

Article

A New Insight into Understanding Urban Vitality: A Case Study in the Chengdu-Chongqing Area Twin-City Economic Circle, China

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Abstract: Addressing the issues caused by urbanization through urban vitality theory has elicited increasing attention in social environment research. However, few studies focus on vitality itself, such as the generative mechanism of urban vitality (GMUV) and the identification of key factors to vitality improvement. Therefore, a new insight into vitality is presented in this study through the exploration of GMUV based on partial least squares structural equation modeling (PLS-SEM). Concretely, the GMUV and the key factors to vitality improvement are analyzed and identified based on nighttime lights data, points of interest, and the statistical data of the Chengdu-Chongqing Area Twin-City Economic Circle in China. The results show that external representations and internal elements constitute the structural basis of the GMUV and that environmental vitality and social vitality are the key factors to enhance vitality. Finally, suggestions on improving regional vitality are provided to urban policymakers. This study may promote a better understanding of vitality, and the proposed vitality evaluation model may serve as a reference for other regions.

Keywords: urban vitality; generative mechanism; urban sustainable development; partial least squares structural equation modeling; points of interest; nighttime lights data



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1. Introduction

Rapid urbanization since the 20th century has brought urban issues such as land shortage, vacant residential buildings, and high-density urban blocks, which become major impediments to urban development [1–3] and further lead to the advocacy for the creation of a vibrant urban space [4]. Urban vitality (UV) is the comprehensive reflection of regional development and an endogenous engine to promote development. Scholars realized the importance of vitality for urban development very early and elaborated the theoretical concept of vitality from different perspectives [5–10]. Nonetheless, most of the existing studies are qualitative and based on personal experience. Recently, rapid development in information and communication technologies (ICTs) such as big data have offset the deficiency of traditional statistical data and enabled quantitative measurement and application regarding UV. For example, taking several Italian cities as research objects, De Nadai, et al. [11] validated the relationship between UV and four conditions introduced by Jacobs using big data, including mobile phone records and web data. Wu and Niu [2] have verified the influence of the built environment on UV using mobile phone location data in Shanghai, China. Furthermore, Kang, et al. [12] studied the influence of activity, time, and space diversity on UV and concluded that the three together significantly impact UV.

According to the literature, more efforts were dedicated to exploring relationships between the manifestation of UV and its factors, but few studies paid attention to UV itself, which thereby has raised concerns regarding the generative mechanism of urban vitality

(GMUV). Despite previous studies that were conducted to understand the theoretical basis of vitality, the GMUV still remains unknown, and there also lacks a quantitative approach on the macroscale level, especially based on the influence trajectory of each factor on vitality, to investigate the GMUV. Therefore, a new insight into UV is presented in this study using partial least squares structural equation modeling (PLS-SEM) with empirical data from the Chengdu-Chongqing Area Twin-City Economic Circle (CCATEC) in China. The research objectives are to: (1) reveal the GMUV from the perspectives of external manifestation and internal structure; (2) identify the key factors to vitality improvement and analyze how they interact with each other; (3) propose several suggestions to improve UV.

This study quantitatively provides a new insight to understand the connotation of UV based on PLS-SEM with nighttime lights data (NLD), points of interest (POI), and statistical data, which is conducive to supporting decision-makers in terms of making policies. The rest of this article is structured as follows. Section 2 reviews the related work. The theoretical framework and analytical model are introduced in Section 3. Section 4 describes the methodology adopted and the analysis process, including the data sources and research methods. The results and analysis are presented in Section 5. Section 6 presents discussions and conclusions of this study.

2. Background

2.1. The Theoretical Context of Vitality

According to Jacobs [5], activities and areas in a city interweave to form urban life, and such diverse urban life constitutes UV. Maas [7] argued that successfully maintaining a vibrant area depends on street life and the social interaction they produce. Landry [13] argued that economic, social, and physical environment factors interplay to form vitality. Gehl [10] has pointed out the importance of the life, space, and architecture sequence in creating vitality from the perspective of behavioristics, and divided activities into three types: necessity, spontaneity, and sociality. Gehl also found that vitality could be improved through pedestrianization, reduced traffic, reduced car parking, and the provision of cycle lanes [14,15]. It is certain that these theoretical findings have laid a solid foundation for understanding vitality. However, there is a lack of consensus on both the definition of vitality [16,17] and of quantitative studies concerning the GMUV from a macroscopic level [3,18], although a few scholars have explored the driving mechanism of vitality [19,20]. In practice, the demand for urban space increases with the growing economy, which has motivated an increasing number of scholars to begin to study the role of vitality in urban planning and urban space design [21,22]. Thus, a holistic understanding of UV itself is indeed necessary.

2.2. Related Works on Understanding UV

UV, a highly elusive system interwoven with multiple factors and layers, is not determined by a single factor alone [23,24]. In the literature, works on understanding UV generally focus on the research scale and the method used.

Notably, the research scale may affect the accuracy of vitality evaluation [2]. In the literature, current research related to vitality evaluation mainly focuses on either the macroscale or the microscale [2,25,26], whereas the in-depth understanding and systematic evaluation of vitality itself from both the macroscale and microscale are scant. Moreover, most studies now focus directly on the impact of certain factors on the manifestation of vitality within a limited space [16,27,28], and offer little structural analysis on the GMUV. Furthermore, according to the literature general processes to understand UV can be divided into two steps: establishment of index system and selection of the analytic method. At present, scholars mainly use a single index system or composite index system in UV research. The dominant single indicator includes mobile data [29], POI [30], and the number of restaurant service comments [25,31]. The composite index mainly refers to integrated indicators in terms of society, economy, and environment aspects, which are shown in Table 1.

Table 1. The literature on vitality evaluation.

Composite Indicator System	Methods
Number of active and stationary people per unit area [2]	Summation method
Density (e.g., population density), accessibility (e.g., distance to school), livability (e.g., number of foodservice sites), diversity (e.g., urban land use diversity) [32]	Spatial Topsis method
Population demographics, employment, retail sales, number of restaurants, crime rate, business activities, diversity of uses, and pedestrian flows [33]	Questionnaire survey
Accessibility to amenities, land use diversity, visual propositions, sense of place, flexibility and intensity of land use, flexibility, organizer structure [34]	Analytic hierarchy process
The number of dwellings, population, business area, the per square meter prices of land [35]	Factor analysis
Pedestrian traffic, bank card transactions, and Wi-Fi hotspots represent social vitality, economic vitality, and virtual vitality, respectively [36]	Correlation analysis
Road junctions, POIs, and location-based service data [1,37]	Product of the three indicators
The ratio of fixed investment and social retail to GDP, living wages, disposable income, and general middle school [38]	Principal component analysis
Pedestrian traffic flow, purchase, transaction, and investment [39]	Questionnaire and statistical analysis
Retail sales of consumer goods per capita, the proportion of tertiary industry, the number of students enrolled, and per capita park green space area [26]	Entropy method

According to Table 1, previous methods applied in understanding UV include multi-variable regression analysis, analytic hierarchy process, and principal component analysis, but they still retain some deficiencies. For example, as with most statistical analysis methods, the equation traditionally derived from regression analysis consists of a single dependent variable [40], which would render the regression analysis inappropriate if there are multiple dependent variables. In the meantime, regression analysis does not consider the relationship between independent variables [41] and their errors [42], leading to misleading results. In summary, none of these methods is suitable for illustrating the GMUV clearly and visually as they lack the ability to analyze the intricate interrelationships between variables. Furthermore, the explanatory variables and response variables in this context are often intrinsically unobservable and need to be replaced by observable indicators [43]. Structural equation modeling (SEM) has gained popularity in social sciences as it considers measurement error [44,45]. SEM includes the measurement model and the structural model, i.e., the model that comprises the observed variables to describe the latent variables and the model that demonstrates causality between latent variables [46]. Therefore, it is suitable for the research context in the present study. However, the application of SEM in the investigation of vitality generation and vitality evaluation modeling is still at an early stage, thus it holds considerable promise.

