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A Derivation of Factors Influencing the Innovation Diffusion of the OpenStreetMap in STEM Education

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Received: 6 July 2018; Accepted: 21 September 2018; Published: 27 September 2018

Abstract: Geographic information is a confluence of knowledge from spatial science, information technologies, engineering, and mathematics, etc. Effective spatial training can enhance achievement in science, technology, engineering, and mathematics (STEM) education. Therefore, the geographic information system (GIS) plays a daily role in modern STEM education. Volunteered Geographical Information (VGI) is characterized by the openness of the geographic information being generated and accumulated by volunteers. Within the VGI sphere, OpenStreetMap (OSM) is one of the most well-known VGI due to its openness, flexibility, cost-effectiveness, and web-based mapping capability, making it one of the best alternatives for use as the mapping application for STEM education. However, very few or no prior works have investigated the factors influencing the innovation diffusion of OSM in STEM education. Therefore, to fill this gap, this work aims to investigate these factors. To achieve this purpose, the authors have defined an analytic framework based on innovation diffusion theory (IDT) and the technology acceptance model (TAM). The factors influencing students' acceptance and intention to continue using and diffusing OSM in STEM education will be investigated. Partial least squares structural equation modeling (PLS-SEM) was used to confirm the hypothesized IDT–TAM integrated model. An empirical study based on sample data collected from 145 Taiwanese undergraduate and graduate students from engineering-related institutes was used to demonstrate the feasibility of the proposed analytic framework and to derive the factors related to the adoption and diffusion of OSM in STEM education. The proposed theoretical framework forged in this study was proven to be successful. Based on the empirical study results, ease of use, observability, and compatibility are the most influential factors in OSM diffusion. Therefore, activities that enhance the ease of use, observability, and compatibility of OSM should be emphasized so that STEM students' perception of the usefulness of the technology and their perceived attitude towards it leads to the intention to continue the use of OSM. The analytic results can serve as a foundation for the design, development, and accelerated adoption and diffusion of OSM in STEM education.

Keywords: science; technology; Engineering and Mathematics Education (STEM); OpenStreetMap (OSM); Volunteered Geographical Information (VGI); Innovation Diffusion Theory (IDT); Technology Acceptance Model (TAM); Partial Least Squares Structural Equation Modeling (PLS-SEM)

1. Introduction

A geographic information system (GIS) is a computer system designed to collect, store, retrieve, manipulate, and display spatial data [1]. Traditionally, geographic information has come from national mapping agencies of governments or recognized professional producers in commercial firms. However, due to government institutes' or private firms' extraordinarily high costs of drawing and calibrating maps, such geographic information is not affordable for most educational institutes. The Volunteered Geographical Information (VGI) [2–4] initiatives that have emerged during the past decade are becoming a better alternative for education purposes in general and for STEM education in particular [5–7].

GIS consists of massive computer software packages with a user interface that provides a range of functions for creating, acquiring, integrating, transforming, visualizing, analyzing, modeling, and archiving information about the surface and near-surface of the earth [8,9]. The nature of GIS revolutionized the methods and dimensions of spatial analysis and resulted in a change in the direction of geography while becoming a major component in other disciplines with a spatial component (biology, political science, urban planning, geology, sociology, etc.) [10]. Therefore, previous research has suggested that academic cooperation among multiple disciplines is an effective strategy for developing GIS based education programs [11]. The emergence of STEM is mainly due to the fact that problems encountered in real life cannot be restricted to one specific discipline [12]. Effective spatial training will improve STEM achievement [13]. Examples of spatial reasoning across STEM disciplines include chemistry, astronomy, physics, computer science, and mechanical engineering [14]. Thus, GIS technology can engage several critical elements in STEM curriculum and instruction due to the characteristics of GIS tools and systems, which can prompt an understanding of cross-disciplinary phenomena and solve issues identified in scholastic and real-world ideas [15]. As a result, GIS has become a vital application in interdisciplinary STEM education [15,16].

VGI is the geographical information being generated and provided by users. Typical examples of the VGI include WikiMapia, OpenStreetMap (OSM), Tracks4Africa, and Yandex. VGI volunteers and users come from virtual social communities that share the geographic information with the public. VGI is shared on public websites or as third-party data being overlaid on virtual globes, such as Google Earth [17]. VGI provides flexible and cost-effective alternative geographical information for educational institutes and users with very limited or no budget for purchasing expensive commercial and authoritative geographic information. OSM, one of the most well-known VGIs, provides geographic information in the Wikipedia style [18]. OSM has attracted more than 4.2 million registered users (as of September 2017) [19]. Meanwhile, the geographic information on OSM has been licensed to various mobile application ("app") development companies. The apps being developed based on VGI have become widely distributed. For example, the "Maps.me" [20,21] app based on VGI by OSM has been adopted by more than 100 million users [21].

Although OSM has attracted a large population of registered users, existing research related to OSM has focused mainly on the quality of the geographic information being provided by the participants and the possible applications of such geographic information [3,22–28]. Very few studies have examined the status of students' acceptance of OSM or its use and diffusion. However, OSM has comparative advantages to other mapping applications in various aspects: the collaborative-creation and edition feature, better granularity, and time-enabled map layers [27]. These features are especially important for STEM students in urban design, civic and environmental engineering, geography, sustainability, visual communication design, and other related disciplines. In geography and urban design, students can compare historic landscapes and street maps by using OSM. Sustainable development is the balance of meeting humankind's present needs while protecting the environment to ensure the fulfillment of future generations' needs. The time-variant nature of landscape changes enables STEM students to investigate these topics further and discuss the implications. Hence, this research is focused on OSM in the STEM educational realm. Moreover, OSM is an excellent learning tool for thinking spatially. According to the National Research Council's Learning to Think Spatially [29], spatial thinking combines space representations (like a computer modeling program or a physical manipulative) and cognitive processes for reasoning. Spatial thinking is critical for helping students learn STEM content and find early success in STEM careers [13]. Thus, OSM is a very suitable tool. Although OSM is critical for STEM learning, it has not been widely diffused to educational institutes in general, and STEM education in particular. Thus, an investigation on the factors influencing the acceptance and diffusion of OSM in STEM is a critical issue for OSM promoters and worth further investigation.

This study aims to determine the factors that influence STEM students' acceptance as well as initial and continued usages of OSM. First, an analytic framework based on Rogers' innovation diffusion theory (IDT) [30] and Davis' technology acceptance model (TAM) [31] was proposed. IDT and TAM have been integrated by many researchers. The IDT–TAM integrated model has been adopted by various researchers to analyze the adoption behaviors of users of a new technology [32–35]. To the best of the authors' knowledge, the IDT–TAM integrated model has not been used to investigate the application of OSM in STEM education. However, the topic is so important, as Baker mentioned [36]. Thus, such an analysis is worthwhile. The hypothesized IDT–TAM integrated theoretical framework was confirmed by using the partial least squares (PLS) [37,38] structural equation modeling (PLS-SEM) [39]. In this study, students from northern and southern Taiwan, as potential OSM users, were recruited to provide the data for research. The online Chinese questionnaire was distributed to students after a section of an OSM course led by an active OSM contributor. Students answered the questionnaire right after the OSM course. All of the respondents were undergraduate students except for two graduate students taking the undergraduate course, and they were majoring in civil engineering and visual communication design. An empirical study based on sample data collected from 145 Taiwanese undergraduate and graduate students in engineering-related institutes was used to demonstrate the feasibility of the proposed analytic framework and derive the factors related to the diffusions and adoptions of OSM in STEM education. The proposed theoretical framework was proven successfully. Thus, based on the empirical study results, observability, perceived usefulness, and perceived attitude are the most influential factors influencing the diffusion of OSM. In addition, the activities that can enhance the observability of OSM should be emphasized so that the perceived usefulness and thus, the intention of continued usage for students can be greatly enhanced. The theoretical framework and analytic results can serve as a basis for future research on STEM learners' behaviors related to their acceptance and diffusion of OSM in STEM education.

The remainder of this paper is organized as follows. In Section 2, a literature review deals with the concepts and theoretical background of this paper: GIS and STEM education, Openness and STEM, OSM, the two theories related to users' acceptance of technology innovations (i.e., IDT and TAM), and the IDT–TAM integrated model. An analytic framework with research hypotheses is proposed based on IDT and TAM reviews. Section 3 introduces the PLS-SEM-based research method. To illustrate how the proposed approach works, an empirical study to confirm the hypothesized theoretical framework is conducted in Section 4. The major factors correlated to the use and diffusion of OSM are derived. Our discussion of the results and suggestions for future research is presented in Section 5. Section 6 presents our conclusions.

2. Literature Review

OSM's major characteristic is its absolute openness to everyone. OSM is not dependent on any government, company, university or international organization [40]. Consequently, OSM is successful because of the combination of both this openness and its web mapping [22]. To provide an overview of OSM in the field of STEM education, a literature review of GIS, openness, and their relationships with STEM education will first be presented. Second, the literature related to OSM, a novel model of a web mapping platform based on VGI, will be reviewed, thereby identifying research gaps related to OSM in STEM education. Furthermore, two theories, IDT, and TAM, will be introduced and reviewed. Finally, an analytic framework based on IDT and TAM will be proposed based on the results of our literature review.

