Research on GIS and CAE cooperative coupled dynamic geographical situational response

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Abstract. The relationship between geographic entities and geographical environment is a vital research topic of geography, and the response characteristics of geographic entities to geographical environment are the basis of Geo-design and geographical decision. Building entities and geography modeling is the key to intelligent cities and disaster response. In the traditional GIS domain, the modeling of building entities was limited to the representation of geometric features and spatial relations, which was unable to simulate the "action-response" relationship between geographic entities and geographical environments for the lack of the expression of the structural characteristics of architectural entities. In this paper, the structural model of the building, which is taken as a link between the organic coupling of GIS and CAE two heterogeneous systems, is built to achieve geographical entities on the dynamic response of the geography of the environment simulation, thus providing the support for the intelligent geographic decision and disaster emergency. This paper focuses on the definition, composition and expression of the building structure model, which is geared to the coupling of GIS and CAE. It also discusses the methods of GIS-based dynamic geographical simulation and CAE-based response analysis. Moreover, the "role-response" model taken the building structure model as the core is built between "Model-simulation-evaluation-decision" geographic entities and geographical environment. The results of structural analysis and the evaluation of diagnosis results are visualized by means of "3D thematic map", and the components are modified and optimized based on the interactive modification method. The structure analysis and design efficiency are improved and the iteration cycle of structure design is accelerated. Design of building structure and modeling quality are been improved. This research extends the static spatial characteristics expression of GIS to dynamic geography scene simulation, further expending the study category of relationship between geography entities and geography environment.

1. Introduction

Combining the spatial data management capability of GIS with the environmental action simulation capability of CAE is a trend that cannot be ignored in the construction of smart city. However, the current exploration of this aspect is very limited. Architecture and geographical environment modeling is the foundation of the simple, smart and speedy wisdom city\cite{1,2}. With the development of laser, LIDAR and Multiple view geometry and oblique photography, etc., modeling ability of buildings or geographic environment has expanded from the macroscopic outdoor scene towards more micro
indoor scene[3-5]. The integrated modeling and presentation of indoor and outdoor integrated architecture and geography environment have been paid more and more attention. The integrated indoor and outdoor modeling of the building and its environment can help us better manage the city and respond more quickly and intelligently to disasters[6-8]. It is limited to the traditional GIS model expression and data organization characteristics, which cannot describe the geometric entities information except the geometric features and spatial relations, such as physical, chemical, structural and other aspects[9]. In the study of human-land relationship, this information is the basis of researching and simulating the characteristics of geographic entity's response to external environment. This information is also the key point to promote the study of the relation between geographical entity and environment from static spatial relation expression to dynamic "action-response ", and the promise to better carry out the geography design for the dynamic geographical situation. Unlike GIS, CAE (Computer Aided Engineering) is the primary means to study the "action-response" relationship between geographical entities like architecture and geography environment[10,11]. Because GIS and CAE have significant differences in model organization, data structure, and semantic features, it is necessary to explore a method that can better couple both. Geographic entity model as a link to connect GIS and CAE, and to simulate the dynamic geographical situation, is to give geographical entities the environmental perception ability of “sensing cold and warm" and "knowing wind and chill", and research key to build smart city and virtual geographical environment. Building structure is the "skeleton" of building entity. In this paper, based on the structural model of building entity, the cooperation coupling research of GIS and CAE is carried out. By simulating the response characteristic of building structure in dynamic geography situation, the method to study the relationship "action-response" between geographical entity and environment is discussed. It is hoped to provide reference for building intelligent city and the emergency response of disaster.

2. Theory and method

Building entities are closely related to the geographical environment in which they are located. In addition to being affected by its own structural characteristics, such as component materials, component cross-section, etc., building entities are not affected and constrained by many external environmental effects such as vibration, pressure, temperature, etc. in their geographical environment[12]. It is an effective way to realize coupling between structural design, analysis and environment by building architecture structure model as the link of different systems. This paper attempts to build a bridge between the building entity and the geographical environment by using the building structure model as a link, and combine the geographical environment simulation with the analysis of the geographical entity response, and provide the basis for the following related research.