3. Theoretical Analysis and Research Model

3.1. Theoretical Analysis Framework for the GMUV

According to existing studies, vitality herein is the external embodiment of a whole function with specific operation rules and structural characteristics and is generated under various influencing factors that complement each other. In other words, mutual connection and interaction between the different elements drive the GMUV. In this regard, the GMUV should consist of two types of enablers: humankind and the environment [47]. As the main body of vitality, people and their activities are the primary manifestation of vitality [5,24,26], which are defined as external representations in this study. Due to the pooling of people and their pursuit of basic life goals, environment requirements, and spiritual culture, three types of activities have emerged [10]. The result of these activities is that more people from different backgrounds are attracted to participate in more activities, thus forming a diversified life. Meanwhile, the environment, which supports and guarantees people's various activities, is the space carrier of the activities above [34,48]. Without the environment, activities cannot be sustained. Therefore, the environment is a prerequisite to generate vitality, which is defined as internal elements herein. Unlike previous work

that only focused on the urban physical space environment [16,49,50], the environment in this study refers to both the macroscopic physical environment and the immaterialized environment that includes the socio-economic context.

As analyzed above, from a microstructural perspective, the composite index system is adopted herein to decompose vitality accurately into the indicators associated with external representations and internal elements. The former is the result of people engaging in a variety of activities in the environmental space, while the latter is the environmental attribute of a region that comprises the material environment properties and immaterial environment properties. Therefore, based on the two perspectives, a composite index system with 20 factors as indicators is preliminarily established with reference to previous studies (see Table 2). Additionally, from a macro perspective, UV is an abstract and systematic concept that is difficult to understand directly. In this regard, Bromley and Thomas [39] split the concept into social vitality and economic vitality. Similarly, Lan, Gong, Da and Wen [26] divided UV into economic vitality, cultural vitality, social vitality, innovation vitality, and environmental vitality. Besides, many scholars have decomposed vitality into one or more aspects such as economy, society, environment, and even culture [36,48,50,51]. Based on which, UV in this study is divided into environmental vitality (EnV), economic vitality (EcV), social vitality (SV), and cultural vitality (CV).

Therefore, an analysis framework for the GMUV is created and illustrated in Figure 1. It is depicted as integration with micro enablers and macro manifestations. At the microscale, it consists of external representations (1.a) and internal elements (1.b). The arrows in 1.a with + signs mean that the pooling of individuals and the activities positively stimulate each other, thus promoting vitality generation. Moreover, 1.b consists of the physical and immaterial environment elements, offering the people engaging in activities a necessary environment. The 20 initial indicators are used to establish the four types of vitality (2.a, 2.b, 2.c, 2.d) and connect the micro and macro scales as a bridge. From a macroscale point of view, this study provides an in-depth understanding of UV based on PLS-SEM.

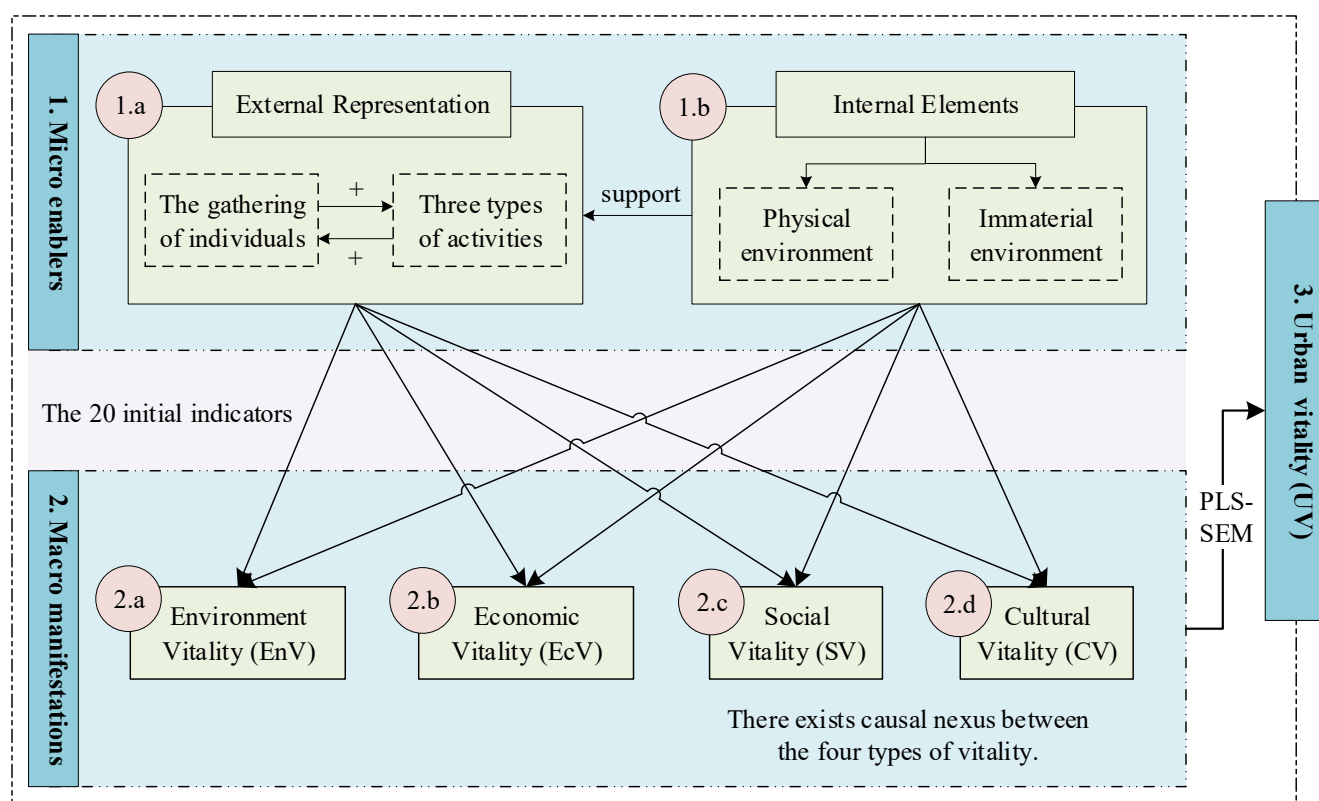


Figure 1. A theoretical analysis framework for the GMUV.

3.2. Research Model Establishment

In this segment, the research model is established by presenting research hypotheses based on the theoretical framework and developing measurement where the 20 indicators are used to describe five latent variables (i.e., the 2.a–2.d and the UV).

