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Using GIS and Multi-criteria Decision Analysis for Conflict Resolution in Land Use Planning

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Abstract

Based on the principles of sustainable development, land use planning often requires the compromise between economic development and environmental conservation while advocating social justice. Given that ideas, values, and attitudes vary among the stakeholders involved, land use planning inevitably incurs a variety of conflicts. The conflicts in land use planning can be described from the perspective of the conflicts among land use types and the conflicts among stakeholders. Accordingly, land use planning can be conceived as the process of dealing with conflicts among different land use types through resolving the conflicts among stakeholders. This study centers around two important issues in land use planning: land use allocation and specific land use proposal deliberation. A Conflict Resolution Framework was proposed based on GIS and Multi-criteria Decision Analysis techniques. A Consensus Building Model was established to address the conflicts among different stakeholders with competing interests in the process of land use allocation. A Spatial Conflict Resolution Strategy was developed to help stakeholders and planners formulate specific land use proposals through an iterative modification process. The both models were tested and evaluated in the context of Lantau, Island Hong Kong. Moreover, the challenges of this research and future work are also covered in this paper.

Keywords: Land use planning; conflict resolution; GIS; multi-criteria analysis

1. Introduction

Sustainable development emphasizes the need for integrating economic development and environmental protection, as well as promoting intra- and inter-generational equity [1]. In recent years, sustainable development has been gradually recognized as a critical principle for land use planning. Land use planning has an important task in promoting sustainable development [2]. Land use planning is concerned with specifying the mix of land use types, the particular land use pattern of these land use types, the areal extent and intensity of use associated with each type based on a variety of considerations [3]. Land use planning problems are sufficiently complex, controversial and non-routine in nature that their resolution requires knowledge, expertise, and data drawn from several distinct domains [4]. Moreover, there are usually a wide range of stakeholders with different values and views involved in the process. Land

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use planning requires a collaborative and participatory process that engages different stakeholders and concerned groups [5,6].

The economic, social and environmental processes involved in land use planning are inherently spatial. Geographic Information System (GIS) technology has the capabilities to produce, store, analyze and visualize spatial data and holds great potentials to deal with land management issues. Land use planning, like any other spatial decision problems, typically involves a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria. Multiple Criteria Decision Analysis (MCDA) techniques offer a structured method to evaluate alternatives and select the most satisfactory one according to the decision maker's priorities across a number of relevant criteria [7]. To address geographical issues, MCDA has been a popular approach for decision analysis in the GIS environment [8,9].

In this study, there are two issues or stages identified in land use planning: land use allocation and deliberation of specific land use proposals. The former is to search for suitable areas for different development or conservation land use purposes based on land use suitability and the preferences of stakeholders. This is to allocate land for different land use types and generate an overall land use pattern. The latter is to formulate particular land use proposals in specific locations through the deliberation among planners and stakeholders. This deliberation designs specific land use projects in selected sites. This study concentrates on developing a Conflict Resolution Framework based on GIS and MCDA techniques to address the conflict problems in land use planning. A Consensus Building Model is developed to address the conflicts among different stakeholders in the process of land use allocation. A Spatial Conflict Resolution Strategy is built to help stakeholders and planners formulate publicly acceptable land use proposals. Moreover, a prototype system was constructed in the context of Latau Island, Hong Kong to test the theoretical findings of this study. The experiment of evaluating the models and prototype system was also conducted.

2. Proposed Conflict Resolution Framework

In this study, the core process of conflict resolution in land use planning with public participation was described as: 1) participants express and share individual preference; 2) planners identify and characterize the preference information; 3) planners help participants build consensus through negotiations in a repetitive fashion. The workflow of land use planning is designed as illustrated in Fig. 1. The procedures could be specified as follows:

1. Data preparation

Planners prepare the background data of the planning area. Planners assess the land use suitability and map the Multiple Land Use Conflict Space based on experts' opinions by using GIS-based MCDA techniques. The land use suitability maps and land use conflict maps are presented to the participants.

