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A parameter to featuring the cultural landscape genes of traditional settlements in China: a perspective of geographical information

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Abstract

Creative transformation and innovative development of traditional cultures is a pressing social need in China because of the deep reform and rapid socio-economic developments. It is crucial to understand the natural features of cultural landscapes of traditional settlements because they are indispensable components of these heritages. Although there are significant findings on the cultural features of traditional settlements, people still face substantial difficulties in using Geographical Information Systems (GIS) to directly handle their cultural factors due to a lack of theoretical models or described methods. To address this issue, at first, this study analyzed the component elements and contents of Cultural Landscape Genes of Traditional Settlements (CLGTS) from the perspective of Geographical Information (GI). Then, the concept "Feature Parameter of Geographical Information of CLGTS (FPGI-CLGTS)" was proposed based on the above. Simultaneously, the connotations, identification rules, and mathematical meanings of FPGI-CLGTS were also explored deeply. Next, this study developed the identification methods of FPGI-CLGTS. Finally, this study examined FPGI-CLGTS through an experiment on the spatial layouts CLGTS of six samples in Hunan, China. Through this study, FPGI-CLGTS has enormous potential to reveal the critical cultural features and values of traditional settlements.

Keywords Cultural Landscape Genes of Traditional Settlements (CLGTS), Geographic informational features, Directions of values, Recognition dimensions, Feature parameter

Introduction

Human society has been stepping into a new era of Artificial Intelligence (AI) [1, 2]. With the help of Internet of Things (IoT) [3, 4], AI and Information Communication Technologies (ICT) commonly outline a vivid landscape of rapid growth of digital economy [5, 6]. This brings great challenges to most of industries, such as Mobile Internet Industry [7]. In China, this also triggers a series of social reforms and cultural strategies, such as cultural power [8]. These strategies simultaneously draw the attention of the public to traditional settlements with rich values and colossal advantages of development [9, 10]. Note that, hundreds of thousands of traditional settlements are the pivotal part of Chinese cultural heritages and the treasures of traditional cultures. In China, unveiling the key cultural features of traditional settlements is conducive to bolstering the current high-quality development. Hence, this objectively urges to develop a novel method to dig the essential cultural features of these heritages from a perspective of Geographical Information

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Systems (GIS) as the geographical information resources have been showcasing a full play in the current high-quality development.

Due to the wide and rapid applications of IoT [3, 4] and significant advances in earth observation technologies, the volume and scale of big geo-spatial data [11–13] are growing exponentially. Owing to its rich geo-spatial knowledge [14], the big geo-spatial data has attracted the worldwide attention of various industries and fields, including smart cities [15, 16], natural disasters of risk prevention [15], spatial governance [17], and public safety [18], etc. This strongly hints that the shift from geographic information services [19] to geographical knowledge services [20] is inevitable due to the urgent need to rapidly discover useful knowledge. At the same time, the role and potential of GeoAI is more obvious than ever before [21]. For example, it can rapidly mine knowledge from the "nature-humanity-information" system [22]. These actually suggest that the understanding of nature-humanity-information and man-land relations is deepening and also consecutively nourishing GIS.

However, although the existing theoretical fruits of GIS [23–25] can well support the analysis tasks of geographical objects or processes with stark spatial position features, it still is difficult to directly handle the cultural factors of traditional settlements. Because their stark cultural and historical information and implied connotations are often more famous than their position features. And this usually intrigues the strong interests of the public. On the other hand, the obvious differences of cultural factors in carriers, appearances, formation, and connotations often result in the lack of effective representation methods to process them in the current GIS. In a whole, two obvious difficulties have been observed when utilizing the current GIS to directly extract the key features from cultural factors of traditional settlements. The first is the theoretical models and methods of translating their core features from the geographical perspective. The second is description models and methods that can transform their ample historical and sociocultural information into the Geographical Information (GI) space. The key to solve these issues is to find a suitable theoretical model and method through combining the core features of cultural factors of traditional settlements and the principles of GIS.

In a bid to meet this scientific challenge, this work introduces the theory of Cultural Landscape Gene of Traditional Settlements (CLGTS, which was proposed by Chinese human geographer in order to examine the core cultural features of traditional settlements [26] based on Meme [27] and Morphongensis [28]), and explores the GI attributes and properties of CLGTS based on the principles of GIS. For traditional settlements, CLGTS provides a useful theoretical tool for revealing their rich traditional knowledge of man-land relations and understanding the key features of their cultural factors [29–31]. Through its current research landscape, although it has attracted wide attention since its beginning [31–35], CLGTS is still a lack of description models or methods for the key features of cultural factors from the perspective of GI. Hence, this work first presents Feature Parameter for CLGTS (FP-CLGTS) from the perspective of GI. This work aims to support the current pressing social needs for extracting rich knowledge from the cultural resources of traditional settlements and narrow the gap between such knowledge and the existing GIS. In this work, GI features of CLGTS, the conception of FP-CLGTS and its related identification method are deeply explored.

The remainder of this work is organized as follows. "The nature of GI features of CLGTS" section reveals GI features of CLGTS by analyzing their component elements and contents. "FPGI-CLGTS" section presents a conceptual framework for FPGI-CLGTS, which mainly covers the understanding dimensions, conception, and mathematical features. "The extraction methods of FPGI-CLGTS" section explores the principles and methods for recognizing FPGI-CLGTS. "Experiment and results" section examines the identification methods for FPGI-CLGTS through a simple experiment. "Discussion" section discusses some pivotal issues regarding FPGI-CLGTS for the next work. The final section concludes the main findings.

The nature of GI features of CLGTS

A brief for CLGTS

In order to capture the traditional cultural characterizations of traditional settlements from the perspective of geography, inspired by Meme [27] and Morphongensis [28], Liu PL first proposed CLGTS in 2003 [26]. For a certain traditional settlement, he defined the cultural factor(s) with a decisive role in the formation of its cultural landscape as CLGTS. CLGTS was founded on the spatial image of cultural landscapes [29] and the corresponding influencing factors and the inheritance characterizations of cultural factors of traditional settlement. In essence, his related research can date back to the mid 1990s, such as geomantic features [29], human settlement environment [30], and image of cultural landscapes of traditional settlements [31]. On the other hand, CLGTS underlined the uniqueness of cultural factors according to the principles and natural features of DNA. This means that for a certain traditional settlement, a CLGTS is the most important cultural factor to feature itself. That is to say, a CLGTS of a certain traditional settlement can help this traditional

settlement distinguish itself from the other settlements. According to this view, Liu PL developed four rules to help identify CLGTS, namely inner uniqueness, external uniqueness, local uniqueness, and superiority [26].

In fact, only the following conditions are met, can a cultural factor be defined as CLGTS: (i) it must exist in a certain traditional settlement; (ii) it can be inherited from generation to generation; (iii) and it can help to identify the prominent features of a certain landscape of traditional settlement. Based on these rules, Hu et al. developed an indicator system of CLGTS, which included architectural features, cultural features, environmental features, and spatial layouts of cultural landscapes of traditional settlements [32]. And this enabled the development of identification methods of CLGTS, such as object-oriented identification method [33]. Since its introduction, CLGTS has been widely applied in many areas (Fig. 1), such as the identification of natural features of the cultural landscapes [32, 33], preservation of traditional buildings [34], and tourism development of traditional settlements [35], etc.

