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A BIM-GIS-IoT-Based System for Excavated Soil Recycling

Tong Huang [1,2,3], Shicong Kou [2,3], Deyou Liu [2,3], Dawang Li [2,3] and Feng Xing [1,2,3,*]

[1] Key Laboratory of Earthquake Engineering and Engineering Vibration, Institute of Engineering Mechanics, China Earthquake Administration, Harbin 150086, China; zjlwood@szu.edu.cn
[2] Guangdong Provincial Key Laboratory of Durability for Marine Civil Engineering, Shenzhen 518060, China; kousc@szu.edu.cn (S.K.); 1900471019@email.szu.edu.cn (D.L.); lidw@szu.edu.cn (D.L.)
[3] College of Civil and Transportation Engineering, Shenzhen University, Shenzhen 518060, China
* Correspondence: xingf@szu.edu.cn

Abstract: The increasing excavated soil from construction projects has become a big problem in the sustainable development of megacities worldwide. Even though excavated soil management concerns are receiving increased attention, low rates of excavated soil recycling remain a barrier to the continuous improvement of the construction industry. Nowadays, Building Information Modeling (BIM) technology has gained popularity for construction and demolition (C&D) waste management purposes. However, few studies and cases of recycling excavated soil using BIM technology have been found. This paper gives a BIM-GIS-IoT-based excavated soil recycling system to effectively integrate BIM and Internet of Things (IoT) technologies into a geographic information system (GIS) to achieve scientific and reasonable recycling for excavated soil. The system mentioned above could collaboratively manage information from the government, developers, construction enterprises, transportation companies, and recycling facilities to meet the requirement for the specific communication, analysis, decision-making, and recycling plan preparation of the excavation project. In addition, it provides a systematic method and applies relevant information technology required to recycle the excavated soil effectively in the excavation project. The system is intended to provide a fundamental digital construction model for excavated soil recycling, regardless of whether it is invoked by the existing application software or a program tailored to the demands of a specific organization or stakeholders. It makes excellent use of the rich information stored in digital information models, may create a mapping to the input data required by the application, or automatically convert the basic model to facilitate the specific analysis. This system can not only serve as an excavation project simulation tool before construction, but also serve as a tool to recycle the excavated soil and cost evaluation. The developed model is applied via case studies within an excavation project. Different plans are described and compared in detail in several aspects of the schedule, revenue, and contract, finding that actual benefits will differ depending on the project's limiting conditions. The result indicates ample opportunity for the advantages of the BIM-GIS-IoT-based excavated soil recycling system in the excavation project.

Keywords: excavated soil; recycling; BIM-GIS-IoT-based; system

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1. Introduction

With the acceleration of urbanization, the construction industry has grown leaps and bounds, generating sky-high amounts of construction and demolition (C&D) waste (mainly excavated soil, concrete, masonry, wood, plastic, glass, waste paper, rubber) in the city-building campaign of Renewal in developing countries [1]. In order to reduce the threat and impact of these wastes on the environment, some local government authorities and related industries stipulate that enterprises and individuals who generate, transport, and discharge C&D wastes need to adopt corresponding measures and means to promote the source reduction in C&D wastes [2–5]. Soil excavation is among the fundamental facets of infrastructure development [6]. Few infrastructure building activities can be done without excavation, especially in the urban Renewal of metropolitan regions, where underground space is inevitable as obtaining new land is typically tricky [7]. The excavation project produced significant volumes of excavated excess soils. According to Eurostat, excavated soil is Europe's most significant source of rubbish. In several European nations, excavated dirt dumped in landfills without recycling has become a significant problem [8]. As the most significant component of C&D waste [9–11], the amount of excavated soil exceeds the total amount of municipal and another C&D waste was mainly transferred to landfills, accounting for more than 50% of the total landfill volume [8]. However, there are no longer enough landfills in the cities to accommodate this excavated soil. Some megacities have established several excavated soil recycling plants to resolve the above problems. However, the disposal of the excavated soil mainly relies on the manual coordination of government, developers, construction companies, transportation companies, and waste recycling facilities to recycle excavated soil. It is challenging to communicate effectively between all construction participants. The phenomenon of "Information Isolated Island" is severe. There is often a contradictory situation that it is challenging to transport the excavated soil from the excavation projects on one hand, while on the other hand, there is no excavated soil to collect for the recycling plant. As Omar pointed out, "the unmanageable waste generated during the construction process is mainly due to poor coordination between the various participants in the chain [12]". Therefore, it is necessary to find an effective method to overcome the difficulties above. The current research about the reuse and recycling of C&D waste mainly focuses on the demolition waste (concrete, masonry) generated in the demolition stage [13–18]. There is little research on excavated soil reuse and recycling [19,20]. Building information modeling (BIM) is a spatial and data transmission technology that could be systematically and effectively linked with IoT and GIS technologies to realize the efficient communication of all the stakeholders during construction [21]. BIM refers to creating and employing a digital model to simulate a construction project's planning, design, construction, and operation. Moreover, it is a data-rich, object-oriented, intelligent, and parametric digital representation of the building facility [22]. BIM has become a popular research topic for estimating and managing C&D waste.