2. Land allocation

Participants explore land use situations based on land use suitability maps, land use conflict maps, and other introductory information. Planners help the participants to elicit preference and build consensus according to the Consensus Building Model in land use allocation. Participants can elicit preference through weighting different criteria and discussing particular concerns on a spatially referenced forum. If participants can achieve agreement, then planners calculate the collective preference of all participants according to which land can be allocated. If participants cannot build consensus, planners classify participants based on their preference similarity. Land use pattern scenarios are generated based on the collective preference of different participant categories. The best scenario would be selected by using some publicly accepted principles. Finally, planners could modify and improve the land use patterns by combining the particular concerns of participants according to the forum discussions.

3. Proposal deliberation

Planners and participants formulate specific land use proposals following the Spatial Conflict Resolution Strategy. Planners suggest land use proposals based on the land use allocation results. Impact analysis techniques, particularly environmental impact assessment, are utilized to facilitate stakeholder's analysis of the possible consequences caused by different proposals. Participants then evaluate the performance of each individual land use proposal and propose their suggestions. Based on the suggestions and preference of participants, planners can modify the land use proposals. These improved proposals are provided to participants for further evaluation and discussion. The iterative process continues until a publicly acceptable land use proposal is achieved.

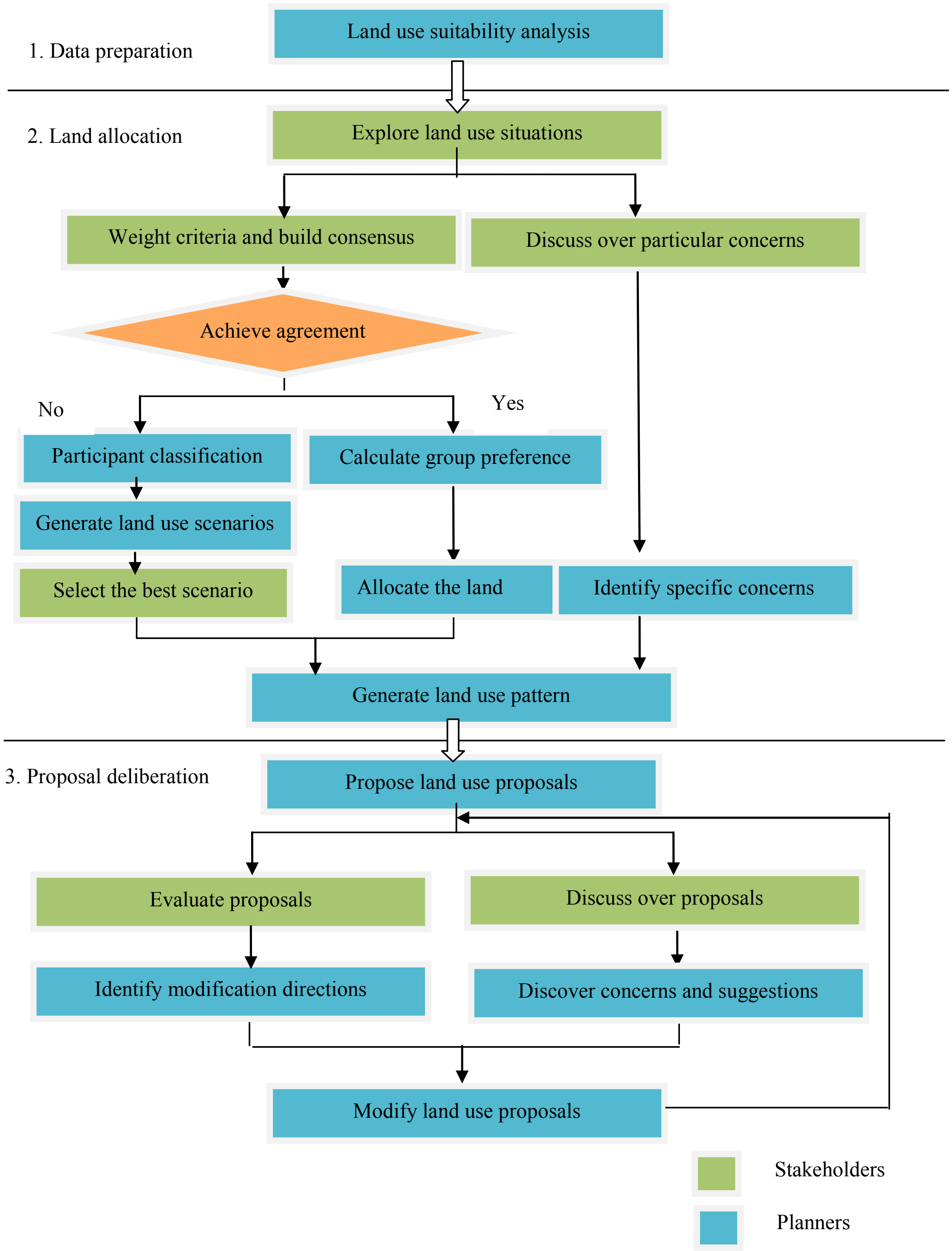

Fig. 1. A flowchart describing the process of land use planning with conflict resolution for public participation

3. Consensus Building Model in Land Use Allocation

Basically, there are two procedures in land use allocation with public participation: *consensus building* and *decision making*. The former refers to how to obtain the maximum degree of consensus or agreement among all participants with the aids of the system's moderation. The latter process consists of capturing the group opinion and obtaining land use patterns using land suitability analysis techniques in accordance with the collective preference of group or sub-group participants. The designated procedures of the Consensus Building Model as well as the variables involved are introduced in this section.

3.1. Agreement Level and Group Consensus Degree