The existing research on CLGTS mainly focuses on a single traditional settlement or the identification of cultural landscape features and the cluster rules of different traditional settlements at the regional level. Note that people seldom examine the geographical features of CLGTS according to the formal, quantitative, visual, and inferential methods and models or from the perspective of cultural computation [36]. Consequently, it still can not support an examination on the natural characteristics and spatial associations of various CLGTS of different traditional settlements with the help of GIS.

The GI constituent elements of CLGTS

With the volume and scale of geospatial big data [11–13] has been growing rapidly due to the significant improvement of spatial data capture abilities and earth observation tools, methods, and instruments, so much bewilderment has been exposed to the public, such as "massive data- information explosion- knowledge poverty" [37]. This therefore raises an interesting issue on deepening the understanding of the nature of GI and establishing a GI recognition model with multiple dimensions, perspectives, all-round description, and approaches to describe the natural features of geographic systems and related laws.

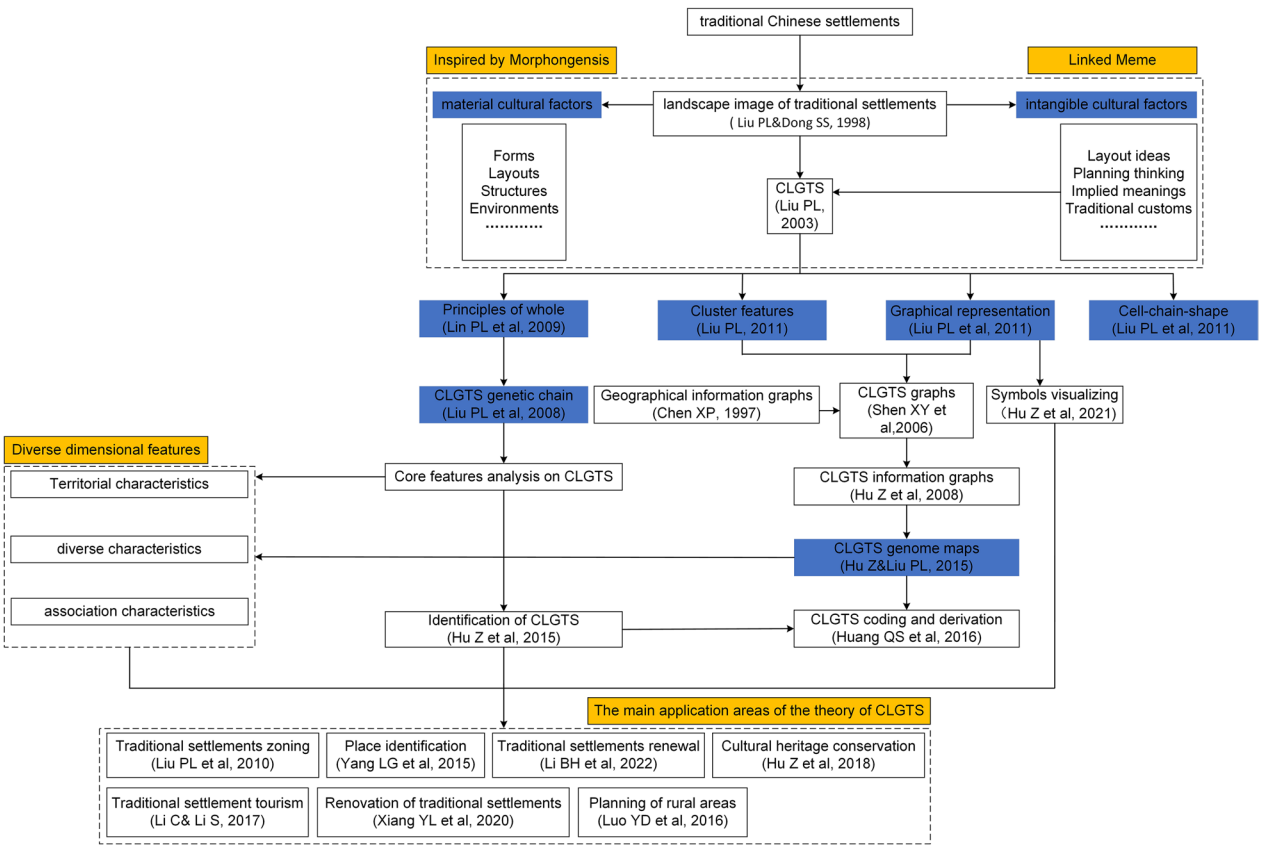

Fig. 1 The main advances and application areas of CLGTS

Table 1 The categories of geographical information in distinct stages

Items	2DGIS	Geographic semantic GIS	Multi-dimensional GIS	Ternary space (information geography)
Basic elements	position, geometric form, property	position, geometric form, time, semantic, property	position, geometric form, property, relations, evolutionary process, semantic, time	time, place, people, object, event, phenomenon, scene, process, state, dynamic
Expression model	2D-Euclidean oriented expression model	Geographical semantic expression model based on the spatiotemporal features	Multi-dimensional spatiotemporal consistency oriented geometric algebra expression model	Geographical representation from the perspective of unified ternary space of nature, human society, and cyberspace
Features	it can cope well with the 2D spatial relations; 2) it is hard to analyze and describe time, processes and dynamics	1) It can merge 2D and 3D data into a whole; 2) it is good at description of geographical processes and evolutionary features	1) It can describe the complex geographical evolutionary processes by using the principles of geometric algebra; 2) it can centrally express the spatiotemporal variations with multi-dimensional information	1) It can converge much information with multi-dimensions, multi-perspectives, all-round, and multiple approaches; 2) it can map and represent the features of ternary world of nature, human, and cyberspace

In 2007, Geo-Atom [23] was proposed to describe GI. Moreover, in order to effectively process the mass geographic data and unveil the nature and laws of geographic environmental systems, a GIS architecture based on geometric algebra was proposed [24]. It constructed a unified temporal-spatial computational framework to integrate the spatial position, geographic semantics, attributes, geometric forms, evolutionary processes, and interrelations among the constituent elements of geographic systems. In 2022, a spatial aggregation framework was developed to capture the temporal-spatial distribution patterns and structural modes of the natural and social human systems and the related associations [22]. This provided a new vision to observe the regulars, rules, and laws among natural spaces, social-human spaces, and cyberspaces. Hence, from Geo-Atom [23] to the geometric algebra based GIS [24] and to the information geography [22], the connotations and scopes of GI have been largely enriched because of the fast increasing and broadening application areas.

Through the existing GI description and expression models (Table 1), the expression principles and methods of the GI features of CLGTS still need to be explored in depth.

CLGTS contains rich information about historic cultures, spatial positions, carriers, associations, functions, and formation, etc. As a matter of fact, like biological genes, CLGTS is a basic unit of ample information of sociocultural factors. This also signifies that people can examine the constituent elements of CLGTS from a perspective of GI [38]. According to the definition, CLGTS can be used as an entry point to understand the core cultural features of traditional settlements. Because we can characterize the cultural landscapes of traditional settlements through the pivotal features of CLGTS, such as formation or origination time, geometric forms (for example, the patterns or arrangement mode in the settlement's space, spatial layouts of settlement, shapes of appearances, constituent patterns, etc.), and geographical value. In particular, some key features of CLGTS that have involved with by the development and evolution of traditional settlements can also play active roles in characterizing the core features of traditional settlements, such as spatial positions, sociocultural values. Obviously, the important features of CLGTS are helpful to catch the natural features of traditional settlements from the GI perspective. In other words, these paramount features can be defined as GI constituent elements of CLGTS.