3.2.1. Presentation of Research Hypotheses

To holistically understand the GMUV, it is imperative to identify the causality between the aforementioned latent variables. Figure 2 illustrates the conceptual model to analyze the GMUV in this study. According to previous studies on UV evaluation, EnV and EcV are regarded as the foundations of vitality and their positive influence on vitality has been quantitatively studied from different perspectives [32,38,50]. Similarly, Lefebvre, Rabinovitch and Wander [52] and Ye, Li and Liu [31] have claimed UV is dependent on urban morphology. In addition, SV and CV are the essential components of an urban life with better quality [26]. Likewise, Montgomery [9] has defined UV partly based on the number of cultural events over a year. According to Yue, Chen, Zhang, and Liu [3], the social dimension should be considered when evaluating UV. These studies have presented theoretical knowledge on what can directly influence UV. However, Lan, Gong, Da and Wen [26] have argued that environmental factors, for example, excessive population inflow, can decrease UV. Nonetheless, to be scientific and comprehensive and further test these arguments later, this study proposes the following hypotheses for being scientific and comprehensive:

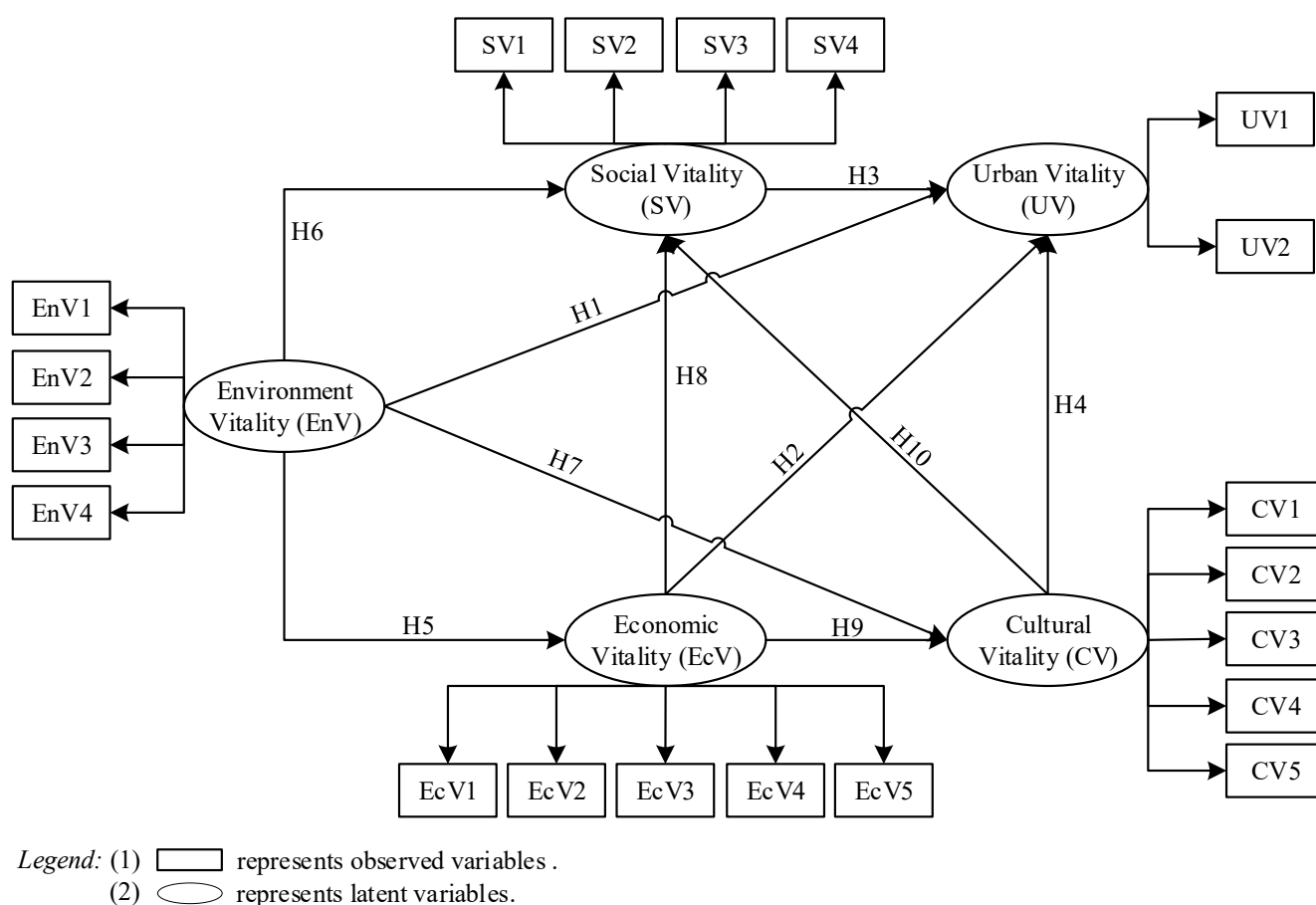


Figure 2. The research model of the GMUV.

Hypothesis 1 (H1). *EnV directly influences UV.*

Hypothesis 2 (H2). *EcV directly influences UV.*

Hypothesis 3 (H3). *SV directly influences UV.*

Hypothesis 4 (H4). *CV directly influences UV.*

The environment of a city including the physical environment and socio-economic context has been regarded as the main driver for the relationship between urban morphology and economy, as the urban environment, especially the physical environment, offers people opportunities to engage in economic activities. Long and Huang [48] have revealed that indicators of urban design, including intersection density, mixed-use level, and access to amenities and transportation can influence EcV. Social activities require a physical environment and contribute to the gathering of people [7], therefore, the EnV is the cornerstone to promote SV [3], and even CV. Then, the following hypotheses are proposed:

Hypothesis 5 (H5). *EnV directly influences EcV.*

Hypothesis 6 (H6). *EnV directly influences SV.*

Hypothesis 7 (H7). *EnV directly influences CV.*

Enormous inflow of population and capital has greatly shaped the cities, especially in developing countries, thus leading to a prosperous economy of a city. In return, more opportunities and social infrastructure, including educational resources, social security, as well as medical and health services can be provided in a city [26]. Therefore, the more developed the regional economy is, the more active the regional social activities are. The reason for this is that such a developed economy usually offers more opportunities and more life facilities to promote people gathering. Over the past two decades, the influence of human capital on economic transformation has attracted more and more attention [53]. With the high-quality development of the economy, innovative businesses gradually gain an edge in the market, which means there is a tremendous gap in terms of talent. In this regard, a prosperous economy facilitates cultural development. Then, the following hypotheses are proposed:

Hypothesis 8 (H8). *EcV directly influences SV.*

Hypothesis 9 (H9). *EcV directly influences CV.*

The CV, not only the creativity of the educated but also culture inheritance representing cultural identity, plays a vital role in urban life. Urban sociologists have conveyed that a community with heterogeneity, that is, without shared cultural identity, leads to the absence of trust, negative behaviors, and impersonal social interactions, thus deteriorating social cohesion [15]. Therefore, activities related to the culture and the dissemination of traditional culture, both called cultural vitality in this study, promote social cohesion, which is the prerequisite for SV. Thus, the following hypothesis is proposed:

Hypothesis 10 (H10). *CV directly influences SV.*

3.2.2. Measurement Development

It is noteworthy that these four latent variables are too abstract to be directly measured. For this reason, the initial 20 indicators identified and adjusted based on the relevant studies (see Table 2) are used to measure each latent variable, which has structured five constructs (see Figure 2) and will be further verified in the following section.

Table 2. The statistical description of indicators and assessment of measurement model.