2.1. GIS and STEM Education

GIS technology can engage several critical elements in STEM curriculum and instruction due to the characteristics of GIS tools and systems, which can promote the understanding of cross-disciplinary phenomena and solutions to issues established in scholastic and real-world ideas [15]. From a curricular perspective, GIS allows us to study climate change, design cities, inventory geologic samples, plan ecological growth models, catalog contents of an archaeological site, and engage in countless other activities [15]. A combination of the global positioning systems (GPS) and GIS technologies provides a powerful set of learning tools for collecting, analyzing, and interpreting spatial information [41]. Instructionally, GIS has a significant potential to be easily integrated into problem-based learning (PBL) [42]. As one of the powerful technological tools in schools, GIS is used in combination with PBL to produce, store, display, manipulate, and analyze data on computers [42]. Thus, GIS-based PBL may help improve geographical content knowledge as different phenomena can be approached with GIS from the map-layer point of view [43]. In general, teaching with GIS provides the opportunity for issues-based, student-centered, standards-based, inquiry-oriented education [44]. Past research has shown that GIS can be used to teach project-based science, environmental education, and geography concepts to middle school students [45]. For example, given the nature of STEM problem solving, STEM students' descriptions of how land masses move over centuries ostensibly rests on how capable they are involving GIS abilities [14]. Research also suggests that the use of GIS helps students develop analytic and problem-solving skills [46]. GIS empowers students to use computers as a professional tool in order to solve problems independently. Students must select the appropriate data layers, analyze the data and develop technology assisted solutions for real-life problems related to the STEM disciplines [46]. Using GIS in STEM education benefits students from the aspects of knowledge, perception, skills, and the science-technology-society environment [16].

2.2. Openness and STEM Education

Openness is an overarching concept or philosophy characterized by an emphasis on transparency and free, unrestricted access to knowledge and information, as well as the collaborative or cooperative opposite of secrecy [47]. The developments in information and communication technology enabled learning offer increasing relevance of openness and education [48]. The benefits of openness for STEM education are significant [49] because many STEM institutions have to invest large amounts to provide students with up-to-date learning materials, associated platforms, and practices to fulfill the market's human resource needs. STEM academies may use the open system as an appropriate replacement for commercial, proprietary operating system to reduce the information technology costs inherent in STEM education. Teachers can develop open education content or education tools by themselves at very low or no costs. Students can learn at home by using such open-source technology with no license fee(s).

Openness in STEM education not only results in the ability to share information openly and freely, but also provides all users with licenses to reuse and distribute such resources [50]. Being able to reuse and distribute resources is the most important feature of openness because it allows for more derived materials to be created and distributed. Thus, participants can collaborate with each other to develop and improve their teaching materials without being restricted by the license issue [50]. For example, the crowdsourcing of online education resources actually contributes to openness in STEM education [51]. Participants throughout the STEM community can benefit each other with this openness.

Moreover, experiencing openness is an important educational value as freedom is the best way of encouraging curiosity and experimentation [52]. The advantages of openness have led to education being combined with do-it-yourself (DIY) or do-it-together approaches in different learning areas, such as computer science [53–55], biology [56], and industrial design engineering [57]. Such combinations in education have benefited students in the following ways: (1) the cost spent on hardware and software is normally lower than the proprietary solution; (2) if a student wants to know the details or improve mechanisms that teachers have taught (e.g., source codes of a computer program), openness makes this work; (3) teachers and students can pass open creations (e.g., software or artistic creations) to each other freely under an open license; and (4) DIY education makes students learn in solid work, as students not only know the theory, but also learn how to create a solid object [52].

2.3. OpenStreetMap

Internet users began interacting with each other via the network, contributing massive amounts of data, around the end of the 20th century. This phenomenon is described as Web 2.0 [58]. User-generated contents have made up a majority of the Internet [59,60]. Wikipedia, YouTube, and Facebook are typical examples of websites providing user-generated contents. In past decades, information and communication technologies have changed GIS drastically. GPS, remote sensing, wireless, and communications moved to the client-server architecture on PCs, tablets, and even cell phones have already been integrating user-generated contents into GIS, freeing GIS users from the slow, laborious technical problems associated with handling data. Thus, GIS is available to broader audiences, including volunteers [61]. VGI systems, in which geographic data are created, assembled, and disseminated by volunteers, emerged during the past decade. The geographic information from VGI can be easily generated and uploaded to the VGI repository via apps or web mapping platforms because of the wide adoption of computers and mobile devices and apps.

Typical examples of VGI systems include OSM, Eye on Earth, Geowiki [62], Here Map Creator [63], Map Maker [64], Map Share [65], Wikimapia [66], and Waze [67]. Among them, OSM, which was founded by Steve Coast at University College London in 2004 [68,69], is the most significant example of a VGI system because it attracts millions of users to VGI [28]. The OSM project is unique and attractive due to the free and rich geographic information. The VGI is authorized by the Open Data Commons Open Database License (ODbL); the ODbL allows users to freely copy, distribute, transmit, and adapt the geographic information downloaded from OSM [70]. Meanwhile, the massive geographic information system is provided to more than 4.2 million registered users—another strength that cannot be easily superseded by other VGIs with many fewer users.

2.4. Innovation Diffusion Theory

Innovation diffusion theory, proposed by Rogers, is “the process by which an innovation is communicated through certain channels over time among the members of a social system” [30]. It includes four main elements related to diffusion: innovation, communication channels, time, and the social system [30]. Rogers further indicated that the diffusion of innovation is affected by five characteristics: (1) relative advantage: the degree to which an innovation is perceived as better than the idea it supersedes; (2) compatibility: the degree to which an innovation is perceived as being consistent with the existing values, past experience, and needs of potential adopters; (3) complexity: the degree to which an innovation is perceived as difficult to understand and use; (4) trialability: the degree to which an innovation may be experimented with on a limited basis; and (5) observability: the degree to which the results of an innovation are visible to others [30].The five characteristics of IDT explain the end-user’s decision-making process concerning the use of innovations. In general, IDT can be used to explain why “potential users make decisions to adopt or reject an innovation based on beliefs that they form about the innovation” [71].

IDT has been used in various areas to predict how and why an innovation will succeed, including education [33,72,73], communication [74], marketing [75,76], and information technology [77,78]. IDT has also been widely adopted in examining the diffusion of open innovation in several disciplines, which includes crowdsourcing [79,80] and open-source software [81,82].

Because IDT can serve as a comprehensive conceptual framework to understand the diffusion of innovation, many scholars have combined IDT with other theoretical models to conduct empirical tests. For example, Wang et al. used IDT and the transaction cost theory to identify the factors that affected users’ adoption behavior of an online automated teller machine (ATM) [77]. Yang et al. [78] used the technology-organization-environment framework to analyze the adoption of cloud computing software-as-a-service from the perspective of organizational users. Shiau and Chau proposed a united model to analyze the behavioral intention to use a cloud classroom [33]. Six well-known theories—service quality, self-efficacy, the motivational model, technology acceptance model, the theory of reasoned action (also known as the theory of planned behavior), and IDT—were tested, compared, and unified in Shiau and Chau's work, where the six theoretical models and the united model exhibited adequate explanatory power for behavioral intention to use the cloud classroom.

2.5. Technology Acceptance Model

Some researchers (e.g., Nelson et al. [83]) have explained the adoption of open-source software using existing theories of software adoption, such as TAM. Davis proposed TAM in 1989. It includes two specific variables, perceived usefulness and perceived ease of use, that determine end-users' acceptance of technology [31]. The attitude about using a particular system consists of these two determinants, and this attitude determines the intention to use and then form the final actual usage behavior. "Perceived usefulness" is defined as the extent to which users believe using this particular system will enhance their job performance whereas "perceived ease of use" refers to the extent to which users believe that using a particular system would require little effort [31].

TAM has been used extensively by many researchers to study the acceptance of new technology. For example, Venkatesh and Morris investigated gender differences introduced in new software systems using TAM [84]. Lu et al. developed a TAM framework for analyzing factors being related to the adoption of Internet via mobile devices; their TAM was extended to theoretical frameworks with more external factors, including technological complexity, wireless trust environment, individual differences, facilitating conditions, and social influences [85]. TAM has also been integrated with other theories, such as IDT or theory of planned behavior [86], in studies of users' acceptance. For example, Agag and El-Masry [76] integrated IDT and TAM to examine customers' intentions to participate in the online travel community.

2.6. The Integration of TAM and IDT

Some researchers argued that the constructs being employed in the TAM are fundamentally a subset of the IDT; the integration of both models can provide an even stronger model than either standing alone [34,72,75]. Because strong similarities and complementariness exist between the constructs of IDT and TAM, researchers proposed the IDT–TAM integrated models so that the advantages of both theoretical models can be leveraged when studying the innovation adoption process.

The IDT–TAM integrated model has been applied in numerous fields regarding the adoption of innovation. Typical examples include the interpretation of the IT adoption behavior of individual Chinese users [35], the derivation of factors influencing business employees' behavioral intentions toward the e-learning system [72], the investigation of Thailand's small and medium enterprises' intention to use e-Marketing [87], the derivation of the factors influencing the adoption of haptic enabling technology based products [88], and the study about the factors influencing the intention to use mobile banking services in Yemen [89]. These studies are typical examples that have derived satisfactory results by using the IDT–TAM integrated model.