The GI contents of CLGTS

GI has great implications for abstracting and generalizing the important associations and rules hidden in the complex geographical systems and their constituent elements or the interaction relations and influencing patterns of the human social systems and their constituent elements. In essence, GI is the contents of the structural data which depict the abstract and generalized results of geographical systems or human social systems. In other words, GI is the mapping results from the distinct phenomena, events, objects of natural and human social space, and their natural features and rules to the cyberspace, and must conform to the special cognition purposes and strict mathematical methods. Similarly, the GI of CLGTS is the map and collections of key geographical characterizations, rules and laws of the cultural factors of traditional settlements.

In the history, over their development and evolution, traditional settlements accumulated numerous cultural factors which could directly record and represent the interrelations between human and land. These cultural factors, which can be distinguished as CLGTS according to the related identification rules and methods [33], are the quintessence of various cultural activities that had created or made by the ancients during a long survival and development in the natural environment. Hence, from this point of view, the ample historical and cultural information and corresponding features are the critical part of GI contents of CLGTS (Fig. 2).

From Fig. 2, the scope of GI contents of CLGTS mainly covers spatial positions, traditional cultures, form characterizations, evolutionary features, properties, and geographical value (e.g., survival experiences and wisdom of living in harmony with the nature). Spatial positions mean the location where is CLGTS or spatial coordinates are located. Traditional cultures primarily include historical information, social cultural features, and implied sociocultural meanings. Form characterizations stress the physical appearances of a single cultural factor or its physical carriers, or the unique spatial forms of interactions within a group of cultural factors, such as patterns, graphs, shapes, textures, and styles. Evolutionary features mainly include the emergence or formation of cultural factors, and the development or variation process of influence or impact of various factors and related features. Properties indicate the carriers, functions, arrangements of modes, and patterns of interaction effect of cultural factors in settlements' spaces. Geographical value can reflect the geographical implications, including the corresponding experiences, methods, or the accumulated knowledge and technologies of coexistence and sustainable development between man and land.

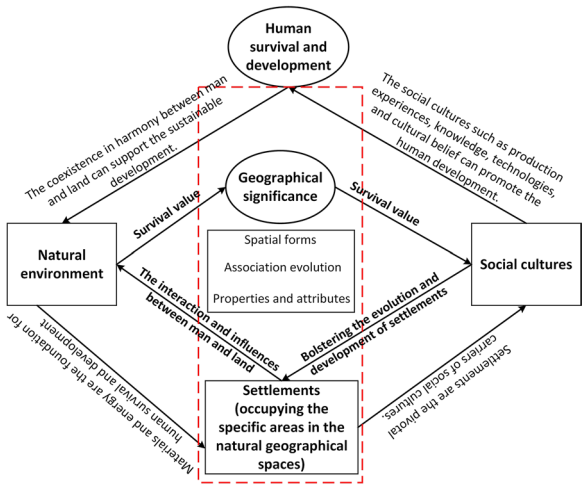

Fig. 2 The GI contents of CLGTS

FPGI-CLGTS

The existing GI expression models mainly focus on the computation and reasoning of spatial relations. Accordingly, some GI analysis methods and expression models, such as thinking of spatial analysis [39], geographical modelling, information retrieval, and query, also intend to support the quantitative computation and analysis of entity relationships that are prone to abstractly describing and visualizing. However, they cannot support the computation and relations analysis of qualitative entities well [40].

Based on the existing research findings, CLGTS can be qualitatively represented and visualized through the unstructured data, such as graphs, images, pictures, photos, and texts. Note that the representation of GI connotations of CLGTS should deeply examine the existing GI cognition models and theories. By referencing the theory of ternary space and information geography [22], this section mainly elucidates the cognition dimensions, details the definitions, and clarifies the mathematical meanings and features of FPGI-CLGTS from the correlations of environment spaces, settlement spaces, and sociocultural spaces of traditional settlements and the related valuable features.

The dimensions of GI cognition of CLGTS

Traditional settlements are the living and production systems created by the ancients for survival and sustainable development. Therefore, in the history, during their development and evolution, traditional settlements had fostered and unremittingly aggregated numerous cultural factors, including production tools, skills, farming knowledge, building technologies, arts, social institutions, religions, ethnics, and ancient ethics. Diverse cultural factors can meet the tremendous needs of the ancients, which were conducive to the well-being of the ancients. This strongly implies that CLGTS is an indispensable link between the natural environment, settlement space, and sociocultural space.

From the perspective of values and functions, CLGTS has great values namely nature, social cultures, and survival. The natural value refers to the scientific use of the laws and rules of the environments to improve the quality of life. For example, Niangziguan Village, located in Pingding County, Shanxi Province, China, reasonably utilize the water power to grind grain or wheat through a mill in the center of village; this vastly reduces the villagers' labor intensity, and indicates the natural values of the mill. The sociocultural value covers a wide range of the social traditional knowledge including ancient politics, religions, ethics, cultures, institutions, production and living tools, skills, and customs, etc. For example, many ancient buildings in traditional settlements, such as family temples, Wenchangge, Shuikou, gardens, frequently gain wide attention due to their stark architectural technologies, skills and arts. The survival value is about the traditional ecological knowledge, experiences, and wisdom of harmonious coexistence with the nature, such as conquering the adverse conditions to create the suitable settlement spaces. For example, Ziquejie terraces, located in Xinhua County, Hunan Province, China, exemplify how the ancients subtly improve the environmental conditions to farm the rice in the mountainous areas through understanding the natural laws in depth, such as slopes, soil, annual precipitations.

According to the above, CLGTS can characterize its natural value if it owns the prominent geographical environmental features; and it can outline its social value if it has the outstanding sociocultural features; and it can highlight its survival value if it possesses the salient dwelling cultural features. So CLGTS is the natural bond because it links the environment space, settlement space and culture space, and synthetically reflects the interaction, associations, and information properties of the cultural factors of traditional settlements at the same time. Therefore, the dimensions of GI cognition of CLGTS (Fig. 3) are made of spatial dimensions (settlement space, environmental space, and sociocultural space), values (natural value, survival value, and social value), and information properties (spatial positions, spatial forms, associations, traditional cultures, attributes, and geographical implications).