![Figure 1. The response model of building structure based on GIS and CAE cooperative coupling.](image)
In this study, firstly, the architecture structure model which used as the link coupling GIS and CAE, was built. The model can not only express the structural characteristics of CAE-oriented buildings, but also can be coupled with the spatial data organization and expression of GIS.

Secondly, based on the GIS platform the current geographical environment in which the construction entity situated has been modeled. Modeling geographic entities and geographic elements is an advantage of GIS and virtual geographic environments. This paper provides an interface for artificial adjustment and setting of environmental load under different geography scenarios by increasing the function of human-computer interaction for the needs of dynamic geographical simulation.

Thirdly, the response simulation of building structure is based on CAE platform. The load information of various geographical environments in the dynamic geographical situation is applied to the building structure model in real time by calling the load input interface of CAE. Based on the simulation function of CAE built-in structural analysis solver, the response of environment load to building entity is calculated and simulated, and the response result of simulation analysis is outputted.

Finally, the response result of CAE output is rendered and visualized under GIS platform. The CAE output such as displacement, force, deformation, etc. are rendered and visualized on the 3D GIS platform based on the building block of building structure model. It provides a visual observation of the "action-response" characteristics between the environment and the geographic entity, making the decision simpler and speedier.

After the above process, the research model of "action-response" between geographic entities and geographical environment based on GIS and CAE is proposed, which is based on building structure model as shown in Figure 1. In contrast to the traditional static model of 3D geographic entities, the "action-response" model shown in Figure 1 is dynamic, that is, the model can simulate the "action-response" relationship between geographical entities and geographical environments in dynamic geographic situations. Decision-makers can use this as a basis for observing the response status of geographic entities in different geographical situations, as well as the simulation results of sudden natural disasters such as storm surges, and formulate appropriate emergency measures.

3. Building structure model oriented to GIS and CAD coupling
A structural model for coupling GIS and CAE is the basis for studying the "action-response" relationship between geographical entities and geographical environment. Because of the difference of GIS and CAE in the aspects of model organization, data structure and semantic characteristics, this paper chooses the data structure and model organization characteristic of GIS and CAE, and constructs the building structure model to connect GIS and CAE. As shown in Figure 2, this paper describes the conceptual model of building structure from three levels: semantic layer, unit layer and geometric layer. The semantic layer of the building structure model is used to describe the concept of the building structure and the hierarchical relationship among the different concepts. The unit layer is used to classify the structural elements of the conceptual layer into typical structural units from the perspective of structural analysis. Geometric layer description of the angle describes the geometric characteristics of each structural unit for the component geometry and component entities to provide the basis for visualization.

Building structure model in the conceptual semantics from coarse granularity to fine granularity is divided into different levels. In this paper, it is divided into three levels: building structure, coarse-grained structure and fine-grained structure. The first layer is the building structure, which is a complete force system of the building skeleton; the second layer is coarse-grained component classification, is the structure of the main types, including beams, columns; The third layer is a fine-grained classification, but also a specific type of building structural components.

The unit layer is based on the unit characteristics of the structural model, and the building structure component of the semantic layer is generalized into units according to the different cell characteristics. In the composition of the unit, the building structure model is based on the structural components of the mechanical response characteristics of its divided into different component units. This step also
corresponds to the operation of the discretization threshold in the general finite element analysis model. The difference is that semantically, the semantic information of building structural components is clear and can be easily distinguished into different units. In topology, because each component of building structure itself is connected with each other to transmit various structures force and action each component is segregated based on the connection points. Thus, the whole structure system can be divided into units according to the difference of its structural members, and the members and the units have good correspondence. Different components of the semantic layer in the unit layer have a unique corresponding unit class.

The geometric layer of the conceptual model of the building structure is based on the description of structural elements from the mechanical properties of the element layer, and further describes the structural members from the geometric characteristics. The geometric characteristics of the different building components are different. In general, building structural members can be divided into three types according to their geometric characteristics. First, the cross-section height and width of small size, relatively large length of the size of the components, such as beams and columns - can be called linear components or frame components; Second, vertical height and cross-section length are larger, the section thickness is relatively small Components, such as floor slabs and shear walls, may be referred to as face members or plate members. Thirdly, members with little difference in length, width and height, such as foundation, may be referred to as solid members. On the basis of conceptual model of building structure, this paper designs the logical model of building structure on the basis of "component unit". As shown in Figure 3, the building structure is expressed by the structural members and the relationship between the components of the common expression, and building structure components can be divided into different types of component units, structural components of the geometric and mechanical characteristics of its The unit type is closely related.