2.7. Research Hypotheses

Based on the literature review presented thus far, a hybrid model based on the IDT–TAM integrated framework was proposed in order to take advantage of both models. In this work, the acceptance and diffusion of OSM were proposed to be influenced by seven determinant constructs belonging to the IDT–TAM integrated framework. In addition to the relative advantage, compatibility, complexity, trialability, and observability being proposed in the IDT–TAM integrated framework, two dimensions—perceived usefulness and perceived attitude—were further added. The influence of the determinants on the acceptance of OSMs will be derived based on the opinions provided by students after taking a class of OSM. We proposed the following hypotheses and tested them by using PLS-SEM, which is suitable for models when the sample sizes are small, data are not normally distributed, or complex models have many indicators and model relationships [90]. In the design of questionnaire, the complexity determinant was replaced with the ease of use dimension according to Venkatesh and Davis' study [91]. This is often used when IDT and TAM are integrated so that the questionnaire can be simplified, as demonstrated by previous research [87,88,90,92,93].

The relative advantage is the degree to which an item is superior to another item. In Yu's work, which investigated the factors influencing consumers' attitudes to transfer from online to mobile banking, the perceived relative advantage was asserted to influence relative attitudes of individuals [94]. The same results were derived in a later work conducted by Ayo, Oni, Adewoye, and Eweoya, who demonstrated that the relative advantage of using e-banking significantly influences customer attitudes toward using the technology [95]. Therefore, we developed the following hypothesis:

Hypothesis H1: *Relative advantage is positively related to perceived attitude toward using OSM.*

Schierz, Schilke, and Wirtz's work on the acceptance of mobile payment services demonstrated that compatibility has a positive relationship with perceived usefulness [96]. Plewa, Troshani, Francis, and Rampersad also found that compatibility positively influences perceived usefulness while investigating the adoption of innovation management applications [97]. Accordingly, we developed the following hypothesis:

Hypothesis H2: *Compatibility is positively related to perceived usefulness.*

Putzer and Park found that compatibility had a strong relationship to the attitude toward using a smartphone [98]. Schierz et al. also confirmed that a positive relationship exists between the compatibility of mobile payment services and the attitude toward using mobile payment services [96]. Oh and Yoon concluded that compatibility had a significant influence on the perceived usefulness when examining the factors affecting the adoption of haptic enabling technology based products [88]. Thus, we developed the following hypothesis in order to investigate the influence of compatibility and perceived attitude on OSM users:

Hypothesis H3: *Compatibility is positively related to perceived attitude toward using OSM.*

Earlier studies have been conducted to derive the relationship between ease of use and perceived usefulness. For example, Kanchanatanee et al. asserted that the perceived ease of use affected perceived usefulness when investigating the use of e-Marketing of small and medium sized business owners in the three southern border provinces (Yala, Pattani and Narathiwas) of Thailand [87]. Amin, Rezaei, and Abolghasemi found that perceived ease of use has a positive relationship with perceived usefulness related to user satisfaction with mobile websites [99]. Alalwan, Dwivedi, Rana, and Williams concluded that perceived ease of use positively influences perceived usefulness when using mobile banking in Jordan [100]. Thus, we proposed the following hypothesis:

Hypothesis H4: *Ease of use is positively related to perceived usefulness.*

Mehta asserted that complexity (hence ease of use) has a significant effect on attitude toward the use of free Wi-Fi [101]. Ease of use was also found to have a significant influence on perceived usefulness by Oh and Yoon when considering the factors affecting the adoption of haptic enabling technology based products [88]. Gyamfi concluded that an individual student teacher's perceived ease of use has a positive effect on his or her attitude toward the use of Web 2.0 technologies in

Ghana [102]. Thus, in order to investigate the influences of ease of use and perceived attitude on OSM users, we developed the following hypothesis:

Hypothesis H5: *Ease of use is positively related to perceived attitude toward using OSM.*

Studies of the correlations between trialability and perceived attitude have been conducted in different fields. Md Nor, Pearson, and Ahmad concluded that trialability of Internet banking has a significant positive effect on the attitude toward using the technology [103]. X. Wang, Yuen, Wong, and Teo found that consumers' perceived trialability of automated parcel station is positively related to their attitude toward the initial adoption of automated parcel station [104]. Therefore, in order to investigate the relationship between trialability and perceived attitude for OSM users, we developed the following hypothesis:

Hypothesis H6: *Trialability is positively related to perceived attitude toward using OSM.*

Observability is defined as the degree to which the results of an innovation are visible [30]. Lee et al. investigated the relationship between observability and perceived usefulness concerning supporting employees' intentions to use e-learning systems [72]. They also found that observability had no significant effect on perceived usefulness, which was inconsistent with prior studies. Thus, in order to investigate the relationship between observability and perceived usefulness for OSM users, we proposed the following hypothesis:

Hypothesis H7: *Observability is positively related to perceived usefulness.*

Lee et al. proposed that observability had a positive effect on perceived usefulness of an e-learning system [72]. When the users perceived the systems to be easier to observe or describe, they tended to perceive the systems as more useful and easier to use. In addition, Ajjan Hartshorne, Cao, and Rodriguez regarded "perceived usefulness" as being positively associated with personal attitude to use enterprise instant messaging [105]. Therefore, we developed the following hypothesis:

Hypothesis H8: *Perceived usefulness is positively related to perceived attitude toward using OSM.*

Previous works have studied the relationships between perceived usefulness and the intention of continued usage. Islam et al. confirmed that attitudes toward usages play a moderating role between perceived usefulness and complexity as well as the intention to use advanced mobile phone services [106]. Sheng et al. also affirmed that perceived usefulness is the most influential factor concerning the intention to adopt a new technology [107]. Accordingly, we proposed the following hypothesis:

Hypothesis H9: *Perceived usefulness is positively related to the intention of continued usage.*

Past works have also tried to derive the relationships between perceived attitude and the intention of continued usage. Plewa et al. [97] asserted that attitude towards the technology showed a significant positive association with the intention to use the innovation management applications. Ho asserted that attitude significantly and positively affected continuance intention on the e-learning platform [108]. Thus, we developed the following hypothesis:

Hypothesis H10: *Perceived attitude toward using OSM is positively related to the intention of continued usage.*

The proposed research model is presented in Figure 1.

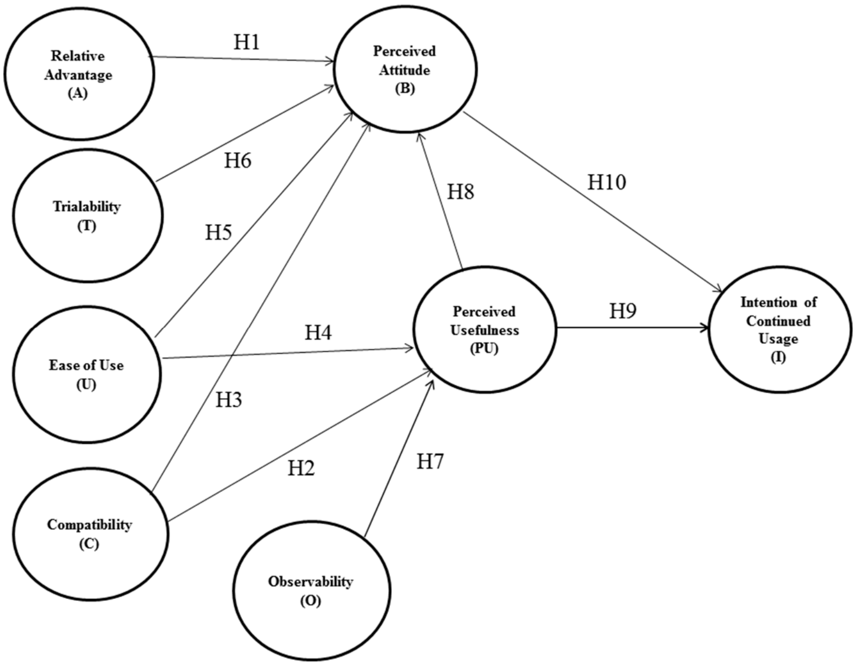

Figure 1. The proposed research model.

3. Research Method

To verify the correlation relationships derived based on the theoretical framework proposed in Section 2.7, the relationships are confirmed utilizing the path model by the PLS-SEM approach based on the mass users of OSM from a university. The statistical significance of the hypothesis testing results confirms the relationships being proposed.

3.1. PLS-SEM

Testing of the proposed model and hypotheses was conducted using the PLS method. Like other Structural Equation Modeling (SEM) techniques, such as linear structural relations (LISREL) [109] and EQS [110], the PLS approach allows researchers to simultaneously assess the parameters of the measurement model and the coefficients of the structural path [111]. Covariance-based SEM techniques, such as LISREL and EQS, use a maximum likelihood function to obtain estimators in models, but component-based PLS uses a least-squares estimation procedure [111]. PLS avoids many restrictive assumptions that underlie covariance-based SEM techniques, such as multivariate normality and large sample size [112,113]. PLS-SEM was used as the research method because the sample size may be comparatively smaller and non-normally distributed.

3.2. Sample and Measures

Based on the proposed hypotheses, a web-based survey questionnaire was developed and used to collect the data required to test the research model. Most constructs in the research model were measured using items adapted from TAM and IDT research. All questionnaire items used a 5-point Likert-type scale, where 0 = completely disagree and 5 = completely agree. A focus group study was employed to ensure that the items were used appropriately in the context of the study. A questionnaire adapted from previous studies [32,93,114–120] was used in this study (see Table 1). The abbreviations for latent variables are also defined in Table 1.

Table 1. Questionnaire of Acceptances and Uses of OSM.