Definition of FPGI-CLGTS

According to Fig. 3, GI of CLGTS can be described through the description of the related features among

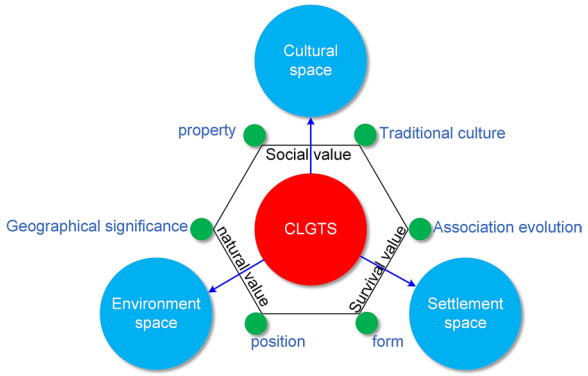

Fig. 3 The dimensions of GI cognition of CLGTS

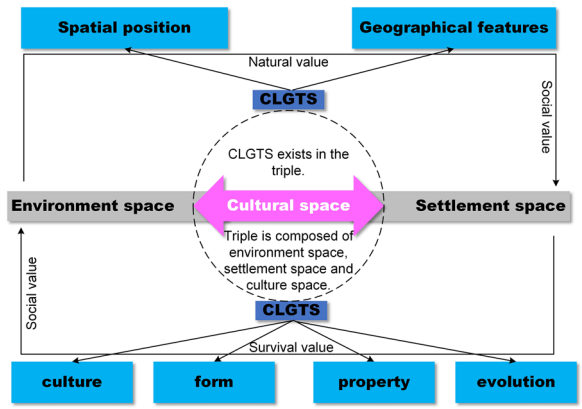

Fig. 4 Transformation of GI of CLGTS into the triple, valuable dimensional functions, and information value sets

environment, settlement, and cultural spaces. Based on the related features of the constituent elements, this study defined GI of CLGTS as the triple $< E, C, S >$, which is composed of environmental space$E$, settlement space$S$, and cultural space C together. This study sets three mathematical functions to represent different dimensions of GI of CLGTS. The natural value is defined as f_n, the social value is defined as f_v, and the survival value is defined as f_s. Simultaneously, considered set p as position information, set g as geographical values, set c as traditional cultural information, set s as form information, set a as evolutionary information, and set f as property information. Therefore, this study transforms the GI of CLGTS into the valuable dimensional functions, and information value sets (Fig. 4), which is difficult to formally describe and quantitatively express in the mapping relation of triple$< E, C, S >$.

Each CLGTS can feature its owned key functions and values due to its especial sociocultural profiles and various functions. This means that each CLGTS can distinguish itself from the others in terms of its own conspicuous features, such as geographical meanings and connotations. According to the GI contents, the prominent features of each CLGTS can be drawn, and so do the differences among the related outstanding features of various CLGTS.

From a mathematical perspective, in essence, the GI content of CLGTS is the value set (p, g, c, s, a, f) of triple$< E, C, S >$. It thus can determine the stark features of CLGTS according to the GI content of CLGTS through the related valuable dimensional functions (f_n, f_v, f_s). This study defines the outstanding features of CLGTS as the Feature Parameter of Geographical Information of CLGTS (abbreviated as FPGI-CLGTS), which can be determined and extracted from the related GI content. According to the theoretical assumption and analysis results, FPGI-CLGTS is an elementary parameter in capturing the core features of cultural factors of traditional settlements from a mathematical viewpoint, and provides a GI analysis tool to understand the traditional cultural resources of traditional settlements.

The mathematical features of FPGI-CLGTS

In terms of FPGI-CLGTS, there must be a mapping relation between the triple $< E, C, S >$, which is composed of environmental systems, settlement systems, and social-cultural systems of traditional settlements together, and the related subsets p, g, c, s, a, f. And this mapping relation must be satisfied with the valuable dimensional functions f_n, f_v, f_s. To help people utilize FPGI-CLGTS to solve the issues arising from the analysis of cultural landscape of traditional settlements, this study explores the corresponding mathematical implications as follows.

To address the mathematical features of FPGI-CLGTS well, this study firstly sets three basic definitions.

Definition 1 If there is a group of elements with the same or similar features in the triple $< E, C, S >$, these elements can constitute a feature subset of the triple $< E, C, S >$ together. In this study, a feature subset is defined as a Feature.

Definition 2 Let a group of Feature $t_1, t_2, \cdots, t_n$, if each Feature t_i $(i \in N)$ of this group is a feature subset in triple $< E, C, S >$, this group of Feature can be called as a full Feature in triple $< E, C, S >$, written as T.

Definition 3 Consider a constraint relationship in triple $< E, C, S >$, if it is in accordance with the mapping relation between one element and a full Feature T of triple $< E, C, S >$, this constraint relationship can be defined as a valuable dimensional function.

Consider x as the FPGI-CLGTS of a CLGTS in triple $< E, C, S >$, and $f_{LG}(x)$ as the function of GI features of this CLGTS. Let p, g, c, s, a, f be the Feature in triple $< E, C, S >$, and T as a full Feature in triple $< E, C, S >$, then $T = (p, g, c, s, a, f)$. Here, x equals the value of a Feature. Accordingly, $\{x|x \in T, x \neq \varnothing\}$. Therefore, the mathematical expression of the FPGI-CLGTS can be written as follows (Formula 1):

$$f_{LG}(x) :< E, C, S > \rightarrow < (f_n, f_v, f_s), (p, g, c, s, a, f) > \quad (1)$$

Furthermore, let R as the spatial domain of triple $< E, C, S >$, and set $f\prime$ as the valuable dimensional functions in the spatial domain R. Here, FPGI-CLGTS can be expressed simply as follows (Formula 2):

$$f_{LG}(x) = f(x) : R \rightarrow (f^{'}, T) \quad (2)$$

Note that, in this case, $f(x)$ denotes the mapping relation in spatial domain R.

Through the above mathematical meanings, FPGI-CLGTS is a mathematical Feature that is in accordance with the constraint of special valuable dimensional functions of the domain that is composed of historical cultural information of cultural landscapes. This also suggests that the FPGI-CLGTS can be distinguished and extracted from the geographical spatial datasets if the reasonable constraint conditions and the related mathematical Features are constructed from the perspective of GI.

The theoretical and application significance of FPGI-CLGTS

FPGI-CLGTS is the entry point to dissect the historical and cultural information of CLGTS and understand its related geographical implications from the perspective of spatial information cognition. It is of tremendous significance to determine, extract, and analyze FPGI-CLGTS to further discover the scientific features and economic functions of traditional cultural resources in the digital economic fields [5, 6].

To begin with, FPGI-CLGTS is helpful to deepen the scientific connotations of GIS, widen the information features of cultural factors of traditional settlements in human geography, and enrich the contents and methodologies of GI analysis.

Next, FPGI-CLGTS is a potential approach for fully understanding the traditional settlements and these heritages and beneficial to accumulating the experiences in developing the associated technical products to creatively use the traditional cultural resources.

Finally, FPGI-CLGTS is meaningful for integrating the ample cultural resources of traditional settlements into the essential scope of GI resources and exploring the related experiences to provide the information services of cultural resources of traditional settlements for the public in the future based on the existing Geographical Information Services [19]. In fact, in the modern society, it is inevitable to fully exert the social economic elementary values and functions of the cultural resources of traditional settlements because of the development of digital economy.

Besides, FPGI-CLGTS has crucial graphical significance. Traditional settlements continuously accumulate traditional cultures, such as the rich scientific experiences and the wisdom of survival. These traditional cultures are well recorded and preserved through various forms, such as the cultivation experiences for the promotion of agriculture, the experiences and lessons for the contradictions between the unreasonable activities and natural laws, and the auspicious meanings toward a prosperous future. Moreover, the traditional knowledge and the ancients' consensuses on the sustainable development are also remained by CLGTS, such as the geographic experiences and approaches of coexistence in harmony with the environment. All of these can be deeply addressed using FPGI-CLGTS.