In this paper, the concept of Agreement Level is proposed to represent the similarity of opinions between two participants. Based on the integration of Agreement Levels between paired participants, the Group Consensus Degree is defined to characterize the overall group agreement situations among participants. This is used to decide whether the consensus building process should be started or finished.

Participants can present their views through deliberating the importance of different considerations involved in land use planning. In MCDA, the considerations are represented by a range of criteria. The criteria weights of individual participant can be represented by using a preference vector. The Agreement Level between two participants can be calculated using the similarity measurements between their preference vectors. Criteria are organized in a hierarchy, the weights of the upper level criterion are reflected in the weights relative to the lower level. Thus, a preference vector can be composed of the weights of the bottom criteria.

In a mathematical format, the preference of the *i*th participant could be represented by a preference vector $P^i = \{p_1^i, p_2^i, \dots p_n^i\}$, where $p_j^i \geq 0$ indicates the weight given by the *i-th* participant to the *j*-th criterion. We can define a similarity function using any traditional distance measure between vectors, as for example, the Euclidean distance, or the cosine of their vector angle [10, 11]. The similarity between two vectors could also be defined as their correlation coefficient. Basically, all of these concepts can reflect the differences between the preferences of paired participants. In this study, the correlation coefficient is selected to represent the Agreement Level of paired participants, which is defined below.

Definition 3.1 The Agreement Level of paired participants *i* and *k* can be calculated using the Pearson correlation between their preference vectors, p^i and p^k, The degree of consensus will be measured in the unit interval [-1,1], as follows,

$$C_{ik}(2) = r_{ik}(p^i, p^k) = \frac{\sum_j\left((p_j^i - \overline{p^i})((p_j^k - \overline{p^k})\right)}{\sqrt{\sum_j\left((p_j^i - \overline{p^i})^2 (p_j^k - \overline{p^k})^2\right)}} \quad (1)$$

Where,

$$\overline{p^i} = \frac{1}{n}\sum_{j=1}^{n} p_j^i \text{ and } \overline{p^k} = \frac{1}{n}\sum_{j=1}^{n} p_j^k$$

$$-1 \leq r_{ik} \leq 1$$

The closer r_{ik} is to 1, the more similar the preference vectors of participant *i* and *k* are, while the closer r_{ik} is to -1, the greater the difference in the preference vectors of participant *i* and k. The greater the similarity, the greater the Agreement Level between the two participants.

In this study, Group Consensus Degree is proposed to evaluate the conflict level of all participants, which is obtained by combining all the Agreement Levels between paired participants. It is used to guide the consensus building process until a balance achieved.