Indicators	Min/Max	Mean	Standard Deviation	Std. Indicator Loadings ^a	Source	Code
Economic Vitality (EcV): Cronbach's $\alpha = 0.872$ ^b ; CR = 0.941 ^c ; AVE = 0.726						
Proportion of tertiary industry (%)	0.21/0.97	0.43	0.14	0.816 ***	[26,48]	EcV1
Per capita GDP (¥ 10,000 yuan)	2.06/18.25	5.50	2.85	0.783 ***	[13,26,54]	EcV2
Number of construction enterprises (pieces)	1.00/338.00	52.07	61.69	0.861 ***	[55]	EcV3
Entertainment facilities (pieces)	0.00/71.00	9.79	12.73	0.941 ***	Experts' opinion	EcV4
Per capita fixed asset investment (¥ yuan)	8459.87/109,389.22	43,966.12	20,776.82	0.172	[56,57]	EcV5
Environment Vitality (EnV): Cronbach's $\alpha = 0.929$; CR = 0.955; AVE = 0.876						
Year-end resident population density (person/km ²)	47.41/27,836.36	1288.82	3182.16	0.963 ***	[5,12,58]	EnV1
Road network density (km/km ²)	0.33/12.43	1.90	1.17	0.866 ***	[50]	EnV2
GDP/km ² (¥ 10,000 yuan/km ²)	175.22/507,739.86	12,448.25	49,005.84	0.976 ***	Experts' opinion	EnV3
Transportation facilities (pieces)	3.00/1356.00	305.98	282.96	0.586	[50,59]	EnV4
Social Vitality (SV): Cronbach's $\alpha = 0.915$; CR = 0.947; AVE = 0.857						
Urbanization rate of permanent resident population (%)	0.31/1.00	0.55	0.17	0.960 ***	[60,61]	SV1
Per capita retail sales of consumer goods (¥ 10,000 yuan)	0.71/14.74	2.21	1.80	0.857 ***	[26]	SV2
Per capita disposable income of residents (¥ yuan)	16,389.00/45,298.00	26,497.10	6629.52	0.955 ***	[38]	SV3
Per capita public fiscal expenditure (¥ yuan)	3071.92/19,103.70	7420.62	2475.99	0.068	[26]	SV4
Cultural Vitality (CV): Cronbach's $\alpha = 0.711$; CR = 0.858; AVE = 0.753						
Public cultural services (pieces)	11.00/1076.00	245.16	188.19	0.958 ***	[62]	CV1
Number of teachers in middle and primary school (person)	158.00/7054.00	2484.21	1369.77	0.767 ***	[57]	CV2
Number of middle and primary schools (pieces)	12.00/524.00	80.38	61.66	0.172	[48]	CV3
Number of collections in public libraries per capita (items/person)	0.01/3.92	0.36	0.44	0.517	[26,54]	CV4
Number of students in regular school (Person/10,000 persons)	143.21/1025.35	464.38	158.84	0.202	[26,57]	CV5
Regional Vitality (UV): Cronbach's $\alpha = 0.757$; CR = 0.887; AVE = 0.797						
Nighttime light data	9.12/489.20	118.97	105.03	0.842 ***	[26,28]	UV1
POI data (pieces)	167.00/7473.00	1570.00	1267.98	0.941 ***	[12]	UV2

^a Verification of the measurement model was presented after deleting the indicators whose factor loading is less than 0.700 [63].

^b CR = composite reliability. ^c AVE = average variance extracted; *** indicates $p < 0.001$.

4. Methodology

4.1. Research Area

In January 2020 China proposed the construction of the CCATEC between Chongqing and Sichuan Province in the southwest, motivating scholars to conduct related research. The CCATEC, located in the core area of Sichuan Basin (see Figure 3b), is the largest and most developed region in western China (see Figure 3c). The Economic Circle covers an area of about 200,000 km², with a permanent population of around 95 million. The research area covers 140 districts and counties including 27 in Chongqing Province and 113 in Sichuan Province (see Figure 3a), which are regarded as 140 sample units in this study.

According to the China Statistical Yearbook (2019), 90% of the GDP (6104.132 billion yuan) of Chongqing and Sichuan Province is contributed by the CCATEC. However, such issues as industrial division, low radiation capacity of core areas, and imbalanced development have rendered a low degree of urban integration. In this regard, this context provides an opportunity to analyze these issues from the perspective of vitality, and further investigate the GMUV.

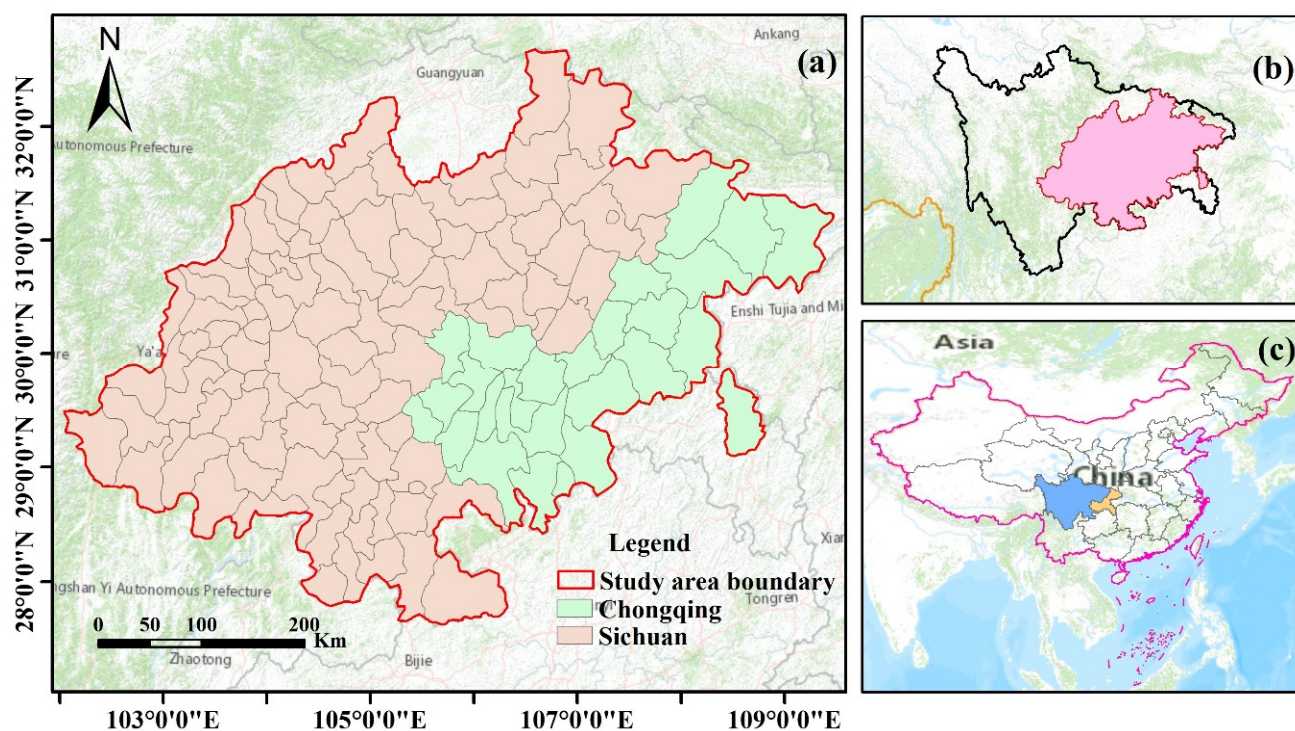


Figure 3. Study area: (a) 140 districts and counties, which are sample units; (b) the position of the study area in Sichuan Basin in China; (c) the geographical position of Chongqing and Sichuan Province in China.

4.2. Data Collection

The data used in this study from the sample units includes NLD, POI, and 18 statistical datasets, with a total of 2800 valid data. In this section, three types of data are reviewed.