Latent Variables (LV)	Item Code	Descriptions	Source
Relative Advantage (A)	a_1	OSM is free of charge and lets me use GIS in work or life at a low cost	Revised from Premkumar and Roberts [114], Moon and Kim [115], Lee [116], Liu and Li [119]
	a_2	The scale/granularity of OSM provides diverse services to meet different kinds of needs	
	a_3	OSM is good and suitable for extensive use of GIS	
	a_4	The visualization techniques and symbolization of OSM lets me communicate with others easily	
	a_5	OSM lets me finish a job more quickly	
	a_6	OSM can increase my efficiency in work	
Compatibility (C)	c_1	OSM is compatible with other systems/services I am using and consistent with my habits	Revised from Park and Chen [117], Lee [116], Liu and Li [119], Giovanis et al. [32]
	c_2	OSM is interoperable with other formats of GIS, so it's spatial reference system can be integrated into geographic information applications	
	c_3	The dynamic data can be combined with OSM map layer to show a real-time map, and it can be published on a website	
Ease of Use (U)	u_1	OSM meets my own values	Revised from Moon and Kim [115], Park and Chen [117], Lee [116], Liu and Li [119]
	u_2	OSM is very consistent with my working model	
	u_3	OSM is very consistent with needs in work	
	u_4	I believe OSM data are guaranteed	
	u_5	I can use OSM system service anytime, anywhere	
	u_6	I believe OSM is easy to use	
	u_7	I can understand the functions of OSM and think it is not complex when using it, such as the procedures to contribute the data	
	u_8	It is easy for me to find the usage info or material of OSM	
Trialability (T)	t_1	I can try any kind of function before using OSM officially	Revised from Park and Chen [117], Malek [118], Shih [120]
	t_2	I know how to try it out before using OSM officially	
	t_3	I can quit it if I am not satisfied after trying OSM	
	t_4	I can try the technology provided by the OSM vendor to evaluate if it meets my needs in work or research	
	t_5	The OSM technology I am using has accumulated some good testing results	
Observability (O)	o_1	I have seen people around me using OSM	Revised from Park and Chen [117], Liu and Li [119], Shih [120]
	o_2	It's easy for me to find others sharing and discussing the usage of OSM	
	o_3	I can easily feel that OSM could bring me some benefits	
	o_4	I have seen my coworkers or friends using OSM	
	o_5	I have seen the demonstrations and applications of OSM	
Perceived Attitude (PA)	pa_1	Overall, I believe it's a good idea to adopt OSM	Revised from Moon and Kim [115], Lee [116], Park and Chen [117]
	pa_2	Overall, I am positive about adopting OSM	
	pa_3	Overall, I support adopting OSM	
	pa_4	I believe it's very good to use OSM in work	
	pa_5	I like the OSM technology	
Perceived Usefulness (PU)	pu_1	I can describe the possible benefits of using OSM in work or life	Revised from Premkumar and Roberts [114], Moon and Kim [115], Park and Chen [117], Tung et al. [93]
	pu_2	I believe OSM makes work or life more efficient	
	pu_3	I believe OSM can cut costs in work or life	
	pu_4	I believe OSM is helpful in work or life	
Intention of Continued Usage (I)	i_1	I believe OSM can make people use VGI more frequently	Revised from Moon and Kim [115], Lee [116], Liu and Li [119]
	i_2	I believe OSM makes me more willing to use VGI	
	i_3	I will adopt OSM as the tool for constructing VGI	
	i_4	I will increase the frequency of OSM use	
	i_5	I will do more to understand the functions and user interface of OSM	
	i_6	I will highly recommended OSM to others	
	i_7	I look forward to using OSM to meet the needs of work or life in the future	

The online Chinese questionnaire was distributed to 160 students after a section of an OSM course led by an active OSM contributor. The OSM training course first introduced OSM functions and procedures such as thematic layers, tags, the spatial reference system, visualization techniques and symbolization, data downloads, and granularity. Second, an OSM hands-on course enabled students to use computers to learn how to contribute the data to OSM via a web mapping platform. Students answered the questionnaire right after the OSM training course. From the 160 questionnaires collected, 145 valid responses were received, of which 43.4% were males and 56.6% were females, 29.7% were majoring in civil engineering, and 70.3% were majoring in visual communication design. The age of the majority of the respondents (97.2%) ranged from 18 to 22. Most respondents (98.6%) were undergraduate students, and only two were graduate students. Table 2 summarizes the respondents' descriptive statistics.

Table 2. Profile of respondents.

Profile Category	Frequency	Percentage (%)
Gender		
Female (left 0.3 cm)	82	56.6
Male	63	43.4
Age (years)		
<17	1	0.7
18–22	141	97.2
23–26	3	2.1
Education		
Graduate	2	1.4
Undergraduate.	143	98.6
Others	0	0
Major		
Civil engineering	43	29.7
Visual communication design	102	70.3
Use OSM time (years)		
1–3	1	0.7
<1	144	99.3
OSM use frequency		
A few times in a week	31	21.4
Seldom use	114	78.6

This sample size satisfies both the guidelines as suggested by the '10-times rule' and the guideline being suggested by Hair Jr. et al. [121]. One of the most popular rule of thumb in estimating the minimum acceptable sample size of the PLS-SEM method is the '10-times rule'. According to this rule, the sample size should be greater than 10 times the maximum number of inner or outer model links pointing in the model [111]. Further, according to a recent work by Hair Jr. et al. [121], the sample size of the PLS-SEM method is determined by the often-cited 10 times rule, which indicates that the sample size should be equal to the larger of: (a) 10 times the largest number of formative indicators used to measure a single construct, or (b) 10 times the largest number of structural paths directed at a particular construct in the structural model. Since the total number of formative indicators is five and the largest number of structural paths directed at a particular construct in the structural model is also five, the minimum same size should be 50. Moreover, based on the guidelines being suggested by Hair Jr. et al. [121], 70 observations to achieve a statistical power of 80% for detecting R-square values of at least 0.25 (with a 5% probability of error). Therefore, 145 valid responses are sufficient.

4. Results

Before PLS-SEM was introduced to confirm the hypothetical framework, the distribution of the collected data sample was tested and shown in Appendix A. Based on the analytic findings shown in Appendix A and Figure 2, the 10 hypotheses were tested with the following results. H1 examined the effects of relative advantage (A) on perceived attitude (PA). Relative advantage (A) had a highly significant effect on perceived attitude (PA) ($\beta = 0.271$, $p < 0.01$). Next, H2 examined the effects of compatibility (C) on perceived usefulness (PU). Compatibility (C) was shown to have a significant effect on perceived usefulness (PU) ($\beta = 0.265$, $p < 0.05$). H3 examined the effects of compatibility (C) on perceived attitude (PA). Compatibility (C) did not have a significant effect on perceived attitude (PA) ($\beta = -0.056$, $p > 0.05$). H4 examined the effects of ease of use (U) on perceived usefulness (PU). Ease of use (U) had a significant effect on perceived usefulness (PU) ($\beta = 0.267$, $p < 0.05$). H5 examined the effects of ease of use (U) on perceived attitude (PA). Ease of use (U) showed a significant effect on perceived attitude (PA) ($\beta = 0.314$, $p < 0.05$). H6 examined the effects of trialability (T) on perceived attitude (PA). Trialability (T) had no significant effect on perceived attitude (PA) ($\beta = 0.111$, $p > 0.05$). H7 examined the effects of observability (O) on perceived usefulness (PU). Observability (O) demonstrated a statistically very highly significant effect on perceived usefulness (PU) ($\beta = 0.376$, $p < 0.001$). H8 examined the effects of perceived usefulness (PU) on perceived attitude (PA). Perceived usefulness (PU) had a significant effect on perceived attitude (PA) ($\beta = 0.301$, $p < 0.01$). H9 examined the effects of perceived usefulness (PU) on intention of continued usage (I). Perceived usefulness (PU) showed a statistically very highly significant effect on intention of continued usage (I) ($\beta = 0.586$, $p < 0.001$). Finally, H10 examined the effects of perceived attitude (PA) on intention of continued usage (I), and the results showed that perceived attitude (PA) had a statistically very highly significant effect on the intention of continued usage (I) ($\beta = 0.374$, $p < 0.001$). Therefore, all hypotheses except H3 and H6 were supported. The hypothesis test results are presented in Table 3.

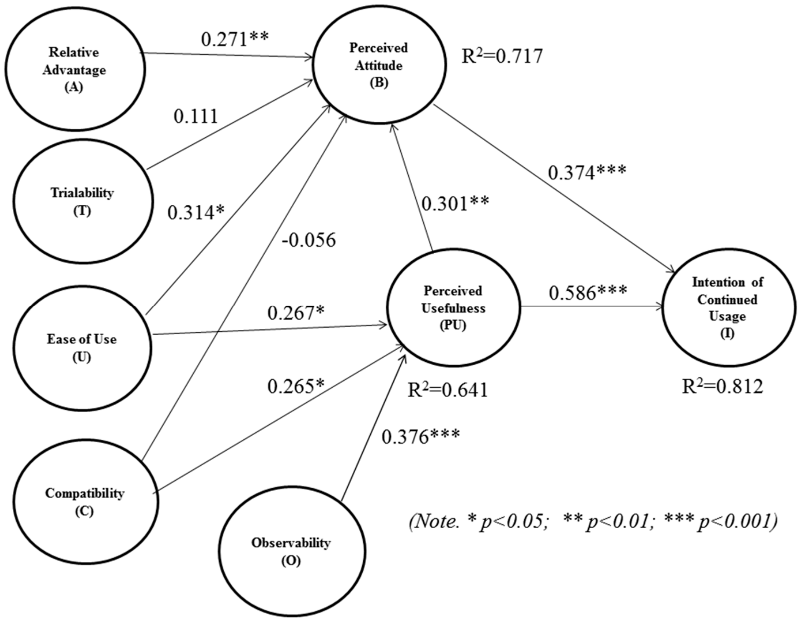

Figure 2. Path analysis results.