Definition 3.2: Group Consensus Degree can be defined as the arithmetic mean of all paired participants' Agreement Levels.

$$C = \frac{\sum r_{i,j}}{C_n^2} \quad (2)$$

Where, $i, j \in (1,2,3, \dots, k), i > j$

r_{ij} refers to the Agreement Level of participant *i* and *k*,

n indicates the number of participants involved.

3.2. Preference Aggregation

Preference aggregation serves the purpose of combining individual participants' preferences to obtain an expression of the group's preference. Lands should be allocated based on the group opinion. Besides, the process of consensus building requires identification of the proximity of individual participant's preference to group opinion. Hence, achieving group opinion is the foundation for both consensus building and the final decision making. Generally, there are two categories of aggregation methods: the arithmetic mean and the geometric mean [12,13]. In this study, preference aggregation is conducted through calculation of the arithmetic mean using an ordered weighted averaging (OWA) operator [7,14] as shown in Definition 3.3. A fundamental aspect of this operator is the re-ordering step; a weight is associated with a particular ordered position of aggregate [15].

Definition 3.3 Collective Preference can be defined as the OWA aggregation of individual preferences.

$$G^k = OWA(P^1, P^2, \dots, P^l) = \left\{ g_j^k \middle| g_j^k = \sum_{i=1}^{l} w_i p_j^i \right\} \tag{3}$$

Where,

$$p_j^1 < p_j^2 < \cdots < p_j^l$$

p_j^i is the ith largest weight against criterion j of the participants $p_j^1, p_j^2, \dots, p_j^l$. G^k is the collective preference vector of participant's preferences in a subgroup k. Further, G^k can represent the collective preference of all the participants. g_j^k refers to the collective weight of the j-th criterion. w_i is the order weight and satisfies the following: $w_i \in [0,1]$ and $\sum_{i=1}^{l} w_i = 1$. p_j^i is the weight given by the i-th participant against the j-th criterion. l is the number of participants.

The aggregation results of collective preferences vary according to the OWA operator employed, i.e. the ordered weights. Different OWA operators imply different rationales. In public participation, some participants might hold radical views. They elicit their preference only based on their own like and dislike without careful consideration of the real situation. They seldom compare the importance of different criteria carefully. They only weight the criteria they think are important to them and put almost no weight on other criteria which they think unimportant. To reduce the influence caused by such participants, an OWA operator aiming at reducing the influence caused by radical views is adopted in this study [16], which is defined as follows,

Definition 3.4

$$w_{i+1} = \frac{C_{l-1}^{i}}{\sum_{k=0}^{l-1} C_{l-1}^{k}} = \frac{C_{l-1}^{i}}{2^{l-1}} \tag{4}$$

Where, i=0, 1, 2 … l-1, $w_1, w_1, \dots, w_{l-1}$ are the order weights.

From mathematical perspective, the characteristics of this operator can be described as,

1) Symmetry

$$w_i = w_{l-i+1} \quad i=1, 2 \dots l$$

2) a. If n is an odd number,

$$w_1 < w_2 < \cdots < w_{(l-1)/2} < w_{(l+1)/2} > w_{(l+3)/2} > \cdots > w_{l-1} > w_l$$

b. If m is an even number,

$$w_1 < w_2 < \cdots < w_{\frac{l}{2}-1} < w_{l/2} = w_{\frac{l}{2}+1} > \cdots > w_{l-1} > w_l$$

According to the order of the weights, the ones at the two ends are smaller than those in the middle. Referring to the definition of OWA aggregation (Definition 3.3), this OWA operator puts little emphasis on the participants at two ends that put either extremely high or low importance weights against some criterion. In this manner, radical views can be removed.

3.3. Consensus Building Process

As mentioned in the model design, consensus building process will be started in case the Group Consensus Degree is not high enough. This begins with planners identifying participants holding different views from the group preference. Then a feedback advice report regarding this difference will be generated and sent to the participant. The report includes a brief review to indicate the difference between the participant's preference and the collective preference of all participants. Besides, recommendations and advice will be provided to the participant to suggest adjusting his/her position with an aim at achieving the highest possible degree of group consensus. After participants adjust their preferences, the Group Consensus Degree will be calculated once again. The process will be repeated until a satisfactory consensus level is reached or when a stop condition is satisfied, e.g. the iterative process reaches the maximum cycles or the Group Consensus Degree remains unchanged.

