Collaborative Design Process for Encouraging Sustainable Building Design: A Game Theory-Based Approach

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Abstract. Information permeated in a daily life through ambient urban media may have positive effects on people's behavior and consciousness. This approach can be adapted to enhance sustainable building design in an educational environment. In this paper, information about sustainable building design is provided and the visualized evaluation is fed back, as a way to encourage sustainable building design. In addition, to maximize the effect of the interaction between competition and cooperation among students, we have applied a game theory approach called 'prisoner's dilemma'. Information visualization is effective to change the focus of interests in the students' design and a game theory helps produce a variety of design alternatives. The method can improve the design capabilities and change the students' consciousness as well.

Keywords: Design Process, Design Education, Game Theory, Collaboration, Protocol Analysis.

1 Background

Major social problems include lack of natural resources, destruction of ecosystems, environmental pollution and imbalance of the community (Pearce et al. 2012). Accordingly sustainability has become a foremost issue but it can be misunderstood to mean only those related to energy in many cases. However, sustainability is typically illustrated as three intersecting dimensions connecting environment, community and economy. The architecture and architects might be well suited to lead the change toward sustainability in this sense. It is because when design is informed by the knowledge leaned from sustainable systems, it has the potential of changing how buildings, communities, and societies function to sustainable one (Williams 2007). Therefore, designers increase awareness of sustainable lifestyles and are required to realize eco-friendly buildings and sustainable cities. Lifestyles of people are embodied by the nature of the specific individual or may be determined according to the environment (Alexander 1977). Therefore, sustainable design helps change the lifestyles of citizens into sustainable ways to a certain level.

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Designers pass through the design process to derive the design results by solving a variety of design requirements and constraints. A design process is constructed and affected by a variety of behaviors and cognition of designers (Kim and Kim 2007). There are interactions between "the information that has been learned" and "the reasoning of the designer in the process of solving design problems". At this time, design process is more effective when the information (specific data) is delivered to the people naturally through the ambient media in daily life than in a determined way unilaterally such as Web page access and participation to the lecture (Holmes 2007). In a previous study, we had conducted a study that provide the information visualization collected using various sensors to designers and increase the awareness of designers about environment in cities and buildings (Kim et al. 2012). In terms of pedagogic purposes, it can be used to enhance learning by providing the information to novice architecture students who don't have enough knowledge. Moreover, various knowledge acquisitions from effective visualization can help the designer build the sustainable buildings and cities in the long run.

2 Research Method

We carried out preliminary experiments to find out how visualized information affects the design outputs. Every design process has individual unique characteristics (Gough 1981) but also significant portion can be affected by learning and teaching (Akin 1996; Oxman 2001). There are methods of information transmission through the screen visualization as one way to influence the final design output, but the previous research focused on only the visualization of the design process (Kim 2006). In this research, however, sustainable design information is provided to architecture students by ambient visualization. By providing students with visual representations of the evaluation of design, we indirectly encourage the students to design sustainable buildings and urban planning. Especially environment-friendly images that are well known in general as sustainable buildings are provided in the test setting and then we observe how the students design the environment-friendly building naturally.

Like this, we reconsider student's interest on the topic as the visualized information is provided by the ambient way. Also, the experiment is conducted for proving the hypothesis that the competition can enhance the intensity of design activity as well. The interaction of competition and cooperation with others that may occur directly or indirectly in the design studio might affect the design results. Game is a tool with great educational potential (Malgorzata 2007). To facilitate this effect, a game theory is called the 'Prisoner's dilemma' was applied.

2.1 Game Theory: Prisoner's Dilemma

Prisoner's dilemma game has been widely used in experimental psychology to study how people act when faced with situations where conflict exists between self-interest and mutual cooperation (Takai 2010). Prisoner's dilemma is a strategic game between both players. If you cooperate in this case, it illustrates the problem of selecting a disadvantage to each other in personal greed at the time of the situation that will benefit most from each other (McCain 2004). As shown in Table 1, each player has two

strategies: 'cooperate (C, c)' and 'defect (D, d)'. The combination of each strategy is defined a payoff pair, like (C, d) for (0, 3). When both players decide to choose 'defect' because of strategic dominance, it is only the equilibrium point. However, it is not the optimal choice for both people but choosing cooperate both is the optimal choice. In this situation, whatever the opponent chooses, selecting defect is more advantageous. However, if both players choose defect, the payoff is diminished.