4.2.1. Statistical Datasets

Using the Chongqing and Sichuan Province statistical yearbook (2019) and telephone interviews, 18 socio-economic datasets, including datasets of EnV1, EcV2, etc., were collected, except for NLD and POI. Table 2 describes these data from the perspective of statistics.

The normal distribution test, taking EcV2 as an example, was carried out, and the frequency distribution histogram and Q–Q plot were drawn in SPSS 25.0 (see Figure 4). It can be seen that EcV2 does not meet the multivariate normal distribution. It was found from further tests with the same method that other indicators do not comply with the normal distribution hypothesis, either.

4.2.2. NLD

As a part of the application of remote sensing, the image of NLD, which can directly reflect human social and economic activities, has been more widely used in urban design, GDP measurements, and urban vitality measurements [26,64,65]. At present, there are two main types of NLD, namely DMSP-OLS and NPP/VIIRS. The spatial resolution of DMSP-OLS is low and the digital number (DN) ranges from 0 to 63, which does not apply to this study where sample points are districts and counties. However, due to DN saturation,

NPP/VIIRS is complicated to operate. Therefore, this study chose the ‘Luoja 1-01’ remote sensing satellite launched in early 2018 from China, with a high resolution of 130 m and ease of access to data (<http://59.175.109.173:8888/app/login.html>, accessed on 15 August 2019), as shown in Figure 5.

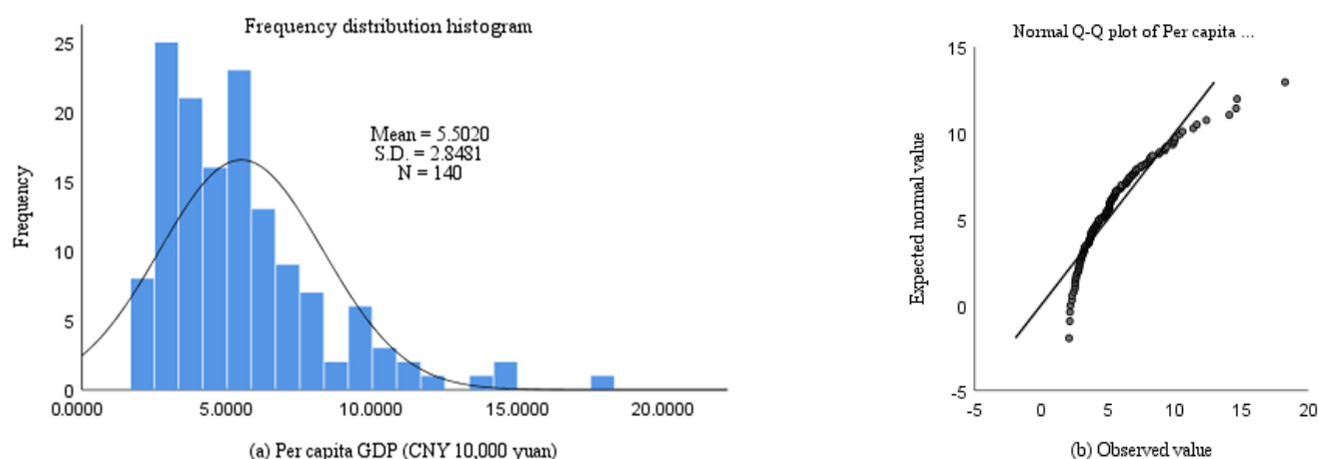


Figure 4. Normal distribution test for EcV2: (a) the frequency histogram; (b) normal Q-Q plot.

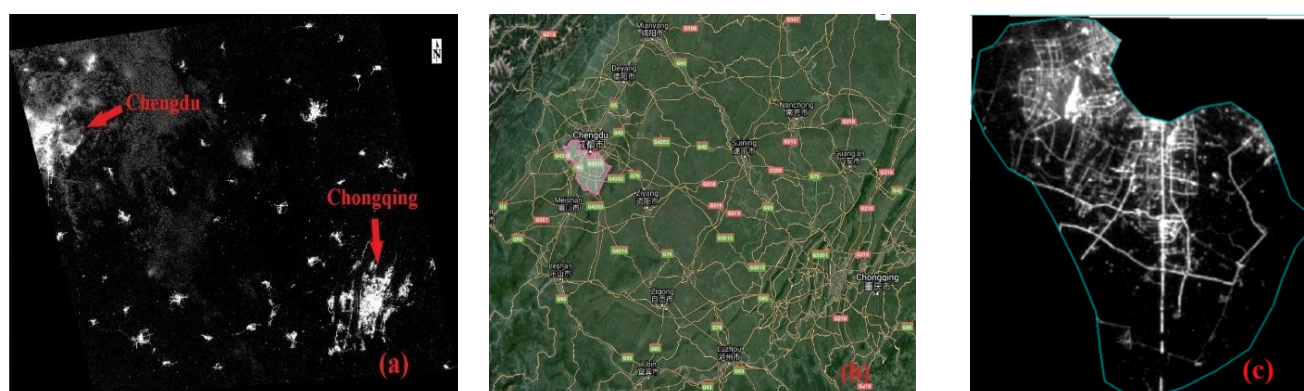


Figure 5. NLD: (a) remote sensing image at night in the study area from “Luoja 1-01”; (b) the position of Shuangliu Districts, Chengdu (in pink line); (c) remote sensing image at night in Shuangliu district in August 2019.

In this study, the mean value of DN of the remote sensing image of a district or county is taken as the NLD of the sample units [26,66] using the region of interest (ROI) tool in ENVI 5.3. Statistical descriptions are shown in Table 3.

Table 3. The statistical description of NLD.

N		Mean	Variance	Skewness		Kurtosis		Min	Max
Valid	Missing			Statistic	S.E.	Statistic	S.E.		
140	0	118.97	11031.38	1.67	0.21	2.55	0.41	9.12	489.20

4.2.3. POI Data

POI data integrates basic information regarding geography and can holistically reflect the diversity of people’s lives in a region. The higher the POI, the higher the vitality, and therefore, POI has been regarded as an important proxy of vitality [30,50]. Based on POI categories of Gaode Map (<https://www.amap.com/>) (in 15 August 2019), one of the largest map search and navigation engines in China, five typical categories selected as the criteria to collect POI data can be further divided into 15 subcategories of POI (Figure 6).