1. Identify participants with different views from the group opinion

The comparison of individual participant's view and collective preference of all participants is carried out by calculating the Agreement Level of individual's preference vector and the collective preference vector. If the Agreement Level is lower than the pre-specified threshold, that participant will be marked as a participant with different views.

2. Generate advice reports

A Proximity Vector is proposed to characterize the difference with respect to particular criteria between individual participant's preference and the collective preference.

Definition 3.5 The Proximity Vector to group preference for a given individual participant can be defined as follows:

$$D^i = \{d^i_j \mid d^i_j = p^i_j - g^i_j\} \quad (5)$$

Where, $p^i_j \in P^i, g^k_j \in G^k$ and $j=1,2,...n$

D^i is the distance vector of the *i*-th participant to group G^k. p^i_j is the preference weight of the *j*-th criteria given by the *i*-th participant. g^k_i is the collective preference weight of group G^k against the *j*-th criterion. The proximity vector as expressed in a numerical value format could be explained by means of understandable words to notify participants where the difference lies. Such transformations are conducted by using some specific thresholds. For example, if the proximity value on some criterion are lower than a pre-specified threshold, the participant might be told that other participants have put much more emphasis on that criterion.

3.4. Participant Classification based on Agreement Level

In case a group consensus cannot be achieved, it is necessary to categorize participants according to their preferences and identify relatively homogenous subgroups from all participants. In this study, participant classification is conducted in an iterative process based on Agreement Level. The classification process is designed based on the group clustering method proposed by Xu and Chen [16]. The Agreement Level between one participant and the collective preference of one cluster is used to determine if that participant should belong to the cluster. If the Agreement Level is higher than the pre-specified threshold, the participants will be allocated to that cluster. Otherwise, the participant will be put into a temporary set left to be allocated to other clusters. The classification process begins with randomly selecting a preference vector as the first cluster. The rest of participants are compared with this cluster and classified according to the condition mentioned above. After one cycle, the process recycles until all the participants are allocated to different subgroups. The procedure of classifying participants can be described as follows:

1) Put the preference vectors of all participants with a random order into a set *U* and create a temporary set *T*.
2) Initialize a cluster number counter $k=1$ and an Agreement Level threshold $\gamma(0 \le \gamma \le 1)$.
3) Pick up a preference vector P^i from set *U* by order. Put it into cluster C^k and remove it from *U*. Set the member counter of cluster C^k $n_k = 1$.
4) Calculate the collective preference *Y* of the cluster C^k by using definition 3.3.
5) If *U* is not empty, keep on picking up preference vectors from *U*. otherwise go to step 7.
6) Calculate the Agreement Level $r^i(P^i, Y)$ of P^i and *Y* by using definition 3.1. If $r^i \ge \gamma$, then put P^i into cluster C^k and remove it from *U*. The members of cluster C^k $n_k = n_k + 1$. If $r^i < \gamma$, put P^i into temporary set *T* and remove it from *U*. Go back to step 4.
7) Calculate the consensus degree c^k_d of all participants in cluster *k* using definition 3.2.
8) If *T* is not Empty, $U = T$ and $T = \emptyset$. Cluster Counter $k = k+1$. Go back to Step3, or go to step 8.
9) Classification results can be explained as follows:
   K=the number of clusters, C^k= cluster *k*, n_k=members of cluster C^k, $\sum_{i=1}^{k} n_i = m$. If $k=1$, all the participants are classified into one group. There is no conflict under the specified consensus degree threshold. If $k>1$, there are more than one sub-groups in all the participants.

The Agreement Level threshold γ plays an important role in determining whether preference vector P^i should be classified into cluster C^k. If the Agreement Level between P^i and the collective preference of vectors in cluster C^k is greater than threshold γ, P^i will be classified into cluster C^k. The greater γ is, the more difficult could P^i be put into cluster C^k and vice versa. The greater γ is, the more clusters will be generated.