Table 1. Prisoners Dilemma game

	c	D
C	2, 2	0, 3
D	3, 0	1, 1

There are two reasons for applying the Prisoner's dilemma in this experiment. First, the strategic exchange of information among designers is possible. There is a limitation for students to gain and understand knowledge so as to solve the design problems. In general, if they are faced with difficulties in solving a problem while advancing the design process, they may browse the Internet, gather information from books or resolve through communication with other people in the design studio. People who provide feedback may bring out everything they know to the other. In this case, if information receiver reflects all of design elements passed from information sender, both design results can be very identical. Prisoner's dilemma can function to prevent this shortcoming. Second, the strategic reflection of design elements is possible. When two people exchange information, there is a possibility for them to come up with design elements that they did not think of before. In general, the designers may not reflect design elements even though they are beneficial if the elements are not agreed with their opinions because they take pride in their works. It is similar to an early fixation in psychology. However when a game theory is applied to trigger psychological competition in this task, reflecting design elements of the opponent in their design can happen. Furthermore, the designer may introduce new design ideas as his or her strategic elements by adapting what is gained from the meeting.

2.2 Experiment Setting

The experiment is targeted for architecture students who enroll in grades 4 or 5 and have basic knowledge of residential buildings. Eight students were tested and two persons organized one team respectively. Each team conducted a complete conceptual design task a day and three design tasks for three days were given. Same consecutive design problem sets were given to each team and each team proceeded design tasks in separate test rooms. The design outputs were evaluated by professional designer and evaluation notes are delivered to each team prior to the next experiment. Whole test process and the outputs were video-recorded for the evaluation and protocol analysis.

Table 2. Team organization

	No information provided	Ambient information provided
Competition Only	A	B
Competition & Cooperation	C	D

The teams, as shown in Table 2, were organized on the basis 1) of the presence or absence of ambient information about the environmental-friendly buildings, and 2) of the competition condition according to cooperation with other team for evaluation result. Team A and C were not provided with any information except for the basic data of the design problem. Team B and C received information about environmental-friendly building designs which are given on the desks and walls to display information without specific orders as if they were part of classroom newsletters to the students. Each team conducted the residential design on the first day and is provided with the evaluation note of the previous design before advancing the experiment on the second and the third day respectively. Team A and B are provided with the evaluation note which displays both the rival team's score and their own score. Team C and D are intended to compete and cooperate simultaneously. Both teams receive the evaluation note of own team, but they do not know the other team's score except for the total score of opponent. They have a meeting time for exchanging information (Fig. 1).

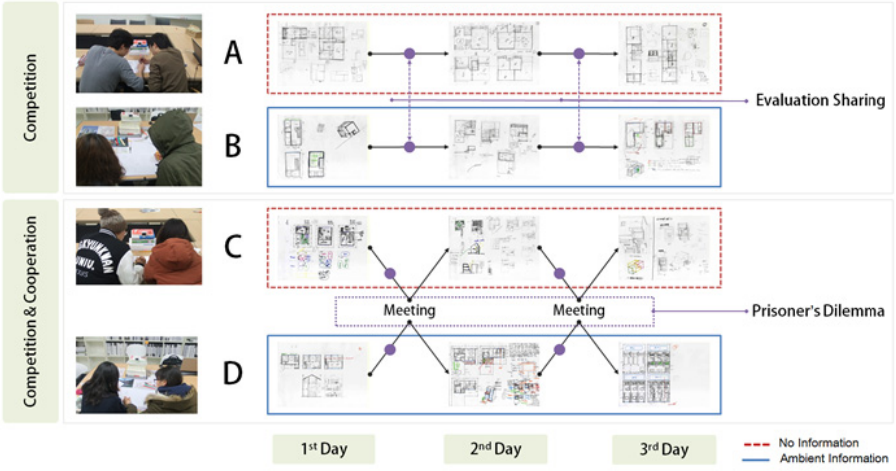

Fig. 1. The design experiment process and the design task results

The information about environmental-friendly buildings is attached randomly on the desk for designers to be able to quickly browse the data such as eco-friendly materials, natural lighting, natural ventilation, and water circulation system, etc.