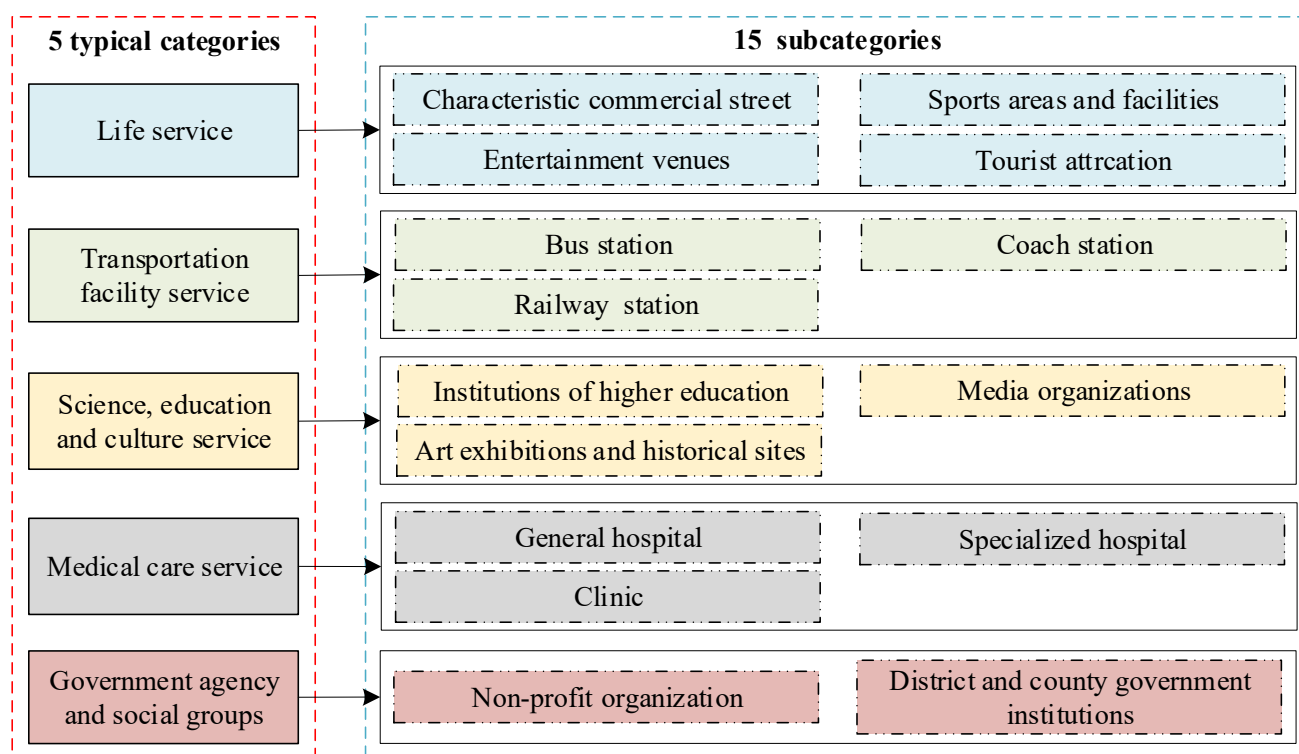


Figure 6. Categories of POI in this study.

Using the application program interface of Gaode Map, this study crawled the data of the 15 subcategories for each unit and summed the number of POI of each unit as the research data, and a total of 219,839 POI data were obtained (see Table 4).

Table 4. The statistical description of POI.

	N	Min	Max	Mean	S.D.	Skewness		Kurtosis	
						Statistic	S.E.	Statistic	S.E.
POI	140	167	7473	1570	1267.98	1.87	0.21	4.29	0.41

4.3. Method of Data Analysis

The raw data were imported into SPSS 25.0 for standardization using the Z-scoring technique by Formula (1) since the dimension and order of magnitude of each indicator are different.

$$x_{\text{new}} = \frac{x - \mu}{\sigma}, \quad (1)$$

where x_{new} is the standardized data for SEM analysis, x is the raw data, μ and σ is the mean and standard deviation of the raw data.

In this study, SEM was employed to analyze the data, and to test and assess the research model of the GMUV. SEM can be used to simultaneously test the construct of latent variables and verify the hypotheses presented by a path diagram. Generally, there are two main types of SEM, i.e., co-variance-based SEM (CB-SEM) and PLS-SEM [67]. Compared with the maximum likelihood used by CB-SEM, PLS-SEM adopts a mathematical optimization technique to minimize the sum of squares of error and has no excessive limitation on the size of sample data, thus not requiring a normal distribution of sample data [68]. With this respect, PLS-SEM is widely applied in practice [67,69], but is scarce in evaluating UV. The reasons to choose PLS-SEM in this study are as follows. Firstly, UV is an intricate system that cannot be evaluated by a single indicator. Secondly, as shown in Section 4.2, the sample size for this study is small and the data are not consistent with the normal

distribution. Finally, the outcomes of the study can be served to predict policymaking and the development of the study area. The PLS-SEM method can be divided into two stages: the measurement model assessment and the test of the structural model.

5. Results and Analysis

5.1. Measurement Model Assessment

SmartPLS 3.0 was used in this study to test the reliability and validity of the measurement model. Reliability, including the internal consistency and indicator reliability, was evaluated by Cronbach's α coefficient, CR, and standard indicator loadings (SIL). Similarly, the validity comprising convergent and discriminant validity was tested through the AVE, Fornell-Larcker criterion, and heterotrait-monotrait (HTMT) ratio in this study.

The results of reliability and validity assessment are shown in Table 2. The values for Cronbach's α coefficient are between 0.711 and 0.929, all satisfying the threshold of 0.70 [70]. As can be seen, SIL values of EcV5, EnV4, SV4, CV3, CV4, and CV5 are less than the threshold of 0.70 [71], which should be deleted to ensure indicator reliability according to Nicolas, Kim, and Chi [45]. In any case, the values of CR range from 0.858 to 0.959, greater than the acceptable value of 0.80 [72]. These results demonstrate that all constructs have good reliability. Concerning the convergent validity, all values of AVE satisfy the acceptable value of 0.50 [73], which range from 0.726 to 0.876. The results of the Fornell-Larcker criterion are shown in Table 5 in which the square root of the AVE (in diagonal line) is greater than the correlation index. Table 6 shows that the HTMT results are less than the threshold of 0.900 [74], except for the value between SV and EcV, 0.907, which slightly exceeds the threshold. However, according to the principle of HTMT, it makes sense to accept the result because of the similar meaning between the two constructs [75]. Therefore, these results show all the constructs have a good validity as well.

Table 5. The results of the Fornell-Larcker criterion.

Constructs	CV	UV	EnV	SV	EcV
CV	0.864				
UV	0.840	0.892			
EnV	0.330	0.416	0.936		
SV	0.581	0.745	0.649	0.926	
EcV	0.720	0.807	0.676	0.847	0.852

Note: Diagonal values are the square root of AVE.

Table 6. Results of the HTMT.