4. A Spatial Conflict Resolution Strategy for Specific Land Use Proposal Deliberation

In this research, a Spatial Conflict Resolution Strategy was designed to address the deliberation of specific land use proposals from a conflict resolution perspective. Basically speaking, the strategy was designed as an iterative process. The government puts forward a list of proposals and a variety of exploration tools. Participants analyze, evaluate and comment on the published proposals. Based on participants' opinions, planners modify the proposals to improve the group's satisfaction level. Proposal modification directions are identified based on the preference structure of participants, particularly opponents. Participants' particular concerns and suggestions are discovered based on the posts of participants, as well. The modification aims to improve the satisfaction level of opponents with a minimum influence to the supporters' interests. The improved proposals together with some possible mitigation measures are provided to participants for further discussion. The iterative process continues until that predefined conditions are satisfied.

Suggestions with reference to spatial locations can be used to identify areas of public concern. Spatial analysis tools can be used to integrate the participants' opinions as well as measure the agreement among participants' suggestions. Fig. 2 indicates the use of map intersections to obtain areas of common concern from individual participants' suggestions. The overlap area of the map polygons can be used to indicate the location and extent of the participants' agreement. Also the common areas can be used to search for compromise space among participants.

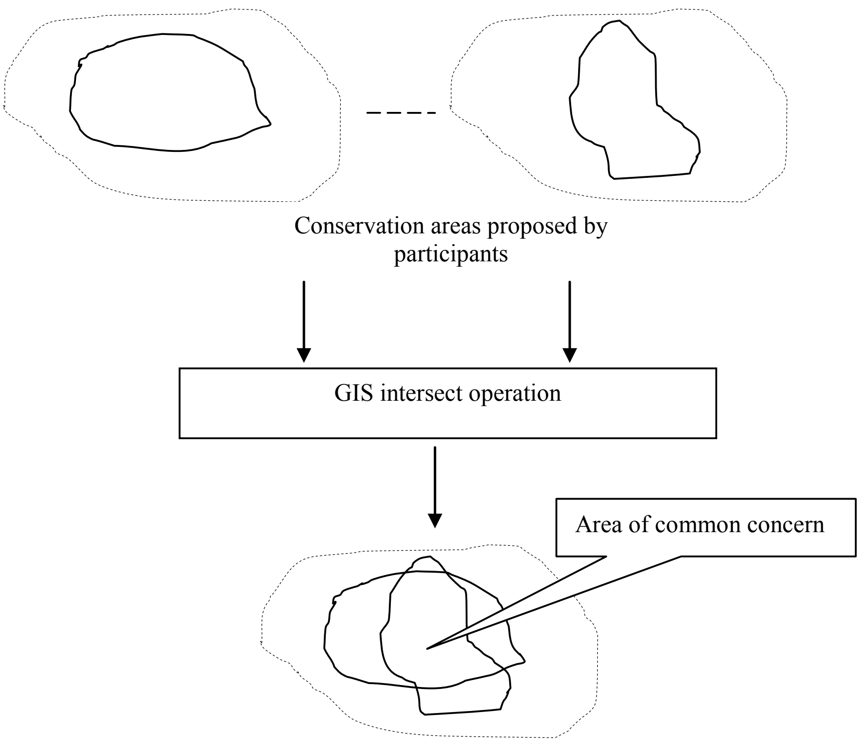

Fig. 2. The generation of area of common concerns (based on [17]).

5. Model Testing and Evaluation

Lantau Island is the biggest island in Hong Kong. With the development of the Hong Kong International Airport, the Tung Chung New Town and strategic transport links in recent years, Lantau offers tremendous development potentials [18]. The island is, on the other hand, well recognized for its natural conservation and recreational value, with over half of the land area covered by Country Parks and much of its coastlines and uplands still in their natural state. Given the diversified perspectives concerning the future development of the island, it is necessary to integrate the public opinions of various stakeholders. Both the public and government will collaboratively determine the future of Lantau Island. The land use plan should be based on a compromise of the conflicting viewpoints. Accordingly, Lantau Island is a good study case to implement the theoretical findings in this research.

