A wants, or hopes, the matter X -, entailing agent A's belief – agent A believes, or expects, that the matter X may exist now or in the future [9].

Belief: The notion of *belief* refers to what an agent believes, i.e., the current matters perceived or interpreted, the past matters remembered, the future matters expected or predicted, the relationships among these matters, the significance or value of matters believed, the likelihood of a course of action achieving certain effects [6], and so on.

Desire: The notion of *desire* refers to an agent's pro attitude towards a matter or preferences over matters such as states of affairs, courses of events, or courses of action. An agent is allowed to have inconsistent desires and does not have to believe that its desire is achievable [6].

Intention: The notion of intention refers to an agent's commitment to a certain goal and courses of action in the future towards the goal [5][6]. The goal committed is selected from the goals, which is a consistent subset of desires that the agent might pursue [6]. The courses of action committed are selected after deliberation based on the desire and belief.

3. Relations among Propositional Attitudes in Architecture

The typical patterns of the relationships among belief, desire, and intention in the rationale of building a house are shown. The patterns are extracted from the contents of conversations about building and rebuilding of traditional houses. It is assumed that an agent is rational in the sense that only a consistent set of desires is selected.

The procedure of whole study is shown below. This paper shows the result of the second step.

(1) Sentences in narratives and essays conveying propositional attitudes behind actions, targeted at introducing modern technologies into traditional houses, are analyzed and categorized into three categories - belief, desire, and intention.

(2) The propositional attitudes are associated with each other in terms of causal relations and logical dependencies to construct the entire structure.

(3) The propositional attitudes and their relationships are formally represented in predicate logic.

(4) The reason of a course of actions to improve the quality of life by introducing modern technologies are explained by using practical reasoning as well as syllogism.

(5) Thought experiments are executed to generate different trajectories of retrofitting traditional houses based on different sets of propositional attitudes.

Figure 2. Retrofit of a Traditional House in Izena Island

Practical Reasoning

Figure 3 shows a simple pattern of practical reasoning where an intention is derived from a desire and some beliefs. Suppose that an agent has a desire (D:) to fulfill a state of affairs which is referred to by proposition D0 (D:D0). With the belief (B:) that the result of action A1 is a state of affairs referred to by proposition D0 (B:A1=>D0), the agent infers that action A1 becomes a candidate of an action to be performed (B:alt.A1). If the agent has the belief that action A1 can be done, or is available (avl.), in a certain circumstance (B:avl.A1), then the agent intends (I:) to do action A1 (I:do.A1). This pattern can be simplified as shown in Figure 4 where the availability of action A1 is implied or unverified yet. This pattern is equivalent to the application of the inference rule of the practical reasoning proposed by Aristotle. Here, A=>B expresses that if action A is performed than B becomes true.
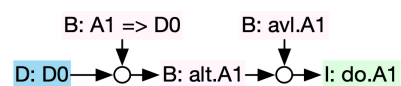
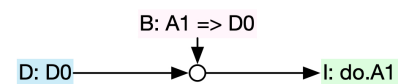

Figure 3. Practical Reasoning 1.

Figure 4. Practical Reasoning 2.

Figure 5 shows a simple pattern of a combination of a syllogism and practical reasoning to derive an intention from a desire and a belief. Suppose again that an agent has a desire to fulfill a state of affairs which is referred to by proposition D0 (D:D0). With the belief that if D1 is satisfied then D0 is satisfied (B:D1->D0), the agent articulates the primary desire as a desire to realize a state of affairs expressed by proposition D1 (D:D1). With the belief that the result of action A1 is a state of affairs referred to by proposition D1 (B:A1=>D1), the agent intends to do action A1 (I:do.A1).
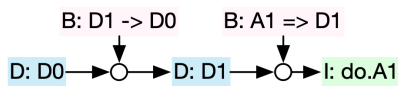

Figure 5. Syllogism and Practical Reasoning.

Selection of Action Alternatives

Figure 6 shows a pattern in which an action is selected from two alternatives. Suppose that an agent has a desire to fulfill a state of affairs which is referred to by proposition D0 (D:D0). If the agent believes that two different actions A1 and A2 have the same result D0 (B:A1=>D0, B:A2=>D0) then the agent believes that action A1 and A2 are alternatives to satisfies desire D0 (B:alt.A1 and B:alt.A2). In the case that the agent believes that action is not possible (imp.) to be executed (B:imp.A1), the agent necessarily selects action A2 and intends to do action A2 (I:do.A2).
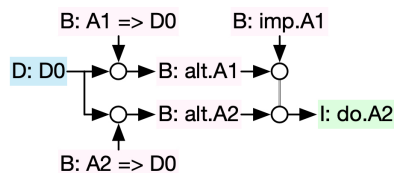

Figure 6. A Process of an Action Candidate Selection.

Figure 7 shows a pattern in which an action is selected from two alternatives by comparing them and the first selection is given up because of a certain situation. Suppose that an agent has a desire to fulfill a state of affairs which is referred to by proposition D0 (D:D0). The agent believes that action A1 and A2 are alternatives to satisfies desire D0 (B:alt.A1 and B:alt.A2). The agent compares the alternatives with each other and concludes that action A1 is better than A2 for some reason. Therefore, the agent intends to do action A1 (I:do.A1), not action A2. Suppose that the agent become aware that action A1 cannot be executed after the decision making (B:imp.A1). Then, the agent gives up action A1 and necessarily selects action A2 instead of action A1 and intends
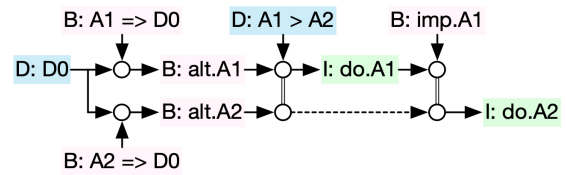
to do action A2 (I:do.A2).