Relative evaluation method was chosen and various evaluation elements are sub-categorized such as aesthetics, functionality, environment, privacy, and so on. Graph scores based on the results of the design were visualized to each team and the score was calculated based on the number of design items per design. The blue bar graph is a score of one' own team and red line graph is that of the rival team (Fig. 2). We brought the evaluation note to students and notified that the incentives will be increased according to the result of the evaluation.

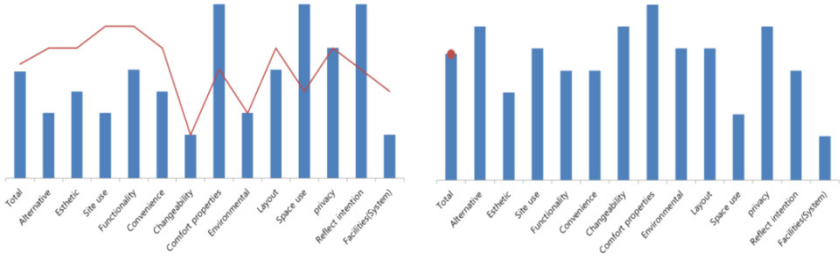

Fig. 2. Example of evaluation in competition (left) and in competition & cooperation (right)

As a part of Prisoner's dilemma implementation, two teams exchange their idea for 30 minutes before conducting the following design. Team C and D have the meeting time and exchange their ideas, views and features of the design. Here the Prisoner's dilemma is applied to allow the strategic exchange of design elements (Fig. 3).

Fig. 3. Meeting of competition & cooperation teams (team C and D)

Table 3. Prisoner's Dilemma: Adapted Score System

	Inclusion	Exclusion
Inclusion	1, 1	2, 0
Exclusion	0, 2	0, 0

The teams in the competitive relation including the cooperation are notified that if both teams contain common elements in their design, they get 1 point each team at the time of evaluation. If one team includes such elements that are not in the rival team, they get 2 points and the other are get 0 point. And if both teams don't include such elements at all, they get no points as shown in Table 3. We conduct experiment on the basis of the above experimental setting. We suggested the three residential design tasks that have different design conditions for 3 days.