In addition, the relationship between components is an important part of the building structure model, but also an important basis for building structural model analysis. In the structural analysis only need to describe the structural members "whether adjacent or not". In this paper, “unit-node relation” describes the adjacency relation between components indirectly. The relationship between the member and the material and section is described by the "Frame element section assignment" table and the "Face element section assignment" table to express the assigned sections on each element. At the same time, the cross-section class associates the material type used in the currently named section instance with the material name, thus indirectly associating the component element with the material.

Figure 2. Conceptual framework of building structure.
Finally, on the basis of the above conceptual model and logical model, the data structure and visual expression of the building structure model are designed for the specific 3D GIS platform, as shown in Figure 4 and Figure 5. "Unit" is a unified abstraction of structural components. The geometric, material and cross-section properties of different semantic components are unified by the unit to encapsulate the structural components of the building structure, which is a general method of structural analysis software. Therefore, the definition of the unit and the data structure are the foundation of the building structure model. According to the characteristics of building structure and facing the analysis of building structure, this study encapsulates different semantic building components into different types of units. The structural members are encapsulated into several different cell types.

4. Simulation of dynamic geographical situation
The "action-response" feature of geographical entities and geographical environment is the key to geographical design and geographic decision-making. In the simulation of a traditional virtual geographic environment, geographic entities are usually unresponsive static spatial locations or geometries. The building structure model constructed in this study provides the support for the coupling of the geographical situation simulation and the geographical entity response. In this study, the advantage of geographic information system in spatial data management and geographical environment modeling is brought into full play. Geographic information platform is used to collect, build and manage geographic information. By combining the environment model and entity model established under the geographic information system with the professional simulation software, the dynamic geographical situation simulation is realized.

In order to narrow the scope of this paper, this paper uses the most conventional CFD (Computational Fluid Dynamics) system to simulate the wind field in the geographical environment of the building entity, so as to study the geographical situation of the geographical entity in the wind load under the dynamic response of the law. In this paper, we first select the specific research area and...
draw the scope of the building entity on the basis of the image base map, and modeling in the geographic information system for three-dimensional entity; Secondly, the building three-dimensional entities are imported into the CFD system, The dynamic response of the CFD system under different iterative conditions is observed in the 3D GIS system.

![Figure 4](image4.png)

**Figure 4.** The visualization of velocity fields in 200 iterations and iterations in 1000 (convergence) state in GIS.

![Figure 5](image5.png)

**Figure 5.** The visualization of pressure fields in 20 iterations and iterations in 1000 (convergence) state in GIS.

As shown in Figure 4, and Figure 5, the velocity and pressure fields of the wind are visualized in three-dimensional geographic information system under different conditions. Based on the three-dimensional GIS, we can directly observe the situation and spatial distribution of external loads under different geographic situations, which provides convenient means and intuitionistic basis for decision-makers. At the same time, it can be seen that the synergistic coupling between GIS and CFD can give play to their respective advantages, and as a means of integration, they can improve their ability to simulate the dynamic geographical situation.

5. **Response of building structure model to dynamic geographical scene**

5.1. **Simulation and response**

This paper obtains the dynamic geographic environment information by GIS. The environmental information is used as the input of CAE to simulate the response of the building entity to the environment. Firstly, the building entity model is organized into a data structure that arcgis software can support, namely the Multipatch model. Secondly, the environmental effects were input into the CAE software SAP2000 to simulate the building structure. Next, the output of SAP2000 response to building structure is returned to the Multipatch model. Finally, the ArcScene component of ArcGIS is used to map the response result of the building entity. By dividing the response result of the model into different levels, select the appropriate render color, and visualize it in the ArcScene.