To examine the proposed Conflict Resolution Framework, a web-based Public Participation GIS prototype was established. Participants could elicit their preference by weighting criteria and posting comments. Also, a decision making support system was developed to help planners identify public concerns and moderate the conflict resolution process. One hundred participants were enrolled using a random calling method for the planning simulation. Geographically, the participants were selected from different districts of Hong Kong. An online survey questionnaire was used to learn about the participants' experience in utilizing the Prototype system. The questions and responses are summarized in Table 1. Based on their responses, we found that most participants agreed that the planning information and technical products developed through the planning process were available and accessible on the Website, enhancing their comprehension of the planning situation, and enabling them to communicate with other stakeholders. Some participants affirmed that the conflict resolution model was efficient. However, some believed that it was very hard to resolve the conflicts arising from real land use planning, though they admitted that the website and mechanism of conflict resolution employed really helps. Basically, the Web Page design could satisfy most participants. They thought the maps and GIS tools could help and empower them in participating land use planning. Most of them acknowledged that the web-based system could serve as an adequate model of effective participation and could supplement the traditional public participation measures and attract more participants.

6. Conclusions

This study centers around two important issues of land use planning: land use allocation and specific land use proposals deliberation. Conflicts involved in land use planning can be examined from two perspectives, conflicts among land use types and conflicts among stakeholders. The former balances environmental conservation and economic development as well as compromising between multiple land use purposes. The latter is to compromise among different values, beliefs, interests, and demands of stakeholders. Land use planning with public participation deals with the conflicts among different land use types through resolving the conflicts among stakeholders. A Conflict Resolution Framework was proposed providing one way for the government to help stakeholders build consensus and generate a publicly accepted land use plan. A Consensus Building Model was developed to address the conflicts among different stakeholders with competing interests in the process of land use allocation. A Spatial Conflict Resolution Strategy was developed to help stakeholders and planners deliberate specific land use proposals. The proposed model works on conflicts involved in land use planning from both a value level and a specifics level. From the value level, the source of disagreement among participants could be identified and addressed. A unique feature of the model was that a consensus building process was designed to help participants promote mutual understanding and improve group agreement. Besides, participants are suggested to compromise from the specifics level and create mutual-gains solutions.

In the future of this work, organizing and extracting the preference information from the text comments of participants needs to be investigated. Besides, it is essential to keep track of participants' inputs with respect to time since the conflict resolution was designed as an iterative process. Time stamps can be used to track when an input is made and when it is modified. Thus, the process of conflict resolution and the change of participants' preference could be documented, retrieved, and analyzed from a temporal dimension. Additionally, particular attention should be paid to manage a great number of possible participants in real-life situations. Dealing with the huge amount of preference information involved in public participation is a challenging issue.

Table 1 Summary of online participation survey

Aspect of Statement	***Statement about online participation***	***Percent of Total Responses to Statement***				
		Strongly Agree	**Agree**	**Disagree**	**Strongly Disagree**	**Don't Know**
Web page design	The Web pages are designed and organized appropriate for the land use planning and public participation	8	56	19	0	17
Usability	I can operate the functions and tools according to the associated instructions.	19	28	17	9	27
Website use	Information about the land use planning is available and easy to access on the Website.	37	45	9	0	9
Website use	I can adequately understand the planning situation through the introductory documents and maps presented on the Website.	19	36	17	9	18
Website use	The maps and GIS tools helped me to better understand the plan and express my concerns.	27	45	10	0	27
Communication	The forums allow me to effectively communicate my thoughts and opinions about the plan to other participants.	18	54	9	10	18
Communication	My thoughts and opinions communicated through the Website will be given serious consideration by the government	0	27	19	10	44
Conflict resolution	The mechanism of conflict resolution is efficient and practical.	12	39	25	11	13
Mode	The Website and its capabilities (documents, forums, and maps) provide an adequate venue for me to participate in the planning process. I don't need to go to meetings and engage in discussion.	28	36	10	8	18

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