FPGI-CLGTS is a critical parameter for transforming the cultural factors of traditional settlement spaces into the cyberspaces and establishing the corresponding analysis methods. FPGI-CLGTS will play an active role in many fields, such as deepening the theory of CLGLTS, and the knowledge services of cultural resources of traditional settlements. On the one hand, FPGI-CLGTS can mark the associations of various GI elements of CLGTS with simple mathematical forms or important features, such as the scientific rules of man-land systems. FPGI-CLGTS can map the information contents of traditional cultural factors that are difficult to describe directly or formally because of their complexities in the mathematical domains. Thus, it can simplify the abstracts, generalizations, and descriptions of GI content of CLGTS. On the other hand, from the point of view of GI analysis, FPGI-CLGTS can also provide theoretical and technical supports for the identification of cultural features of traditional settlements at a regional scale or a national field investigation of CLGTS resources. Simultaneously, FPGI-CLGTS can broaden and enrich human geography from the perspective of GI understanding including its contents and theoretical systems, and is also helpful for the development of human GIS. In addition, FPGI-CLGTS is beneficial for deepening the understanding of the scopes of GI resources, types, and strategic values from the perspective of human geography and enriching the content and application fields of information geography [22].

The extraction methods of FPGI-CLGTS

Rules

In essence, FPGI-CLGTS can help people understand the most prominent geographical features of cultural factors and their implied meanings from the perspective of GI principles and mechanisms. That is to say, FPGI-CLGTS is the representation of geographical features and values within the conceptual framework of GI domains. In other words, the extraction of FPGI-CLGTS should be consistent with the identification rules [28] of CLGTS. This means that the rules of inherent uniqueness, external uniqueness, local uniqueness, and superiority lay a theoretical foundation for establishing the extraction methods of FPGI-CLGTS. In addition, according to the constituent elements and GI contents of CLGTS, FPGI-CLGTS essentially represents the mathematical features of the triple $< E, C, S >$ under strict constraints. Hence, the extraction of FPGI-CLGTS must conform to the following rules.

1) Uniqueness Rule. For a given traditional settlement, FPGI-CLGTS of each CLGTS in its space is unique and determined. Here, the uniqueness rule can be proven by proof by contradiction.

Consider X as a CLGTS in the Space A of a traditional settlement. If X has two parameters of GI features at the same time, and they namely correspond to Feature g and c, then there must be two functions. In other words, the function $f(X) : A \rightarrow (f\prime, g)$, and function $f(X) : A \rightarrow (f\prime, c)$ must be true simultaneously. However, according to the definition of FPGI-CLGTS and related mathematical Feature, the GI features of CLGTS are unique and determined. This means that the Feature g and c must be equal. Undoubtedly, this hypothesis has an apparent contradiction. It is evident that one CLGTS has only a unique parameter of GI features.

2) Consistency Rule. The GI of CGLTS is the abstraction and description of CLGTS' contents, including carriers, formation, evolution, history, traditional cultures, and geographical meanings. FPGI-CLGTS is the expression of the most important and prominent features of GI contents of CLGTS. This means that, from the semantic features of GI [23], both the FPGI-CLGTS and the GI of CLGTS must has semantic consistency. In essence, both of them are all mathematical Feature in the spatial domains R of the triple $< E, C, S >$. Obviously, both FPGI-CLGTS and GI contents of CLGTS have the same mathematical meanings and foundations.

3) Bigger part, higher priority. Although this rule may result in significant bewilderment while concerning FPGI-CLGTS, it is the mathematical description of the identification rule "superiority" of CLGTS [26, 33]. The GI contents of CLGTS contain multiple properties and features. Considering that FPGI-CLGTS is a unique and determined element of spatial domains R, in terms of Uniqueness Rule and Consistency Rule, it is the most important and outstanding properties and features of CLGTS. This is determined by the mathematical Feature and meanings of FPGI-CLGTS since it is under the strict constraint of valuable dimensional functions and has a unique mapping relation of its corresponding mathematical Feature.

The above rules are the theoretical preconditions and standards for discriminating FPGI-CLGTS.

Methods and processes

Unlike the usual spatial data mining or data analysis, the extraction of FPGI-CLGTS is a type of association analysis on the GI features of cultural factors of traditional settlement spaces. From the perspective of geographical data, the classifications of cultural factors are plentiful because of the differences in their carriers and physical appearances. Cultural factors are typically described using unstructured data. On the other hand, the GI contents of cultural factors is mainly represented by texts because of the limitations of current storage, analysis, and representation methods of spatial data, such as properties, meanings, and functions. In terms of the definitions and mathematical meanings of FPGI-CLGTS, this work proposes a workflow for its extraction from the perspective of data analysis (Fig. 5).

In this study, the workflow is composed of four steps: information element analysis, value feature judgement,

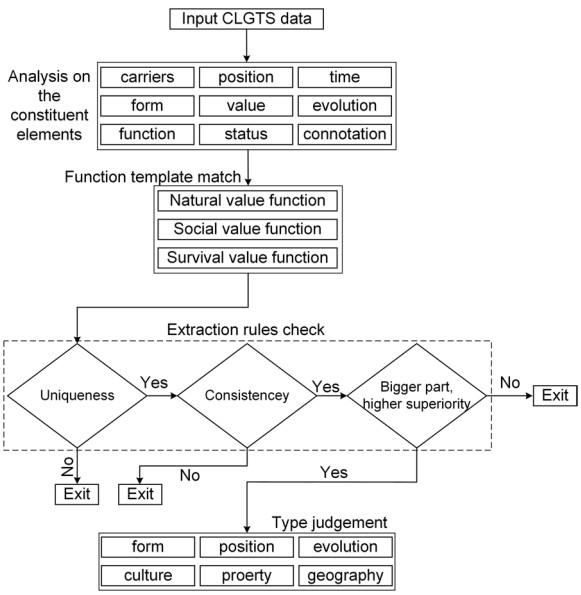

Fig. 5 The flowchart of the extraction processes of FPGI-CLGTS

parameter feature examinations, and parameter type identification.

Information element analysis means that someone can use carriers, spatial positions, and formation time to determine the crucial features, classifications, and features of different information contents according to the related GI contents of CLGTS.

In the step of value feature judgment, based on the GI constituent elements of CLGTS, the value dimensional functions can be determined. Specifically, this step utilizes the natural, social, and survival value functions to determine the value features of CLGTS. In order to reduce the complexity and difficulties in developing the related program, this work designed and established Function Templates according to the features and attributes of valuable dimensional functions, constructed different description templates/bases of value features, and employed special Feature Matching or Feature Comparison algorithms to judge the types of value functions (see Fig. 6).

Parameter feature examinations incorporate three validity checks: uniqueness check, consistency check, and "bigger part, higher superiority" check. The uniqueness check refers to the comparison between an unrecognized FPGI-CLGTS and the existing identification results, which have already been stored in the CLGTS database. The consistency check mainly uses the computation results of the semantic similarity of GI contents of CLGTS to determine FPGI-CLGTS. The "bigger part, higher superiority" check means that we can use disambiguation and attribute overlay to determine FPGI-CLGTS.