Table 3. Hypotheses testing results.

Item Code	Hypotheses	Results
H1	Relative Advantage → Perceived Attitude	Supported
H2	Compatibility → Perceived Usefulness	Supported
H3	Compatibility → Perceived Attitude	Not supported
H4	Ease of Use → Perceived Usefulness	Supported
H5	Ease of Use → Perceived Attitude	Supported
H6	Trialability → Perceived Attitude	Not supported
H7	Observability → Perceived Usefulness	Supported
H8	Perceived Usefulness → Perceived Attitude	Supported
H9	Perceived Usefulness → Intention of Continued Usage	Supported
H10	Perceived Attitude → Intention of Continued Usage	Supported

5. Discussion

This section addresses the implications of STEM students' perceptions on the diffusion of OSM and then discusses the empirical study results as well as differences in students' perceptions of OSM and other similar technologies. The consistencies and inconsistencies between the proposed theoretical framework and the analytic results are analyzed. Finally, limitations of this work and suggestions for future study are discussed.

5.1. Implications of STEM Students' Perceptions on the Diffusion of OSM

Various proposals have been put forth for enhancing STEM curriculum and instruction by integrating interdisciplinary domain knowledge into courses. A significant benefit of integrating OSM into the STEM education is providing an effective approach to use PBL in GIS learning. GIS is an interdisciplinary research that is difficult to use and learn while PBL is an instructional method in which learners conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem. The learners are engaged in self-directed learning, apply their new knowledge to the problem, and reflect on what they have learned as well as the effectiveness of the strategies employed via PBL [122]. Although the PBL approach has been widely adopted in learning GIS, PBL is recognized as being time consuming for both the GIS learner and educator [123]. OSM can offset time constraints for the GIS educator as materials may be prepared in advance. Through the open nature of OSM, students can free reuse and distribute learning materials for free and work in collaborative groups to identify what they need to learn in order to solve a problem. Apparently, OSM and GIS can be a more effective tool for PBL.

However, despite the significant benefits of using open GIS in STEM education, a substantial gap still exists between OSM technologies within OSM communities and the teaching practices of typical STEM faculty. The largest barrier to improving STEM education is the insufficiency of the knowledge related to how currently available VGI such as OSM can be effectively diffused and adopted by STEM educators so that OSM can be integrated into the curriculum and instruction. Once students benefit from PBL with GIS, and through the open nature of OSM, they can contribute more to OSM. Hence, both students and OSM benefit each other.

Based on the analytic results, students' intention to continue using OSM can be improved by integrating OSM into the curriculum and instruction according to the significant positive correlations among ease of use (U), observability (O), and compatibility (C) with intention of continued usage (I). In particular, the ease of use (U) of OSM should be emphasized because it can attract more new STEM learners. Promoters of OSM should help users understand which of its features are superior to other VGI tools and more beneficial to users. Once the advantages of OSM become obvious, users will have a greater willingness to adopt OSM and, thus, have a higher intention to serve as volunteers and contribute to VGI.

The three factors further influenced the user's intention of continued usage (I). In addition, the results also demonstrated that relative advantage (A) and ease of use (U) have the moderate effect on the perceived attitudes (PA) as well as the moderate total effect on the intention of continued usage (I). Further, trialability (T) and compatibility (C) were found to have no direct effects on perceived attitudes (PA). Among these factors, the test of the structural model indicated that the ease of use (U) has the strongest total effect on the intention to continue use (I). Further, both observability (O) and compatibility (C) also have higher total effects on the intention of continued usage (I). Please refer to Table 4 for the direct, indirect, and total effects.

Table 4. Direct, indirect, and total effects.

Relationships	Direct	Indirect	Total
Relative Advantage → Perceived Attitude	0.271	-	0.271
Trialability → Perceived Attitude	-	-	-
Ease of Use → Perceived Attitude	0.314	0.080	0.394
Ease of Use → Perceived Usefulness	0.267	-	0.267
Compatibility → Perceived Attitude	-	0.080	0.080
Compatibility → Perceived Usefulness	0.265	-	0.265
Observability → Perceived Usefulness	0.376	-	0.376
Perceived Attitude → Intention of Continued Usage	0.374	-	0.374
Perceived Usefulness → Perceived Attitude	0.301	-	0.301
Perceived Usefulness → Intention of Continued Usage	0.586	0.113	0.699
Relative Advantage → Intention of Continued Usage	-	0.101	0.101
Trialability → Intention of Continued Usage	-	-	-
Ease of Use → Intention of Continued Usage	-	0.304	0.304
Compatibility → Intention of Continued Usage	-	0.185	0.185
Observability → Intention of Continued Usage	-	0.263	0.263

Regarding the implications of the research results, the results shown in Figure 2 and Table 4 demonstrate that ease of use (U) is the most important determinants with the strongest total effect on the intention to continue use. Here, the correlation coefficient between ease of use (U) and intention of continued usage (I) ($0.267 \times 0.586 + 0.314 \times 0.374 + 0.267 \times 0.301 \times 0.374 = 0.304$)× can be calculated through the paths, ease of use (U) → perceived usefulness (PU) → intention of continued usage (I) as well as ease of use (U) → perceived attitude (PA) → intention of continued usage (I). Therefore, the ease of use (U) should be enhanced so as to diffuse the innovation of OSM in STEM. Web mapping platforms, as part of GIS, are not easy to learn because they cover a wide range of knowledge, such as hardware configurations, web mapping tools, and spatial knowledge. In the past, the graphical user interface (GUI) of OSM was not as user friendly as those of commercial web mapping platforms from the aspects of information richness and functionalities. Currently, the third-party applications are considered as alternatives to assist novices in contributing to the VGI. Those third-party applications are designed based on the VGI of OSM. Maps.me [124,125] and OsmAnd [126,127] are typical examples providing a better GUI for mobile devices. Therefore, STEM educators can promote OSM through third-party applications with better GUIs than OSM. Thus, the ease of use (U) problem associated with the GUI of OSM is the most important determinant because OSM resolves the critical issue of teaching GIS in a real world context. The perceived usefulness (PU) can be increased through the path, Ease of Use → Perceived Usefulness, as demonstrated in Figure 2. Hence, the intention to continue usage (I) will be stronger.

The observability (O) of OSM should be emphasized since the correlation coefficient between observability (O) and perceived usefulness (PU) (0.376) is the second important determinant (see Figure 2). The correlation coefficient between observability (O) and intention of continued usage (I) ($0.376 \times 0.586 + 0.376 \times 0.301 \times 0.374 = 0.263$) can be calculated through the path, observability (O) → perceived usefulness (PU) → intention of continued usage (I). This result is consistent with Hristova, Quattrone, Mashhadi, and Capra's findings [128]. According to Hristova et al., for novices of OSM, learning through the mapping parties involving OSM mappers and novel users (e.g., mapping parties happening at FOSS4G Europe 2015) is more efficient than the novices pursuing their own self-learning [128]. Such mapping parties are organized on a regular basis [128]. The new OSM users may observe (O) how the mapping tools can be used to draw the relevant geographic areas in which they are interested. Thus, these novices have a higher intention of continued usage (I) of OSM. Prior research results also support that observability had a positive effect on behavioral intention to use [72,117]. In general, the activities that can enhance the observability (O) of OSM should be emphasized so that the perceived usefulness (PU) and thus, the intention of continued usage (I) can greatly be enhanced.

Compatibility (C) is ranked as the third important determinant based on the correlation coefficient between compatibility (C) and intention of continued usage (I) ($0.265 \times 0.586 + 0.265 \times 0.301 \times 0.374 = 0.185$). The coefficient can be derived through the path, compatibility (C) → perceived usefulness (PU) → intention of continued usage (I) as well as compatibility (C) → perceived usefulness (PU) → perceived attitude (PA) → intention of continued usage (I). The factors should also be considered when promoting and implementing OSM in STEM education. Our findings indicated that compatibility (C) with other web mapping platform applications like Google maps or Bing maps should be enhanced, thereby facilitating STEM users' adoption of OSM. In practical applications, STEM users can export the VGI data from OSM to other common data formats of mapping applications [19], such as the KML format [129,130], DEF format, and OSM format [131,132]. As OSM can be compatible (C) with most mapping applications, the perceived usefulness (PU) and, thus, the intention to continue usage (I) in STEM will be greatly enhanced.

Finally, the relative advantage (A) is the least correlated variable with intention of continued usage (I) since the correlation coefficient between relative advantage (A) and intention of continued usage (I) ($0.271 \times 0.374 = 0.101$) can be calculated through the path, relative advantage (A) → perceived attitude (PA) → intention of continued usage (I). Since most of the students are new users of OSM, they may pay more attention on how to use OSM than on the relative advantage of OSM.

5.2. Implications of the Empirical Study Results

An understanding of users' acceptance and diffusion behaviors is critical for OSM providers' strategy definitions for sustainable operations and successful diffusion of VGI into STEM education. Hence, this study aimed to develop an integrated analytic model of IDT and TAM. The factors influencing the diffusion of OSM into STEM education as well as the adoption of OSM by STEM learners have been analyzed. To the best of the authors' knowledge, this model is the first such model to be used in the investigation of OSM adoption in general and the diffusion and adoption by STEM education in particular. With the proposed model, the relationships among five innovative characteristics along with perceived attitude, perceived usefulness (PU), and the intention of continued usage were explored, and 10 hypotheses were tested. The overall results confirmed the proposed model and hypotheses.