Figure 7. A Process of Selecting an Action by Comparison.

Articulation

Vague Information is articulated on the basis of an agent's belief about the relation between class and subclass, class and instances, and so on. Figure 8 depicts a process where a vague intention, which cannot be executed by itself, is articulated so as to make the vague intention executable. For example, even though we intend to roof a house, we cannot complete the plan without deciding the material used for roofing and the construction method, i.e., thatched, tile, galvanized iron, etc. After an agent has intention to do vague action A1 (I:do.A1), A1 is articulated. Suppose that the agent believes that action A1' and action A1" instances of the vague action A0 (B:A1'->A1, B:A1"->A1). Then, the agent believes that action A1' and action A1" are alternatives (B:alt.A1', B:alt.A1").

Vague beliefs and vague desires would be articulated in the similar way. Articulation of a vague desire is mentioned in the next session.
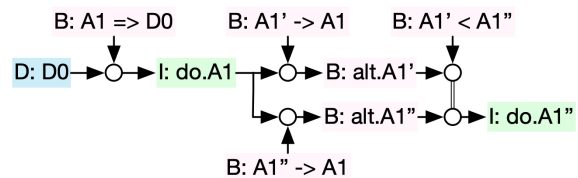

Figure 8. A Process of Articulation.

Resolution of Conflict

Figure 9 depict a process of resolving a conflict among alternatives. In a situation where two actions conflict with each other, one of them is selected and the other one is give up. An agent believes that its desire (D:D1) and desire (D:D2) articulate desire (D:D0). Abductive reasoning is employed to derive a desire to fulfill a state of affairs which is referred to by proposition D1 (D:D1) from a desire to fulfill a state of affairs which is referred to by proposition D0 (D:D0) and a belief about the relation that if D1 is satisfied them D0 is satisfied (B:D1->D0). Equivalently, Desire D2 (D:D2) is derived from desire D0 and belief D1->D0 (B:D1->D0). With the belief that the result of action A1 is a state of affairs

referred to by proposition D1 (B:A1=>D1), the agent believes that action A1 becomes an alternative (B:alt.A1). Equivalently, with the belief that the result of action A2 is a state of affairs referred to by proposition D2 (B:A2=>D2), the agent believes that action A2 becomes an alternative (B:alt.A2). Suppose that the agent believes that the result of action A1 is a state of affairs referred to by proposition ¬D2 (B:A1=>¬D2) and that that of action A2 is a state of affairs referred to by proposition ¬D1 (B:A2=>¬D1). As a consequence, action A1 and action A2 are not compatible with each other. The agent gives up desire D1 and intends to do action A2 (I:do.A2).
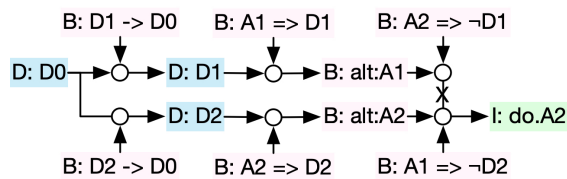

Figure 9. A Process of Articulation.

Substantial Aspect and Conceptual Aspect

A set of propositional attitudes is a subset of all constituents constructing a self-conscious experience in the conceptual aspect. A self-conscious experience also has the substantial aspect. Some constituents in the conceptual aspect emerges through the interaction between an agent's body and its environment in the substantial aspect.

When an action is executed as intended, the relations among the agent and its environment are changed. Figure 10 depicts this process. The changes are experienced in the substantial aspect (the lower part of the figure) and the conceptual aspect (the upper part). Suppose that an agent faces a situation where the agent believes the thing referred by proposition D0 is not satisfied (B:¬D0). Suppose also that the current situation is not preferable for the agent and that the agent has a desire to make a state of affairs which renders proposition D0 true (D:D0). Through the process discussed above, the agent intends to do action A1 (I:do.A1) so as to satisfy its desire. Suppose that the agent executes the action and changes the relationships with its environment (action). The agent experiences the state after the action and confirms the situation where the agent believes that proposition D0 is rendered true (B:D0). The agent also believes that the situation renders proposition E0 true (B:E0) as a by-product. In the case that E0 is not predicted in advance when the action is intended, it could be said that the situation that renders proposition E0 true is noticed by executing the action.
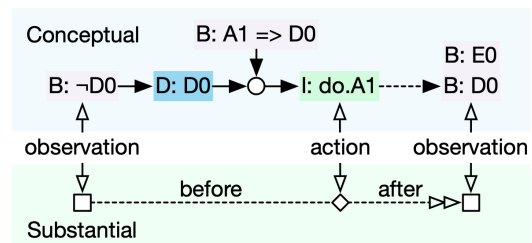

Figure 10. A Process including Execution of an Action.

Conclusion

The main conclusions at this moment are that it is possible to extract the rationale of actions in architectural activity from narratives, and that this rationale could be represented in a form available for design computing. The next steps are to assign each type of relation among propositional attitudes with appropriate inference rules, and to formally represent these in order to confirm that they can be dealt with computationally.

Acknowledgment

[References]
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