In the step of parameter type identification, the type of a FPGI-CLGTS which has passed the validity check is finally determined. For example, for a certain traditional settlement, if its spatial layouts have the wisdom of survival on how to scientifically process the contradictions between more people and less land, it can showcase great geographical significance and experiences on man-land relations; so the FPGI-CLGTS of its layouts can be determined as *g* (geographical values). According to the above analysis, this workflow for the extraction of FPGI-CLGTS has good maneuverability and feasibility. This is helpful in developing the related programs by referencing the existing related algorithms of text information processing.

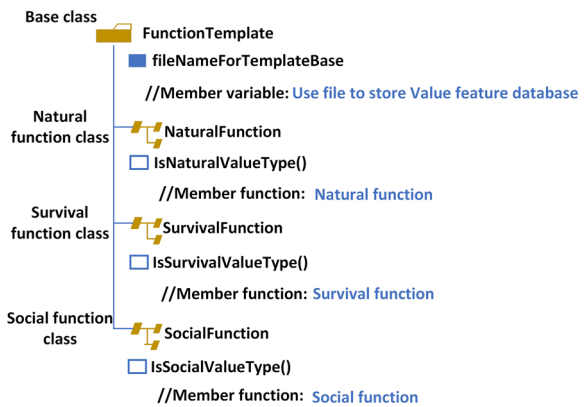

Fig. 6 The functions of value of feature parameters

Experiment and results

Experiment objectives and settings

According to the above theoretical findings, in order to examine the characterizations of FPGI-CLGTS and the feasibility of its identification methods, this study designed an experiment with six famous national historical cultural villages (Fig. 7) in Hunan Province, China, which had been already inscribed on the List of National Chinese Traditional Villages.

In order to identify all samples' CLGTS, this study collected a series of materials and datasets including the briefing materials, high resolution DEM, and field investigation materials (Table 2). The briefing materials played an active role in determining CLGTS of each sample because they provided rich information on cultural, formation, historical, and evolutionary features of all samples. Besides, the first materials from field investigations provided the necessary complements and even direct evidences when analyzing and comparing and determining a CLGTS. DEM datasets directly provided a useful support for drawing the environmental and layout features of all samples. The main identification processes of CLGTS and related results of these samples were detailed in the literature [31–33].

Especially, in order to reduce the difficulties and complexities in developing the requisite programme, this study only examined the spatial layouts of each case. Because a traditional settlement usually owns a couple of CLGTS. In term of the indexes systems and identification methods of CLGTS [32], people may often recognize 14 CLGTS for a given traditional settlement. And if all CLGTS of the cases were used as the experiment datasets, this study would have to attach the importance to developing an effective algorithm to handle these highly complicated data. This would far deviate from the main aim of this paper at exploring a potential way for understanding the GI characterizations of CLGTS. In addition, the more appropriate and effective extraction algorithms will be deeply explored in the next work.

Experiment preparations

The authors extended the definitions and described methods of CLGTS symbols (Fig. 8) according to the Traditional Landscape Genetic Symbols Database (TLGSD),

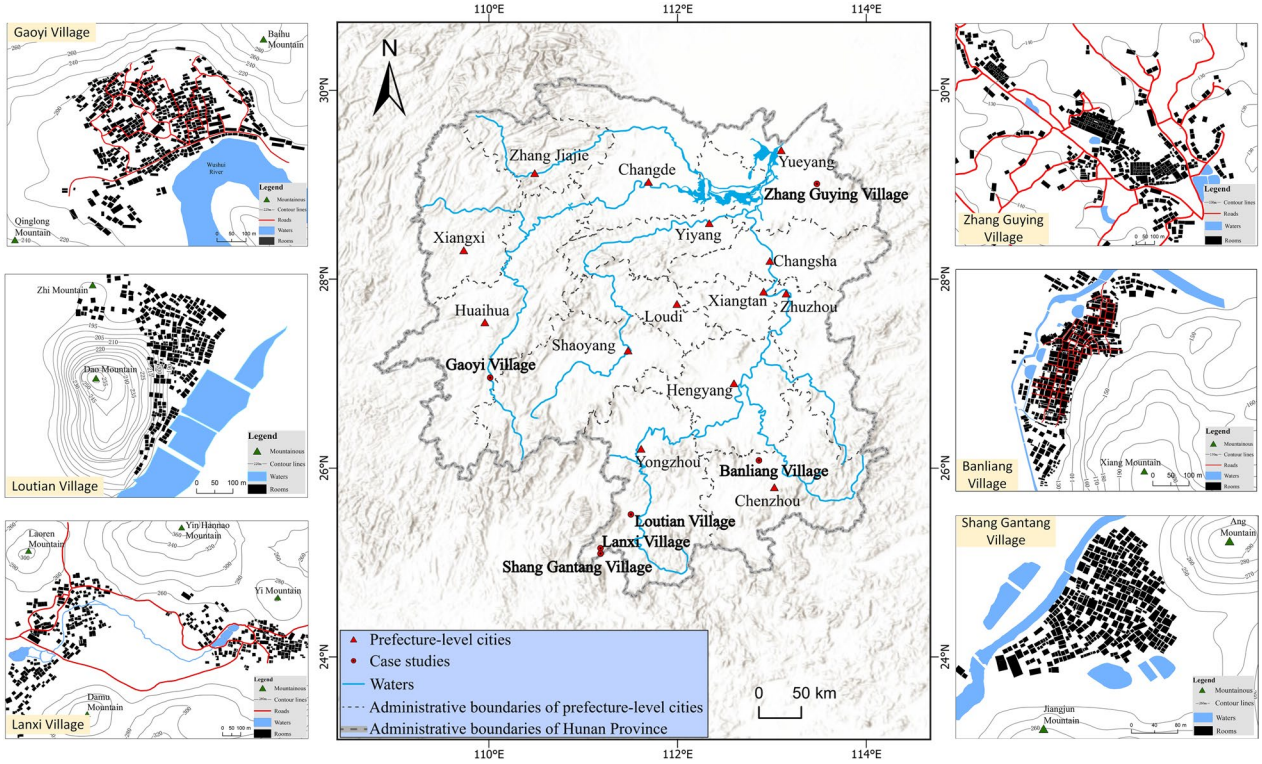

Fig. 7 Experimental examples in Hunan Province

Table 2 the main datasets and materials

Dataset or materials	Source	description
Village briefing materials	Traditional Village (www.chuantongcunluo.com) Traditional Chinese Village Digital Museum (/www.dmctv.cn/) Tourism of Chinese Ancient Villages	Collect the briefing materials and historical and cultural information on all samples
DEM	https://search.asf.alaska.edu/#/	DEM dataset of each sample with the spatial resolution of 12.5m is collected. These datasets are conducive to determine the spatial layouts and environmental features of all samples
Field investigation materials	Through field investigations	These materials include the drafts of spatial layout features, related interviews, historical and cultural information of each sample. These materials can further interpret the spatial layout features of all samples

which had been developed by the authors in 2021 [38]. The main improvements of TLGSD are outlined as follows. (i) Templates of the valuable dimensional functions were proposed. These templates included the base class and three subclasses, NaturalFunction, SurvivalFunction, and SocialFunction, respectively. The related valuable dimensional functions were implemented through the former three subclasses. (ii) A new class "FeatureParameterClass" was developed to represent FPGI-CLGTS in this experiment. And it clearly defined the essential units of GI of CLGTS and designed three validity check functions based on the extraction rules including uniqueness rules, consistency rules, and "bigger part, higher superiority." (iii) This work designed and implemented the template of each valuable dimensional function for the Feature. This template included the head and body of file. The file head defined the description formats and records of GI contents of CLGTS, and the file body recorded the GI constituent elements of CLGTS corresponding to each valuable dimensional function. (iv) We represented