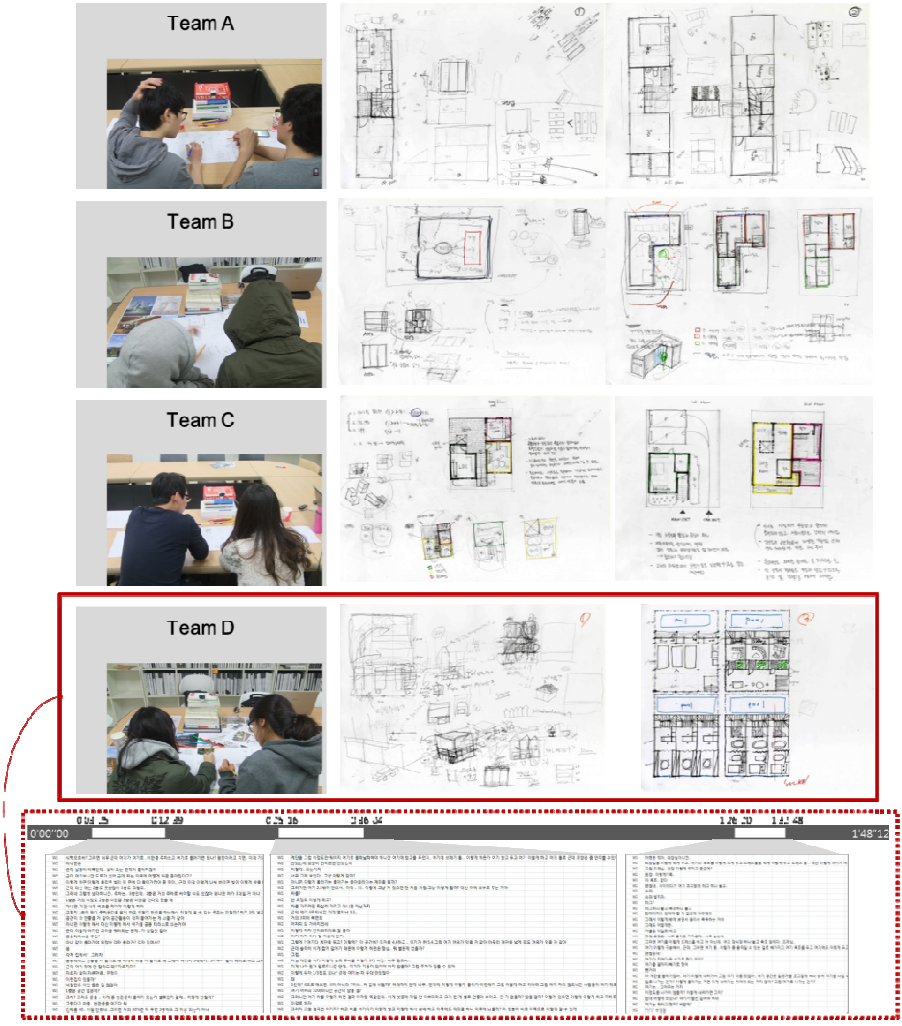

Fig. 4. Progress of design process, design outputs and the script of team D on 3rd day

Students designed the concept of the design of the house. The design output in the drawing cannot represent all the opinions they have exchanged because two members of team resolved the communal problem together. So we take advantage of a protocol analysis method for the delicate analysis. We simultaneously recorded the video and sound to capture the designer`s words and expression. Figure 4 shows the students in the design process and the parts of each team's design outputs on 3rd day. Transcripts for protocol analysis of team D is shown at the bottom of the Figure 4 as well. These records will be used to capture how the students used design contents and how a game theory can influence on their design process in a chronological order. In addition, these findings can be utilized in order to model design learning style and to make collaborative team design strategies.

3 Outcome

Competition condition is more identified that can influence to the design process when the visualized evaluation was used. Especially, while each team which is in the competitive mode designed the house, they paid particular attention to elements which got lower score than those of rival team's design result. In the case of the winning team, it did not carry out analyzing its own previous design and only wanted to know about high scored elements of the other team. Then, they guessed the design of the opponent based on their knowledge of the element and suggested the new design by considering that. And in the case of the losing team, they personally analyzed the weak design part in the previous design, so as not to repeat the same mistake. And they went ahead with a new design.

We can, by looking at the students' behavior during the progress of the design process, find several features as followings; First of all, when they encountered the limits of knowledge in the design process, they show the behavior to try to get information around them. And they try to apply the chosen information to their design as efficiently as possible. Second, they paid a lot of attention to the evaluation of design. They concerned a lot to the elements that they got lower score than the other particularly. And they tried to find a way to improve those of the upcoming design task as much as possible. In addition, the way of graphing the evaluation by design factors attract students' attention considerably. Third, the team situated in the competitive relation does not seriously consider about the high scored design elements. Among design teams, teams that got fewer score promoted a self-analysis of their own lose and this can further increase the possibility of design development. Fourth, when both teams that were situated in the competitive and collaborative relations conducted their design, they can generate various alternatives since it is possible to know the design contents of the rival team. Moreover they suggested a new design by reflecting the criticism from the rival team. When faced with the same problems as the previous design, they showed that they even applied rival team's previous idea to the new problem as well.

4 Conclusion

The ultimate objective of this study is to provide the informatics environment that can change designer's cognition into sustainable way through diverse visualization of information like an environmental-friendly building, the results of the evaluation of design, and information about the surrounding environment by the sensors. We hope that design pattern becomes sustainable ways naturally from the educational viewpoint. Moreover we hopefully conjecture architecture students to propose more sustainable buildings and urban environment. Architecture students will acquire knowledge through education and form a design habit based on this. And they can improve their design quality through communication and collaboration with other students. As a method to enhance the effect of education, the information visualization and game theory-based approach is beneficial. First, it can naturally induce focal points of the design through the information visualization. Ambient visualization can help change people's awareness. In addition, the method of providing visualization

can increase the interest in specific areas. Second, using game theory, a variety of alternative designs could be composed actively. When creating design alternatives, people may experience the limits of their knowledge and abandon probable options. Game theory make increase the number of alternatives through strategic competitive and collaboration with others. This would help design new building and future city where citizens have a sustainable lifestyle.

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