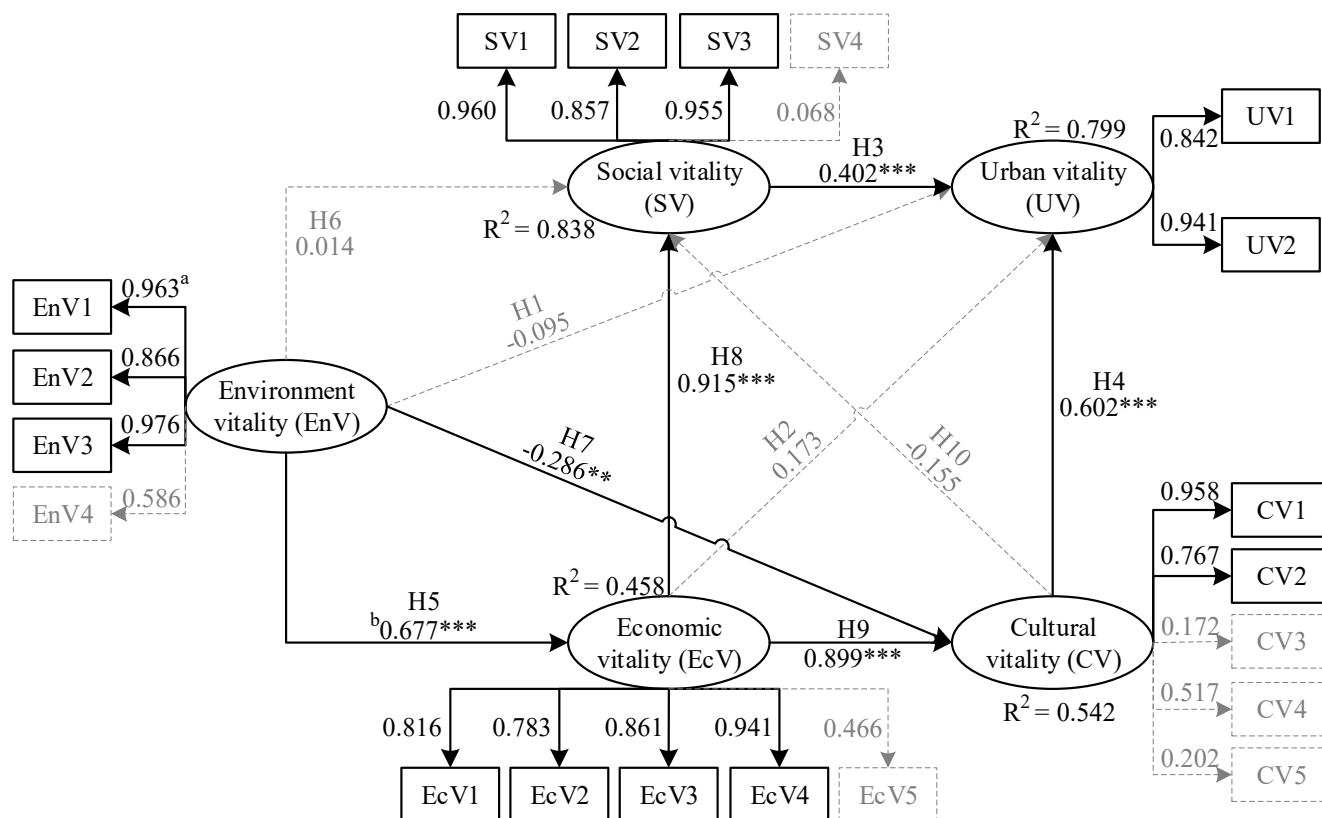
Constructs	CV	UV	EnV	SV	EcV
CV					
UV	0.865				
EnV	0.319	0.468			
SV	0.567	0.863	0.694		
EcV	0.768	0.841	0.739	0.907	

In summary, the analysis above demonstrates that the reliability and validity of all constructs are acceptable and indicates each construct is substantially structured.

5.2. Structural Model Test

Five latent variables, including four endogenous latent variables (i.e., SV, UV, CV, and EcV) and one exogenous variable (i.e., EnV), and ten hypotheses (i.e., H1-H10) are shown in Figure 7. Within SmartPLS 3.0, the bootstrapping method was adopted to estimate the structural model and test the proposed hypotheses. Bootstrapping is a nonparametric procedure that allows the testing of the statistical significance of various PLS-SEM results. In this study, 5000 subsamples were set according to Hair, et al. [76]. Furthermore, the bias-corrected and accelerated (BCa) bootstrap (default) can minimize the peaked and

skewed bootstrap distributions [77], for the most stable result at the significance of 0.05. Given that the hypotheses are not specific in direction, this study employed a two-tailed test referring to Tagod, et al. [78].



Legend: [] indicates observed variables was deleted; ---> indicates hypothesis is insignificant.

Notes: (1) ** indicates $p < 0.01$; *** indicates $p < 0.001$; ^a presents standard indicator loading; ^b presents the path coefficients
(2) Sample size = 2800; bootstrap replications = 5000.

Figure 7. The analytical results of the proposed model.

The results are presented in Table 7 and Figure 7 where standard path coefficients and squared multiple correlations (R^2), and the level of significance of the hypotheses are shown, respectively. As a crucial criterion for the assessment of the structural model, the R^2 of endogenous variables ranging from 0.458 to 0.838 in this study all exceeded the acceptable value of 0.33 proposed by Chin [79], which indicates a moderate model in explanatory ability. Furthermore, the hypothesized nexuses among the latent variables were tested.

Table 7. Testing results of path coefficient of the structural model.

Hypotheses	Path Relationship	Std. Path Coefficient	Standard Error	T Statistic	p-Value	Results
H3	SV -> UV	0.402	0.054	7.450	***	Supported
H4	CV -> UV	0.602	0.049	12.193	***	Supported
H5	EnV -> EcV	0.677	0.069	9.875	***	Supported
H7	EnV -> CV	-0.286	0.098	2.905	**	Supported
H8	EcV -> SV	0.915	0.018	51.774	***	Supported
H9	EcV -> CV	0.899	0.071	12.747	***	Supported

Notes: Other insignificant hypotheses are not shown in Table 7 due to the limited space; *** indicates $p < 0.001$, ** indicates $p < 0.01$.

As can be seen, six out of the ten hypotheses have a significant effect on the endogenous variables at the significance level of 0.05. In detail, the path coefficients of SV to UV (0.402), CV to UV (0.602), EnV to EcV (0.677), EcV to SV (0.915), and EcV to CV (0.899) are positive and statistically significant while the path coefficient of EnV to CV (−0.286) was negative and also significant, thus supporting these relevant hypotheses. However, H1, H2, H6, and H10 are statistically insignificant, meaning these hypotheses are not supported in this context.

5.3. The GMUV Analysis

It can be found from Figure 7 that there are two ways to affect UV: through a direct effect, such as SV; and an indirect effect, such as EcV. In SmartPLS 3.0, the indirect effect and total effect between each latent variable can also be obtained by calculating the model. The indirect effect is the sum of multiplying all the coefficients of the path from one latent variable to UV. Taking the EcV to UV as an example, the indirect effect is equivalent to the sum of $H9 \times H4$ and $H8 \times H3$, namely 0.909, as shown in Table 8. Additionally, it can also be seen that CV and EcV are the top two factors influencing UV. Conversely, EnV and SV both have a weaker effect on UV.

Table 8. Effect coefficient of latent variables for the UV.

Hypothetical Path	Direct Effect	Indirect Effect	Total Effect
CV → UV	0.602		0.602 ***
EnV → UV		0.444	0.444 ***
SV → UV	0.402		0.402 ***
EcV → UV		0.909	0.909 ***

Note: *** indicates $p < 0.001$.

Therefore, based on the efforts mentioned above, the GMUV is conceptualized such that the CV and SV both have direct effects on UV, while EnV and EcV have indirect effects on UV; therefore CV and SV act as mediating factors, playing an important role in promoting the generation of UV.

First, the factor of EcV consisting of four indicators (e.g., the per capita GDP and proportion of tertiary industry) is found to make the greatest contribution to facilitating the generation of UV indirectly, with the total effect of 0.909. It is noteworthy that EcV has also positively stimulated the SV and CV with path coefficients of 0.915 and 0.899, respectively, which indicates the SV and CV will be enhanced in a region where the economy is prosperous.

Second, SV is another crucial factor that directly exerts influence on UV with a path coefficient of 0.402. Urbanization, as a parameter for urban evaluation, is characterized by rapid urban sprawl and brings regional social development. In the literature, many scholars have verified that such indicators as the urbanization rate of the permanent resident population have driven the generation of UV [60,61].

Similarly, CV also exerts a direct effect on UV with a path coefficient of 0.402. Concerning this factor, many scholars have investigated the most tangible manifestation of cultural activities to measure UV, such as public cultural services including museums, libraries, and historical spots. Besides, a more highly skilled or educated population will also enhance CV and UV [57].

The last is EnV, which has a total effect of 0.444 on UV. As Figure 7 shows, the effect of EnV on UV can be divided into two approaches, namely that EnV has a positive effect on EcV with a path coefficient of 0.677, but more interestingly, a negative one on CV. This is possible because excessive population leads to a bad environment such as traffic jams, air pollution, etc., thus hindering social communication [26].