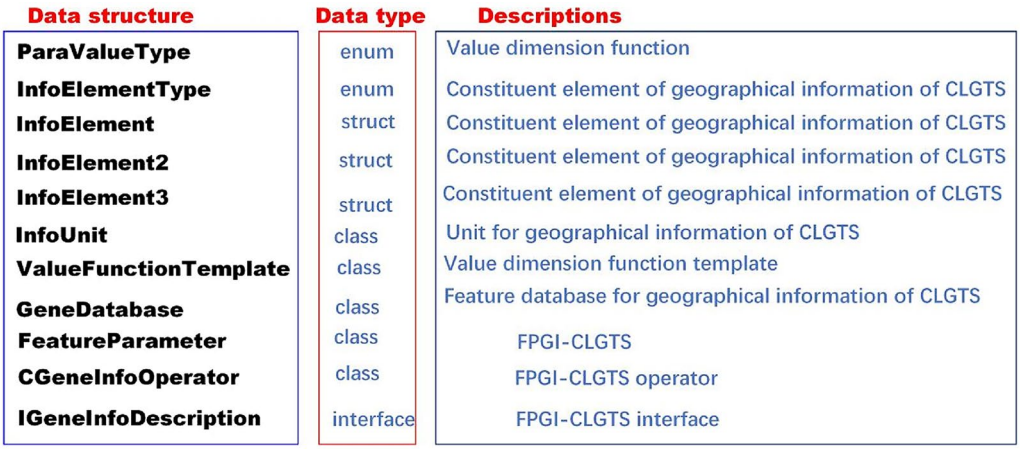

Fig. 8 The extension of data structures and types of TLGSD

the file in the FPGI-CLGTS database. This file described the crucial information of each CLGTS of a traditional settlement by treating it as a unit, such as elementary features, properties, and GI elements. This file provided a reference for the checks of the extraction rules.

Experiment results analysis

According to Fig. 7, the six samples for this experiment namely were Gaoyi Village, Loutian Village, Goulan Campus of Yao nationality (or Lanxi Village), Zhangguying Village, Banliang Village, and Shanggantang Village. First, we identified the spatial layout CLGTS of all the samples and performed preparations before launching the experiment. And then, we ran TLGSD to determine the FPGI-CLGTS of the spatial layout CLGTS of each sample. The steps of the experiment were as follows: (i) to determine the spatial layout CLGTS of all samples; (ii) to establish the templates of valuable dimensional functions; (iii) to analyze the FPGI-CLGTS of each spatial layout CLGTS of all samples and their contents; (iv) to establish the database of GI features of CLGTS of all spatial layout CLGTS; and (v) to run TLGSD to determine FPGI-CLGTS (see Table 3).

Through the results, the ancients' so many important experiences, knowledge and traditional wisdom in harmony with nature are investigated, which can provide valuable support for the modern people when facing the contradiction "rapidly growing population under the limited arable land". For example, China has the largest population in the world, but its arable land is only about 7%; and this brings colossal pressures to survive. Through this experiment, Gaoyi Village, Loutain Village and Zhangguying Village have proved this point. They all translate the survival wisdom and accumulate rich experiences of the ancients on handling the prominent contradiction "a huge population and little arable land" due to the rare cultivated lands in history. Hence, the FPGI-CLGTS of their spatial layouts are recognized as g, and their corresponding value dimensions are determined as survival value.

Moreover, the ancients' wisdom on the site selection and construction ideas of settlements were investigated, which can nourish the modern spatial designs of villages and towns. This is observed through Lanxi Village (or Goulan Campus of Yao natinality). In history, it directly faced serious difficulties in safe defense because the Central Plains Dynasty consecutively expelled or hunted the minorities in order to occupy more arable lands. Hence, in order to shelter all villagers, the whole village was sited in the mountainous areas and constructed in scattered blocks. And an intact and strong defense system was also constructed, including campus-wall, fort, watchtower, watch-house, defense-house. Therefore, the FPGI-CLGTS of its spatial layout is determined as c, and the related value dimensions is social development.

Finally, the ancient social and political needs could deeply impact the site selection and industrial developments of traditional settlements. The comparison between Banliang Village and Shanggantang Village can address this point well. In history, they had good transportation locations including convenient waterways and post road. However, the significant differences in spatial layouts between these two samples were observed well. Banliang Village backs against Xiangshan Mountain and is rounded by Banlinag River. In history, the business and trade industries of Banliang Village were very prosperous due to the convenient transport. This shaped Banliang Village's whole spatial layouts as an impact block. And its FPGI-CLGTS of spatial layout is defined as p, and the related value dimensions is social development.

Table 3 Experimental results

Sample	Spatial layout	FPGI-CLGTS features	Value dimensions	Descriptions
Gaoyi Village	Wutong- "plum blossom"-pattern	*g*	survival	In the enclosed environment, the arable lands are very rare and the layouts of scattered blocks are helpful to save more as possible
Loutian Village	Cradling "Yang"(mountain) and leaning "Yin"(plain)	*g*	survival	In the plain of full of swampland, the village creates lots of habitable spaces back against Daoshan and reclaims the swampland for farming
Lanxi Village (or Goulan Campus of Yao Nationality)	Scattered blocks	*c*	social development	In the enclosed basin in mountains, the arable lands are very rare. In history, the minority nationalities established many watchtowers or Diaolou according to the landform in order to keep safety and avoid the possible hunt at any time. So the campus are designed as scattered blocks
Zhangguying Village	A dragon-shaped layout	*g*	survival	The village is located on the plain in a basin and is designed as the scattered blocks along the foot of Longxingshan mountain due to saving the arable lands as possible
Banliang Village	Linked by rivers and mountains	*p*	social development	The village is famous for its excellent transport location since it is located at the intersection of waterways and ancient post roads. And the village is shaped as the compact block leaning against the mountains and scientifically using the landform
Shanggantan Village	Leaning mountains and rounded by rivers	*a*	social development	In ancient, the village acted as the capital town of county. Because the village owns the convenient waterways and post roads. The village is located in the enclosed geographical environments, so it is prone to stay safe

Shanggantang Village is located in the enclosed spaces that are composed of Xiemohe River and an open basin together. Shanggantang Village, rounded by the mountains and nearing to the river, had the most optimal seat of ancient county government because of the convenient river traffic and the ancient post road and the geographic environmental advantages for defenses. In history, under these circumstances, the business and trade industries often took the second place over the development. Hence, its FPGI-CLGTS of spatial layout is defined as *a*, and the related value dimensions is social development.