The evidence shown in Table A5 indicate that eight of the 10 proposed hypotheses (i.e., H1, H2, H4, H5, H7, H8, H9, and H10) were supported in the research model whereas two (i.e., H3, H6) were not. The discussion of each hypothesis is presented next.

5.2.1. Relative Advantage Perspective

The empirical study results supported H1, which means that relative advantage (A) had a significant effect on perceived attitude (PA). This result is consistent with the previous studies by Md Nor and Pearson [133] and Yu [94]. Relative advantage (A) captures the extent to which a potential adopter views the innovation as offering an advantage over previous ways of performing the same task [134]. In this study, the sample data were collected from first-time users of OSM in engineering schools. When students found the new tool had a relative advantage (A), they expressed positive attitudes toward accepting and learning how to use it irrespective of whether it was complicated and difficult to learn. This result implies that, if users have not used OSM but have an idea of some of the advantages that OSM offers, they will be positively inclined to use it. Therefore, an OSM service provider should highlight its relative advantages (A), such as offline usage, VGI, and real-time responses to user inputs, in order to accelerate its diffusion and adoption by STEM learners.

5.2.2. Compatibility Perspective

H2 was confirmed, indicating that compatibility (C) had significant positive effects on perceived usefulness (PU). The empirical study result is consistent with previous studies [135,136]. The finding suggests that perceived usefulness (PU) could be formed if potential users believe OSM has good compatibility (C). Because OSM is based on openness (i.e., open data and open source), its compatibility (C) with other geographic systems will be superior to other proprietary online VGI. Hence, the OSM features should be highlighted to attract more STEM users.

However, H3 was not supported by the empirical study results, which indicated that OSM compatibility (C) did not affect a user's positive attitude toward OSM. This finding is consistent with previous research results by Md Nor and Pearson [133] and Chen et al. [137]. This result might suggest that, although users regard compatibility (C) as dominant, positive attitudes toward OSM might not be formed only due to the compatibility (C) factor. Other factors may provide stronger incentives to attract users to adopt OSM. The reason could be that if users have experience using VGIs, they may be concerned about how to move existing geographic information into the new format. However, this study focused on first-time users who have no experience with VGI, so compatibility (C) has no significant effect on users' attitude [137] toward OSM use.

5.2.3. Ease of Use Perspective

We found that ease of use has a significant positive effect on perceived usefulness (PU) (H4). The analytic results are consistent with the findings of Chen et al. [137]. The procedure for a registered OSM user to collect and upload geographic information to OSM includes two steps: (1) using a portable, mobile device embedded with the GPS module to collect geographic information and (2) using publicly available aerial imagery to trace outlines of polygons, polylines, and other shapes [138]. The procedure is suitable for professional GIS experts, but not for beginners. This finding suggests that beginning OSM users may feel that OSM would be useful if it is easy to use. To encourage the acceptance of OSM, service providers must make greater efforts to ensure a more user-friendly interface to encourage volunteers' continued usage and contribution of VGI. The results in this study are consistent with those of Cheong and Park [139], who found that ease of use (U) was positively related to perceived attitude (PA), as hypothesized in H5. Although the sample data were collected from engineering students who tended to learn quickly about the usage of new tools, the empirical study results can still imply that positive attitudes (PA) could be formed among potential users of OSM if they feel that OSM is easy to use. Therefore, with a friendly OSM user-interface, users will have a greater willingness to use OSM and contribute VGI.

5.2.4. Trialability Perspective

Based on the empirical study results, trialability (T) (H6) was not supported: It showed no significant positive effect on perceived usefulness (PU). The reason for this may be due to the openness of OSM, which can be used by any potential user without registration or payment. Therefore, there is no need for users to try OSM before using it; any potential user can use it directly. Previous studies [85,140] also mentioned that, among compatibility (C), trialability (T), and observability (O), compatibility (C) is the only factor influencing the usage of systems.

5.2.5. Observability Perspective

As hypothesized in H7, observability (O) was found to have a significant positive effect on perceived usefulness (PU). Prior research [141] has demonstrated the same results. This analytic result also echoes the psychological theory of the bandwagon effect—namely, individuals will do the same thing as what they observe other people doing. This could imply that, when a potential OSM user finds that people around her or him are using OSM or when OSM is mentioned on social network websites, the user will tend to feel that OSM is useful because it is being discussed in many places. Therefore, to attract more people to use and contribute to OSM, OSM service providers could make more efforts to increase its observability (O).

5.2.6. Perceived Usefulness Perspective

The results of this research indicated that perceived usefulness (PU) is positively related to perceived attitude (PA), as hypothesized in H8. This finding is consistent with Chen et al.'s results [137]. The finding suggests that, when OSM is regarded as useful, users tend to have positive attitudes about using it. Therefore, OSM service providers can emphasize features that make users feel its usefulness by providing some success stories.

The analytic results of this study also indicated the high positive correlation between perceived usefulness (PU) and intention of continued usage (I), as hypothesized in H9. Previous studies showed similar results [106,107]. The finding suggests that potential OSM users will keep using it if they feel it to be useful. Hence, making users aware of OSM's usefulness is important for its continued usage.

5.2.7. Perceived Attitude Perspective

Our results strongly supported H10—namely, that perceived attitude (PA) is positively and significantly related to the intention of continued usage (I). This finding is consistent with previous works by Agarwal and Prasad [142] and Chen et al. [137]. The finding can also explain the different influences of perceived attitudes (PA) on the current usage behavior and future use intentions. Perceived attitude (PA) is significantly correlated to current usage. Continued usage intentions (I), however, are not affected by such intentions. The analytic results suggest that the initial OSM usage may be influenced by the perceived attitude (PA). However, existing OSM users will continue their usage only if those users have positive attitudes toward OSM. Perceived attitude (PA) may be important for the initial acceptance behavior because of the extent of behavior modification required. However, an external mandate to change might provide the required motivation. Yet for continued usages in the future, adopters apparently perceive the magnitude of change to be less; furthermore, they can decide future usage based on their own evaluations of the innovation [142]. The analytic result indicates that, once potential users form positive attitudes toward OSM, they will be more likely to continue their OSM usage in the future. Therefore, before accepting and adopting OSM, a positive attitude toward OSM should be formed [137].

5.3. Differences in Students' Perceptions of OSM and Other Similar Technologies

This paper is not only an attempt to solicit positive reviews/ratings of the OSM in STEM education by testing the IDT–TAM integrated framework. Following reviews of OSM from the aspects belong to the IDT–TAM integrated framework further contrast students' perceptions of the OSM to their perceptions of other similar technologies.

From the aspect of relative advantages (A), compared to other commercial web mapping platforms like Google Maps, OSM data is ready for any styling which STEM students need to apply in projects [143]. In addition, because of the web mapping platform, OSM provides always up-to-date mapping data hence students can always browse or download the latest map. The feature is not available in commercial web mapping platforms. Furthermore, OSM is always available for free to STEM users, teachers, and educational institutes [19,143].

In terms of ease of use (U), OSM is easier to use than other mapping software because using mobile and web applications, students are able to quickly access vast amounts of geospatial data without having to go through complex installation procedures or data acquisitions [144]. OSM provides easy-to-use, up-to-date, and readily available data and map service to students [145]. In addition, for those students who learn to program with geodata, the ease of use of Web Mapping 2.0 APIs from OSM, compared to the relative complexity and obscurity of OGC standards (OGC WMS), has made it much easier to develop OSM for mapping services [146]. Especially, from the aspects of STEM students, the collaboratively-creation and edition feature, better granularity, and time-enabled map layers [27] are not available in other commercial mapping platforms.

Regarding compatibility (C), due to the openness of OSM, the data on OSM can be downloaded and used inside of a GIS for geospatial analysis, cartographic rendering, and other geo-related tasks [147]. In addition, OSM is able to convert external map data to and from OSM formats [19], including ArcGIS, Drawing Exchange Format (DXF), GeoJSON, GML, Keyhole Markup Language (KML), GPX, images containing no georeference (.jpg, .png, etc.), and svg. Not all these features are available in similar technologies, such as Google Maps. However, these features are necessary for STEM students.

From the aspect of observability (O) and trialability (T), although OSM may not provide advanced GIS features, users of OSM mobile and web applications are able to quickly access vast amounts of geospatial data without having to go through complex installation procedures or data acquisitions [144]. It does enhance the trialability (T) of applications, thereby enabling users to become more familiar with software by observing its benefits and ultimately helping encourage adoption [144], although from our study results the trialability aspect has no significant effect on students' attitudes toward using OSM. In addition, the apps developed based on OSM have become widely distributed. For example, as mentioned in Section 1, the Maps.me app based on OSM has been adopted by more than 100 million users, which has increased OSM's observability (O). Moreover, OSM's openness means that the most up-to-date geodata can be downloaded freely and used offline, facilitating users' adoption of the app based on OSM data when there is no Internet access, such as when traveling overseas. This feature is also not available in other similar technologies.

5.4. Limitations and Suggestions for Future Study

This research is the first step toward understanding the factors that influence the acceptance and usage of OSM in STEM. Some improvements can be made in future studies. In this sub-section, limitations and suggestions for future study will be discussed.

First, the empirical study was based on data collected from 145 respondents in Taiwan because few teachers wanted to participate in teaching experiments. Therefore, the sampled students in this study only included two majors. This is the first step in investigating OSM and STEM education, as previously mentioned, because OSM has seldom been used by general and STEM educators. Once this study's contributions have been proven, if time and budget allow, this research can be further extended to cover more student majors. A larger sample should be collected from different countries or areas and from different cultures so that service provider strategies can be reconfigured to attract worldwide volunteers.