5.4. Key Factors Enhancing UV

In addition to the theoretical results about the GMUV discussed above, this segment will present the impetus for UV. As Table 8 shows, EnV and SV have the least effect on UV.

In practice, on the one hand, the connectivity of transportation and other infrastructure in the study area is not perfect, and the commuting efficiency between cities is low. On the other hand, the regional consumption structure in big cities is reasonable and diversified, and the resident consumption demand and consumption ability are vigorous as well. However, residents in small towns have low per capita income, weak purchasing power, and a monotonous consumption structure, which has little contribution to the generation of UV. Therefore, EnV and SV are the key factors for the improvement of UV, in which much room for improvement is left.

In the measurement model, the higher the indicator loading is, the higher the degree to which it can be explained by the latent variable. It thus indicates that the influence of the indicator on the variable is more significant. As shown in Table 2, under the EnV construct, the SIL of the road network density (EnV2) is the lowest, which means that the EnV2 of the study area is not perfect enough and traffic accessibility is bad. Similarly, under the EcV construct, the per capita GDP (EcV2) has the lowest value, which is 0.783. The average income level of people in this region is not high, making little contribution to EcV.

6. Discussion and Conclusions

6.1. Discussion

6.1.1. Limitations

In this paper, two limitations of the proposed model should be discussed and clarified. First, the research model was structured based on these hypotheses focusing more on actual circumstances in China, which thus leads to poor generalization of the results obtained. However, UV is actually influenced by different context, and so varies from place to place. While in this study, the results are more applicable to urban areas in developing countries such as Mexico, India, and Brazil. Moreover, the main purpose of this study is achieved by the demonstration of the potential of PLS-SEM. It also demonstrated that the models here can be easily adjusted, in terms of variables used as well as their relationship, thus opening a door to more areas, even in developed countries. Secondly, the collected data had a lag time due to the limited access to socio-economic statistical data. In this regard, with the development of information and communication technologies (ICTs), future studies should be conducted from a dynamic perspective through a combination with spatial and temporal big data to better apply the concept of UV in practice and so serve regional development.

6.1.2. Understanding UV through the GMUV

With the rapid development of big data, such as the NLD, and POI obtained from the empirical case, the authors have proposed a new insight into understanding UV through the GMUV. In this study, the GMUV has been analyzed from both micro enablers and macro manifestation. The UV enablers were defined as the internal engine to promote the GMUV with their interactions. To show these interactions, this study simplified the nexuses as influence paths using PLS-SEM from a structural perspective. The complex UV was divided into four types of vitality, i.e., EcV, EnV, SV, and CV. To connect the micro with macro level, 14 final indicators were identified to structure the four sub-types of UV (see Figure 7).

From the literature review, it can be seen that sufficient efforts have been dedicated to exploring UV in the context of quality of life, urban space expansion, and even urban development. In this segment, the authors presented an in-depth comparison between the GMUV in this study and that in the limited existing literature, to understand UV.

Similar to this paper, [2] employed big data (i.e., mobile phone location data) to explore the influence mechanism of the built environment on UV. In their work, density and proximity to public facilities were the most significant factors enhancing UV, which is slightly different from the results in this paper. This is because, in their work, the empirical case was the central area of Shanghai, one of the most developed urban areas in China.

To explore the spatial pattern and driving mechanism of UV, a conceptual framework has been proposed by [19], in which big data (e.g., internet sharing data and geospatial

data) and the GWR (geographically weighted regression) are integrated. Consistent with the GMUV in this paper, high environment quality, manifested by things such as high road density, has a strong effect on economic vitality. Furthermore, in their work, human-land interaction is also of importance for the GMUV, resonating with human activities in this paper. However, when applying spatial-temporal data, it is crucial to consider spatial and temporal sampling characteristics.

In the GMUV in this study, population distribution is the premise of generation of UV, which is in line with results from [50]. They also found that excessive population may suppress the creation of UV. However, different from this paper, they did not identify the influence path of UV. In addition, [20] and [80] have drawn conclusions on the GMUV that are similar to this paper.

Therefore, the discussion above shows that classic theories about UV (see Section 2.1), still exert their effects in this domain of UV, although slight adjustments are needed when applying them. As can also be seen, ICTs and big data used for the GMUV will continue to be more promising. Nevertheless, the highly consistent results of the GMUV both in this paper and the literature has validated the applicability of PLS-SEM in this domain.

6.1.3. Suggestions for the Development of the Study Area

Based on the GMUV, this study thus puts forward the following suggestions to improve the vitality of the study area.

To begin with, relevant suggestions regarding the EnV have been given. From the physical environment, the road density contributes greatly to the EnV, and further to UV. High road density indicates a good accessibility to public space, which is conducive to gatherings of people and promoting EcV and SV [19]. The study area (200,000 km²) covers 140 districts and counties, among which most of them have low road density which has limited the communication between people, capital, and information. Furthermore, transportation between different districts or counties is still underdeveloped, which further hinders the improvement of the vitality of the region. Thus, more efforts should be invested to transportation infrastructure providing more opportunities for people to access public service facilities.

With regard to economy-society interaction, the positive correlation between EcV and SV is significant (see Figure 7). The areas with high UV have been characterized by sufficient job opportunities and affordable consumption [19]. This implies high employment rate and strong business enthusiasm. Despite this, high consumption and life cost have made many people in the city suffer from a pressure to live, especially in big cities such as Chengdu and Chongqing, which may have an adverse influence on population inflow. Therefore, policies to control price rise and to create more jobs are effective.

In the GMUV (see Figure 7), CV, which refers to science and technology innovation, as well as public culture facilities [26,80], exerts a positive effect on UV. As [80] found, culture is the foundation of making cities more attractive and can be catalysts in reproducing UV. In reality, Chengdu and Chongqing have, for a long time, constantly shared traditional culture. Most importantly, with the construction of CCATEC, this study area will be turned into a highland of technology innovation in western China. To this end, providing more cultural services including educational resources should be considered by policymakers.

6.2. Conclusions

Urban administrators often encounter issues produced by urbanization and have used the concept of UV to tackle them. However, there are still difficulties in the process of problem solving due to the lack of an in-depth understanding of the GMUV. In this study, the GMUV has been analyzed based on the PLS-SEM in CCATEC, China, by combining NLD, POI, and statistical data. At the theory level, the results demonstrate that (1) SV and CV have a directly positive influence on UV, while EnV and EcV indirectly influence UV via SV and CV, that is, SV and CV play mediating roles in generating UV; (2) EnV has an insignificant influence on the CV; (3) EnV and SV provide the strongest impetus for UV.

In practice, three suggestions are proposed to policymakers for improving UV, including more efforts to improve transportation infrastructure construction and provide more job opportunities, etc.

Additionally, the results are consistent with the status quo of the practical development of the study area, which shows the validity of the proposed theoretical framework and even the approach used in this study. Although this paper focuses more on China, this model is open to any reasonable adjustments for generalization. The main achievements are as follows:

- The present study provides a new insight into understanding UV through the exploration of the GMUV based on a PLS-SEM approach, and further conceptualizes the GMUV using a visualized path diagram, which has enriched the methods of UV evaluation.
- Through SEM path analysis, the GMUV, along with key factors enhancing vitality, has provided a reference for urban administrators to formulate policies when utilizing the concept of vitality to solve urban issues.

The GMUV not only gives academia and governments a deep understanding of UV, but also can serve as a reference for evaluating vitality in other areas. Furthermore, based on the results of this paper, it may be valuable to incorporate danger elements to UV in future research on UV.

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