Discussion

With the rapid development and application of information technologies and spatial position services, the strategic values of GI resources in the socioeconomic areas are more outstanding than before. This leads to that the scientific connotations and scope of GI resources are also extended to meet more needs. However, people pay much more attention on the existing GI resources and related services with stark spatial position features than the cultural factors of traditional settlements. There is a lack of theoretical and method exploration on the understanding of cultural factors of traditional settlements from the GI perspective. Hence, the current GIS can't well support the related analysis about these cultural factors. This study presents the conception of FPGI-CLGTS and explores its basic features in a bid to address this issue and still leaves a few questions needed to further study.

Since its beginning, although it has gained so much concern from tourism, planning, conservation, and sustainable developments of traditional settlements, CLGTS still lacks effective methods to catch their core cultural features through referencing GIS. Compared to the existing research findings, this study first integrated the elements and methods of GI to understand the key geographic features of these cultural landscapes. Because with the rapidly growing geospatial big data, the abundance and values of GI resources have been consecutively

enriching than ever before. And this brings more opportunities and challenges to grasping the core features of these cultural resources based on the current GIS. Through defining the spaces of environment, social cultures, and settlements as the cognition dimensions for traditional settlements and the related value dimensional functions, this work set up a formal description model for the core cultural features of traditional settlements. In essence, this formal model lays a theoretical foundation for utilizing the current GIS method to deal with CLGTS datasets. Hence, FPGI-CLGTS is a possible play to addressing these cultural landscapes under the support of GIS principles and recognition models. Currently, in China, it is conducive to bolstering the industries and application fields to stir up their colossal advantages.

And next, it is clear that the theoretical and method explorations are pressing and necessary to recognize the key features from the rich cultural resources of traditional settlements from the GI perspective. This study constructed a conceptual framework of FPGI-CLGTS in terms of the cognition dimensional features and related value functions of GI contents of CLGTS. From the experiment results, the most key features of each CLGTS of all samples can be drawn through TLGSD. TLGSD discriminates the nuances and key differences between every CLGTS of the samples and determines the related FPGI-CLGTS. Obviously, this is very conducive to observe the key features of cultural factors of traditional settlements through different viewpoints. For example, although they have certain highly similar features, such as transportation locations and geographical conditions, the significant differences between Banliang Village and Shanggantang Village are determined through FPGI-CLGTS of their spatial layouts. The experiment directly proves the potential implications of theory and applications, and the feasibility of FPGI-CLGTS. This study can provide a theoretical and methodological support for the development and utilization of GI resources of CLGTS in the future.

Finally, according to the mathematical meanings, FPGI-CLGTS provides a spatial analysis method to mine the association features and essential rules of CLTS. This makes it possible to develop a GIS-based method to deeply mine the essential features of cultural factors of traditional settlements in the future. Of course, The current conceptual framework of FPGI-CLGTS should be extended and enriched. For example, through the experiment, three samples vividly show the ancients' wisdom on saving more arable land as possible and enough development room for the future; and this associations can be drawn and visualized well through their common features of spatial layouts and developments if the methods and principles of geographical knowledge graphs were used. In next research, based on the formal reasoning and logical expressions of GI features of CLGTS under the help of algebra, we will pay attention to the feasibility of using data mining methods to understand the cultural factor features of traditional settlements, such as lattice data mining.

In a whole, compared with previous research findings [32–35, 38], FPGI-CLGTS makes it possible to extract the critical features from the cultural landscapes of traditional settlements using GIS spatial datasets. Since its beginning, CLGTS faces significant difficulties in quantitatively describing the pivotal cultural characterizations of traditional settlements. Because the cultural factors showcase substantial differences in carriers, appearances, or cultural implied connotations. And this makes that the formal and unified data structures and models are seldom developed for CLGTS. Hence, FPGI-CLGTS has made significant progress on this issue according to the current GIS data structures and models. Through constructing the appropriate constriction functions or conditions or mathematical features, FPGI-CLGTS can discover the hidden associations and relations between various CLGTS.

Conclusions

In the era of digital economy, the social needs for GI resources and GI services have been growing rapidly. And the traditional settlements have been showcasing full play in social and economic development due to their rich traditional cultural resources and owned historical cultural appearances. Through bridging CLGTS, it has great importance to deepen the understanding of the cultural landscapes of traditional settlements with GIS and broaden the basic scope of GI resources. This is very helpful to capture the core cultural features of traditional settlements.

First, this study examined CLGTS from the perspective of GI. In this study, CLGTS is regarded as an elemental unit of historical, cultural, environmental information and a type of particular GI with stark properties and hidden positions. In terms of this theoretical premise, this study analyzed the GI constituent elements and contents of CLGTS. The GI elements of CLGTS include carriers, positions, formation or emerging time, form, geographical values, functions, and sociocultural features. The related information of CLGTS mainly includes spatial position, traditional cultures, form features, evolution features, properties, and geographical values.

Then, a conceptual framework on employing the GIS principles to further understand CLGTS was proposed. This conceptual framework includes a cognition dimensional model of CLGTS and the conception of FPGI-CLGTS. CLGTS is a natural tie mapping the interactions among natural environments, sociocultural

systems, and settlements since it owns great natural, social, and survival values. Based on this view, this work considered the environmental space, settlement space, and cultural space as a triple and set the natural values, social values, and survival values as the cognition dimensions. According to these, the cognition dimensional model of CLGTS was set up. And this model laid a foundation for the description of GI contents of CLGTS. Further, this work clarified the understanding features of the GI of CLGTS, and considered them as FPGI-CLGTS, and developed its formal expression and corresponding mathematical meanings under the support of set theory.

Next, this work explored the extraction methods of FPGI-CLGTS. FPGI-CLGTS is a description of the most outstanding and prominent features of CLGTS from the perspective of GI. The identification of FPGI-CLGTS should comply with the rules of uniqueness, consistency, and "bigger part, more superiority." The extraction methods of FPGI-CLGTS mainly included four steps: element analysis, value feature adjustment, parameter consistency check, and type identification. The parameter consistency check was the most important step, and it incorporated uniqueness check, consistency check, and superiority check. This namely corresponded to the rules of uniqueness, consistency, and "bigger part, more superiority."

Finally, the feasibility and potential applications of FPGI-CLGTS was proved through the experiment. By combining the object-oriented programming methods, this study examined the extraction method. Through the experiment, this work made sure the valuable dimensional functions of GI constituent elements of CLGTS and the uniqueness, consistency, and superiority features of FPGI-CLGTS. In the experiment, this work set 6 samples. And through the results, some significant associations, features, and differences among the spatial layouts with similar features of all samples were observed.

Through this work, FPGI-CLGTS is a potential approach for examining the essential features of the cultural resources of traditional settlements from the GI perspective. This is conducive to break the current bottleneck of related cultural resources services and further bolster the nationwide traditional settlements survey, conservation, and sustainable development in the future. However, this work mainly focused on the analysis of GI features of CLGTS, so it still had many aspects needed to improve. For example, the extraction methods and corresponding programs can be improved through the algorithm efficiency, data types, generalization, and big-sample processing.

Author contributions
Zui Hu drafted the whole manuscript and develope the program for experiment. Zui Hu also carried out the experiment and analyzed the related results. Min Tan collected the materials and provided a language edit to the manuscript. Zui Hu and Min Tan proofed the whole manuscript.

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Data availability
The data that support the findings of this study are available on special request.

Declarations

Competing interests
No potential conflict of interest was reported by the authors.

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