The advantage of GIS and CAE is not only in the dynamic simulation and visual expression, but also in the dynamic mechanism of "action-response" for geographic entity to environmental effects.
The key is to use geographic entity model as a link to realize the real-time response of geographical entities to the environment. As shown in Figure 6, with the aid of the "action-response" model constructed above, the environmental loads modeled in the GIS were input into the CAE, and the simulation was carried out to the 3D GIS environment to observe the current geographic entity structural model of the building response characteristics of geographic situation in real time.

The structural response to environmental effects is often expressed as "internal forces" and "displacements". The structure response output is defined as two forms: internal force and node displacement. The "load" expresses which of the external loads the current structural response is caused by, such as internal force and deformation caused by "wind" load, the "load" refers to some kind of pressure effect named wind in CA. "Structure" refers to a specific structural member, which may be a frame element or a surface element, where the current structural response refers to the current internal force and deformation of a globally unique structural member. "Internal force" and "Displacement" are structural responses to the current component and to the current named load.

![Diagram showing the "action-response" simulation cycle with the building structure model as a link.](image)

**Figure 6.** The "action-response" simulation cycle with the building structure model as a link.

The role of geographical environment is not static, the study of dynamic geography scenarios under the "action - response" is the intelligent city and intelligent geographic decision - making key. "Modeling - Simulation - Evaluation - Decision" is an iterative cycle of continuous optimization process rather than a single closed-loop cycle. Therefore, the "action-response" model of the building structure and the geographic environment, which is constructed by the study of the building structure model, supports the cyclic simulation of the above cycle iteration and the optimization process.

### 5.2. Discuss

Building entity is an important geographical entity, which is an important research object of urban management and emergency response. With the development of GIS and the advancement of digital
city and intelligent city construction, the traditional GIS research model confined to the architectural features such as geometry, shape and location of buildings has been unable to meet the actual demand. Objectively, it is necessary to express and manage the important spatial objects of building entities from a deeper mechanism. As one of the most important features of buildings, the structural characteristics of building entities are of great significance for urban planning, engineering construction, earthquake relief, emergency assistance and civil air defense projects. In addition, dynamic, real-time modeling of large-scale building structures on a city scale is also a realistic requirement for emergency decision-making[13]. In practice, the advantages of integrated GIS and CAD coupling have emerged[14-16].

In order to meet the demand of "interaction-response" between geographic environment and geographical entity, this paper constructs the building structure model to realize the cooperative coupling between GIS and CAE. Through the building structure model, the building entity and the geographical environment can be organically integrated, making the building structure model become a "living", "the external environment can respond to" model. At the same time, by combining GIS and CAE's advantages and strengths, it lays the foundation for further research on the relationship between geographical entities and geographical environment.

Geographic information science in the traditional architectural solid modeling is mainly concerned with building geometry, positioning and surrounding information. With the gradual progress of GIS research from the outside into the interior, the internal components of building entities, construction facilities are also increasingly concerned about. However, the expression of architectural entity from the perspective of space cannot reflect the response of the building to its surrounding environment. With the acceleration of urbanization process, a variety of building structure type gushing out, at the same time, the change of exterior load caused by global change is becoming more and more violent. It is required that the modeling of building entity should reflect the influence and restriction of environment change on architecture, so as to provide support for architecture design, urban planning and natural disaster emergency response and decision.

6. Conclusions
In this paper, the coupling of GIS and CAD is used to simulate and analyze the building structure. GIS and CAE take the building structure model as a link to realize the continuous iteration of "analysis" and "feedback modification", and effectively coupling the main part of structural design. The results of structural analysis and the evaluation of diagnosis results are visualized by means of "3D thematic map", and the components are modified and optimized based on the interactive modification method. The structure analysis and design efficiency are improved and the iteration cycle of structure design is accelerated. Design of building structure and modeling quality are been improved.

In the construction of digital city, it not only need to express the geometry of buildings, location information, economic and social information, but also to express the structure of physical and chemical information, including the structure of materials, structure and durability of the useful life of information. On the basis of the building structure model proposed in this paper, the professional model such as increasing the durability model of the structure is the important work of the following intelligent urban construction and BIM and GIS development.

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