Second, participants were almost exclusively beginners. If consumer behaviors of different segmentations can be analyzed, the OSM service provider can define various strategies for users from different stages of innovation diffusion [30], including lead user, innovator, mass customer, and laggard, as well as market segmentations. Other factors (e.g., service quality, trust) potentially influencing users' attitudes about their continued usage of OSM can be studied in the future.

Third, a number of the studies have demonstrated that gender differences exist in computer attitudes, ability, and use in education [148,149]. Compared to male students who have higher levels of computer proficiency and internet experience with respect to off-task behaviors, female students significantly use computers as a tool to accomplish specific tasks participating in academic activities [150]. Bao, Xiong, Hu and Kibelloh [151] further confirmed the dominant role of gender difference in the adoption of mobile learning. The ratings of male students' general computer self-efficacy, perceived ease of use, and behavioral intention to use mobile learning were higher than female students' ratings [151]. Such gender differences also existed among the learners of OSM. When male and female students are similarly motivated to participate in OSM courses, male students contribute to most of the user-generated content and the OSM mapping platform [152,153]. Thus, future studies seeking to confirm the gender differences in the diffusion and adoption of OSM in STEM education should be a dominant topic. Furthermore, strategies for overcoming the gender differences should be studied in the future.

Fourth, in addition to the aspects used in this study, which include relative advantage, compatibility, complexity, trialability, observability, perceived usefulness, and perceived ease of use, other objective measurements can be included in the framework, such as tracking the frequency of continued usage, and comparisons for teaching experiments. This would give more solid results.

6. Conclusions

STEM education is about robust and coherent STEM curriculum and experiences that are multidisciplinary and integrate problem-solving inquiries that foster critical and computationally driven thinking. GIS technology can engage several critical elements in STEM curriculum and instruction. GIS tools and techniques lead to an understanding of cross-disciplinary phenomena and solve problems rooted in academic and real-world concepts [15]. In particular, the recent rise of VGI has provided a flexible and cost-effective alternative for STEM educators, with high collaboration and free distribution possibilities. Numerous research works have attempted to study the quality of VGI and its possible applications. In this research, we proposed a novel integrated analytic framework that examined factors that can influence the innovation diffusion and technology acceptance of OSM in the context of STEM education. Based on the empirical study results, we identified eight significant variables that can influence the acceptance and use of OSM in STEM. According to the results of the empirical study, OSM service providers should focus on observability, perceived usefulness, and perceived attitude to enhance the diffusion of innovation and the continued use of OSM. The results of this study provide a better understanding of the possible perceptions that potential STEM users have about OSM. Accordingly, strategies can be defined to enhance the OSM features. In addition, the analytic framework proposed and verified in this research may be used to evaluate other innovations and new technologies in general and the ones for STEM in particular.

Author Contributions: S.J.H.S. and C.-L.Y. wrote and edited the paper; C.-L.Y. and C.-Y.H. developed the questionnaire; S.J.H.S. proposed hypotheses and ran SmartPLS to obtain the results; and J.-N.J. finalized the paper. C.-Y.H. rewrote the whole article and revised the work.

Funding: This research was funded by Ministry of Science and Technology, Taiwan with grant number MOST 106-2221-E-492-001.

Acknowledgments: This project was supported by the National Center for High-Performance Computing in Taiwan.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

By inspecting the significance of the skewness and kurtosis of each individual variable, information about the choice of an appropriate statistical technique could be decided [112]. To test the normality of the data sample, the method proposed by Kim [154]—the Kolmogorov-Smirnov (KS) test—was introduced to assess the normality of the data sample. The sample data can be considered to have normal distribution when the p value is larger than 0.05 in the KS test results. In addition, when the sample size is medium ($50 < n < 300$), one can reject the null hypothesis at absolute $Z_{skewess}$ or $Z_{kurtosis}$ values over 3.29 and conclude that the distribution of the sample is not normal. As shown in Table A1, among all 43 variables, most deviated significantly from normality. Therefore, PLS-SEM is an adequate research method for this research based on these non-normal distributional characteristics.

We then confirmed the proposed correlation relationships with the PLS-SEM approach using the SmartPLS 3.0 software. Tables A2–A5 demonstrate the results. The results for Cronbach's alpha, R squared (R^2), composite reliability (CR), average variance extract (AVE), and redundancy are included in Table A2. Tables A3 and A4 demonstrate the discriminant validity by using the Fornell–Larcker criterion and loading and cross-loading criterion, respectively. The sample mean, standard deviation, standard error, t statistics, and p values are included in Table A5. Based on the CR, internal consistency reliability (Cronbach's alpha), and validity, the reliability of the measurements of dimensions was assessed according to Barclay et al. [155]. All Cronbach's alpha and CR values (see Table A2) are greater than 0.700, which is an acceptable level for these two parameters. The results indicate that the measurement errors were relatively small [156].

Table A1. Skewness, kurtosis and normality test results.

Item Code	Mean	Standard Deviation	Standard Error	Excess Kurtosis	Skewness	$Z_{skewness}$	$Z_{kurtosis}$
a_1	3.979	0.834	0.069	0.488	−0.537	7.046	−7.753
a_2	3.952	0.791	0.066	−0.173	−0.252	−2.634	−3.836
a_3	3.986	0.788	0.065	−0.084	−0.318	−1.284	−4.859
a_4	3.510	0.84	0.070	−0.230	0.214	−3.297	3.068
a_5	3.745	0.795	0.066	0.014	−0.174	0.212	−2.636
a_6	3.738	0.805	0.067	−0.700	0.034	−10.471	0.509
c_1	3.634	0.768	0.064	0.150	−0.093	2.352	−1.458
c_2	3.814	0.705	0.059	−0.311	−0.077	−5.312	−1.315
c_3	3.876	0.778	0.065	0.199	−0.311	3.080	−4.814
u_1	3.759	0.873	0.072	0.057	−0.324	0.786	−4.469
u_2	3.503	0.831	0.069	−0.183	0.207	−2.652	3.000
u_3	3.566	0.829	0.069	−0.643	0.303	−9.340	4.401
u_4	3.655	0.834	0.069	0.651	−0.287	9.399	−4.144
u_5	3.800	0.802	0.067	−0.857	0.055	−12.867	0.826
u_6	3.883	0.826	0.069	−0.019	−0.370	−0.277	−5.394
u_7	3.690	0.867	0.072	−0.376	−0.119	−5.222	−1.653
u_8	3.752	0.792	0.066	−0.604	−0.027	−9.183	−0.411
t_1	3.779	0.765	0.064	−0.780	0.121	−12.278	1.905
t_2	3.297	0.983	0.082	−0.331	−0.099	−4.055	−1.213
t_3	3.738	0.77	0.064	−1.048	0.400	−16.389	6.255
t_4	3.690	0.775	0.064	0.015	−0.024	0.233	−0.373
t_5	3.738	0.743	0.062	−0.933	0.366	−15.121	5.932
o_1	2.766	1.303	0.108	−0.940	0.161	−8.687	1.488
o_2	3.255	1.137	0.094	−0.456	−0.204	−4.829	−2.160
o_3	3.641	0.802	0.067	0.002	−0.147	0.030	−2.207
o_4	2.821	1.408	0.117	−1.237	0.083	−10.579	0.710
o_5	3.166	1.232	0.102	−0.717	−0.298	−7.008	−2.913
pu_1	3.593	0.913	0.076	0.282	−0.307	3.719	−4.049
pu_2	3.738	0.788	0.065	−0.040	−0.094	−0.611	−1.436
pu_3	3.772	0.759	0.063	−0.885	0.219	−14.041	3.474
pu_4	3.869	0.763	0.063	−0.886	0.040	−13.983	0.631
i_1	3.855	0.761	0.063	−0.878	0.062	−13.893	0.981
i_2	3.793	0.778	0.065	−0.850	0.115	−13.156	1.780
i_3	3.745	0.82	0.068	−0.314	−0.024	−4.611	−0.352
i_4	3.517	0.94	0.078	−0.448	0.050	−5.739	0.641
i_5	3.634	0.854	0.071	−0.336	−0.023	−4.738	−0.324
i_6	3.559	0.893	0.074	−0.510	0.115	−6.877	1.551
i_7	3.634	0.812	0.067	−0.244	0.142	−3.618	2.106
pa_1	3.924	0.831	0.069	−0.277	−0.293	−4.014	−4.246
pa_2	3.952	0.799	0.066	−1.059	−0.076	−15.960	−1.145
pa_3	3.931	0.785	0.065	−0.789	−0.137	−12.103	−2.102
pa_4	3.772	0.777	0.065	−0.849	0.155	−13.157	2.402
pa_5	3.910	0.838	0.070	−0.508	−0.184	−7.300	−2.644

Table A2. Cronbach's alpha, R square, composite reliability, AVE, and redundancy.

Latent Variables	Cronbach's Alpha	R^2	Composite Reliability	Average Variance Extracted	Redundancy
Compatibility	0.877	N.A.	0.925	0.804	N.A.
Intention of Continued Usage	0.935	0.812	0.947	0.719	0.576
Ease of Use	0.921	N.A.	0.936	0.645	N.A.
Observability	0.843	N.A.	0.885	0.607	N.A.
Perceived Attitude	0.957	0.717	0.967	0.853	0.604
Perceived Usefulness	0.930	0.641	0.950	0.827	0.522
Relative Advantage	0.900	N.A.	0.924	0.670	N.A.
Trialability	0.852	N.A.	0.894	0.629	N.A.

The evaluation of validity consisted of the evaluation of both convergent validity and discriminant validity. First, the convergent validity of each dimension can be reflected by the AVE corresponding to that dimension. The analytic results in Table A2 show good convergent validity and reliability because the AVE values ranged from 0.607 to 0.853, which is larger than Bagozzi and Yi's [157] recommended threshold values of 0.500. Then, the discriminant validity for all dimensions was checked based on

Table A3. Two dimensions' statistically difference can be reflected by the discriminant validity [158]. For adequate discriminant validity, the diagonal elements of the correlation matrix of constructs should be greater than the off-diagonal elements in the corresponding rows and columns [156,159]. The analytic results in Table A3 demonstrate adequate discriminant validity for all dimensions except for the square root value of the AVE for the intention of continued usage (0.848), which is a little bit less than the correlation (0.867) between perceived usefulness and intention of continued usage. Sufficient discriminate validity can be assumed, despite the Fornell-Larcker criterion not being fulfilled here, as long as the correlation between the factors (refer Figure 2) is not higher than 0.9 [160,161]. Moreover, the discriminant validity can be further verified by using the cross-loadings assessment proposed by Chin [162]. Table A4 demonstrates the discriminant validity for all dimensions.

Each factor loading (digits in bold) is greater than all of its cross-loadings. Furthermore, in Table A4, the factor loading of all items exceeds 0.500, and 3 of 10 dimensions are significant ($p < 0.001$) (see Table A5).

Table A3. Discriminant validity—Fornell–Larcker Criterion.

Latent Variables	Compatibility	Intention of Continued Usage	Ease of Use	Observability	Perceived Attitude	Perceived Usefulness	Relative Advantage	Trialability
Compatibility	0.897							
Intention of Continued Usage	0.753	0.848						
Ease of Use	0.875	0.793	0.803					
Observability	0.560	0.667	0.614	0.779				
Perceived Attitude	0.734	0.814	0.786	0.508	0.924			
Perceived Usefulness	0.709	0.867	0.730	0.688	0.751	0.910		
Relative Advantage	0.803	0.742	0.790	0.534	0.759	0.683	0.818	
Trialability	0.764	0.730	0.789	0.567	0.718	0.690	0.720	0.793

Table A4. Discriminant validity—Loading and Cross-loading Criterion.

Item code	Compatibility	Intention of Continued Usage	Ease of Use	Observability	Perceived Attitude	Perceived Usefulness	Relative Advantage	Trialability
a_1	0.700	0.596	0.696	0.463	0.691	0.588	**0.833**	0.652
a_2	0.686	0.603	0.650	0.409	0.653	0.569	**0.878**	0.645
a_3	0.574	0.514	0.535	0.322	0.592	0.477	**0.794**	0.588
a_4	0.557	0.598	0.547	0.411	0.487	0.500	**0.698**	0.415
a_5	0.721	0.638	0.707	0.467	0.649	0.561	**0.866**	0.614
a_6	0.691	0.702	0.726	0.570	0.631	0.653	**0.827**	0.584
c_1	**0.846**	0.683	0.760	0.508	0.634	0.594	0.668	0.644
c_2	**0.914**	0.668	0.795	0.512	0.679	0.675	0.732	0.707
c_3	**0.929**	0.675	0.801	0.501	0.662	0.637	0.765	0.703
i_1	0.648	**0.839**	0.626	0.557	0.672	0.816	0.677	0.609
i_2	0.657	**0.845**	0.619	0.614	0.654	0.802	0.659	0.618
i_3	0.662	**0.859**	0.679	0.585	0.685	0.729	0.685	0.612
i_4	0.646	**0.863**	0.720	0.602	0.658	0.722	0.617	0.626
i_5	0.623	**0.876**	0.711	0.562	0.761	0.710	0.607	0.634
i_6	0.625	**0.854**	0.697	0.584	0.667	0.689	0.573	0.611
i_7	0.602	**0.795**	0.658	0.479	0.733	0.662	0.613	0.624
o_1	0.327	0.372	0.337	**0.767**	0.253	0.395	0.279	0.313
o_2	0.466	0.529	0.530	**0.793**	0.399	0.520	0.476	0.455
o_3	0.627	0.695	0.663	**0.742**	0.644	0.698	0.583	0.662
o_4	0.310	0.405	0.354	**0.803**	0.204	0.429	0.276	0.296
o_5	0.321	0.468	0.369	**0.781**	0.315	0.506	0.358	0.341
pa_1	0.666	0.699	0.704	0.443	**0.925**	0.650	0.665	0.658
pa_2	0.653	0.724	0.698	0.431	**0.929**	0.694	0.689	0.663
pa_3	0.712	0.766	0.728	0.481	**0.956**	0.710	0.730	0.657
pa_4	0.683	0.806	0.748	0.537	**0.903**	0.730	0.719	0.692
pa_5	0.673	0.754	0.746	0.475	**0.905**	0.682	0.692	0.633
pu_1	0.593	0.744	0.610	0.732	0.651	**0.866**	0.564	0.560
pu_2	0.666	0.774	0.693	0.658	0.642	**0.919**	0.601	0.644
pu_3	0.666	0.820	0.705	0.615	0.715	**0.938**	0.666	0.668
pu_4	0.651	0.811	0.644	0.517	0.724	**0.914**	0.662	0.637
t_1	0.684	0.641	0.723	0.456	0.663	0.547	0.658	**0.819**
t_2	0.508	0.489	0.541	0.507	0.404	0.456	0.425	**0.725**
t_3	0.410	0.390	0.384	0.287	0.414	0.397	0.413	**0.693**
t_4	0.675	0.639	0.728	0.530	0.670	0.627	0.627	**0.856**
t_5	0.681	0.670	0.667	0.475	0.609	0.658	0.644	**0.858**
u_1	0.714	0.708	**0.827**	0.528	0.730	0.619	0.701	0.634
u_2	0.701	0.618	**0.781**	0.490	0.556	0.557	0.561	0.610
u_3	0.706	0.658	**0.820**	0.521	0.573	0.628	0.612	0.590
u_4	0.685	0.547	**0.742**	0.376	0.566	0.505	0.579	0.511
u_5	0.739	0.621	**0.808**	0.448	0.616	0.557	0.701	0.650
u_6	0.726	0.664	**0.821**	0.519	0.706	0.578	0.679	0.655
u_7	0.643	0.619	**0.800**	0.521	0.637	0.586	0.619	0.668
u_8	0.717	0.649	**0.824**	0.559	0.642	0.649	0.631	0.734

Table A5. The sample mean, standard deviation, standard error, *t* statistics and *p* values.

Hypothesis	Original Sample (O)	Sample Mean (M)	Std. Deviation (STDEV)	*t* Statistics (|O/STDEV|)	*p* Values
Compatibility → Perceived Attitude	−0.056	−0.064	0.153	0.365	0.715
Compatibility → Perceived Usefulness	0.265	0.262	0.118	2.253	0.024
Ease of Use → Perceived Attitude	0.314	0.324	0.157	2.007	0.045
Ease of Use → Perceived Usefulness	0.267	0.274	0.116	2.305	0.021
Observability → Perceived Usefulness	0.376	0.376	0.074	5.112	0.000
Perceived Attitude → Intention of Continued Usage	0.374	0.374	0.071	5.245	0.000
Perceived Usefulness → Intention of Continued Usage	0.586	0.586	0.069	8.455	0.000
Perceived Usefulness → Perceived Attitude	0.301	0.300	0.091	3.308	0.001
Relative Advantage → Perceived Attitude	0.271	0.276	0.096	2.820	0.005
Trialability → Perceived Attitude	0.111	0.105	0.105	1.053	0.293

According to Hair et al. [121], the problem of collinearity happens when the correlation coefficients between two indicators are high. Multi-collinearity occurs at the moment when more than two indicators are involved. High multi-collinearity impact on the estimation of weights and their statistical significance. The variance inflation factor (VIF) of the indicators should be computed to identify the multi-collinearity problem [163–165]. Since all the VIF-scores being derived are lower than 10 [166,167], no severe or serious multi-collinearity exists in this work.

Then, the hypothesized framework was tested using PLS-SEM. By applying the bootstrap resampling method with 5000 subsamples, the *t*-values were derived (see Table A5). Whether each of the hypotheses is supported can be decided by inspecting these *p* values in terms of empirical study results. The explained variance (R^2) for the endogenous dimensions largely exceeded the minimum of 0.1 suggested by Falk and Miller [168]. The analytical findings are presented in Table A5 and Figure 2.

From the explained variances (R^2) in the analytic results in Table A2, the proposed model explains 71.7% of the variance for the perceived attitude, 64.1% of the variance for the perceived usage, and 81.2% of variance for the intention of continued usage.

The goodness-of-fit index (GoF) can be used to further validate the relationship quality of dimensions [90], where ($GoF = \sqrt{\overline{(\text{Communality})} \times \overline{R^2}}$), and the communality value is the same as that of AVE. The GoF in this study was 0.721, which exceeds the cut-off value of 0.360 for the large effect size of R^2 based on Cohen's work [169]. Hence, the proposed model was confirmed to have better prediction power than the baseline values ($GoF_{small} = 0.1$, $GoF_{medium} = 0.25$, $GoF_{large} = 0.36$). Therefore, we can assert that the research results appropriately validate the PLS model globally. The direct, indirect, total effects, and explained variance of all dimensions are presented in Table A5.

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