This paper presents a BIM-GIS-IoT-based system that we developed for excavated soil recycling. To that recycling purpose, it has two specific goals:

(1) A helpful operation platform for excavated soil recycling to explore cross applications in the knowledge of BIM, IoT technology, GIS, excavated soil recycling technology, and building construction. The platform collaboratively manages information from the government, developers, construction enterprises, transportation companies, and recycling plants, considering the links between soil excavation, transportation, and recycling.
(2) To realize the process integration, the object integration, and the platform integration.

After this introductory section is Section 2, which begins with a background; Section 3 describes the BIM-GIS-IoT-based excavated soil recycling system and explains the system's primary components. Section 4 provides the modules, and main functions of the BIM-GIS-IoT-based system for excavated soil recycling is outlined in detail; Section 5 gives a workflow to illustrate the processes of the BIM-GIS-IoT-based excavated soil recycling system. Section 6 is a case study about the system to introduce the operation process of the BIM-GIS-IoT-based excavated soil recycling system in the excavation project. Finally, Section 6 is the discussion, and Section 7 is the conclusion.

2. Background

2.1. BIM, and Integration of Information Technology

BIM includes modeling and analysis software, BIM model conversion tools, multi-source data fusion technology, Web GL, Active X, HTML5, cloud technology, and 3S technology [23]. The kernel of BIM is "information", which assists construction stakeholders to collaborate and stay informed about one another's operations. The information integration in the construction industry has transformed due to increased BIM usage, which has improved the whole construction process interoperability, information sharing, visualization, and decision-making processes [24]. BIM offers a collection of related and cross-referenced information, however, it also generates a 3D visual interface from a 2D drawing to aid management choices for various stakeholders and demands during the project's construction. Then, BIM provides a platform for efficient communication and cooperation among stakeholders from different construction participants to overcome the phenomenon of "Information Isolated Island." BIM has been widely utilized in the construction industry recently.

Some scholars tried to use BIM technology for C&D waste management. Jongsung Won used BIM technology to conduct crash tests at the design stage to avoid construction waste due to design errors. He studied two cases in Korea where 381 and 136 design errors were detected in the BIM model crash tests, respectively, and the results showed that BIM-based crash tests could reduce construction waste by 4.3–15.2% [25]. Lu introduces the application of BIM in construction waste management and identifies two critical prerequisites for "information preparation" and "computational algorithms" to facilitate construction waste management decisions [26]. Beatriz proposed a 4D-BIM model integrating temporary elements in 3D technology for planning the reuse and recycling of concrete and drywall waste from construction projects [27]. Koutamanis found that as a system of information integration and consolidation, BIM can coordinate stakeholders and their actions to achieve high accuracy, reliability, and efficiency in building construction and demolition [28]. Cheng proposed an information management system based on BIM technology to estimate construction waste generated by demolition and urban refinement. The system contains several functions for resource utilization, predicting the quantity of construction waste outbound truck demand, and predicting construction waste disposal fees [29]. Hamidi presented a demolition waste management system based on BIM [30]. Liu developed "a framework for minimizing construction waste based on BIM technology", which aims to be an integrated platform to guide decision-makers and designers to avoid construction waste generation during the design phase by providing known BIM models [31]. Kim created a BIM-based framework for estimating demolition waste early in the design phase to ensure effective and simplified recycling waste management [32]. Xu constructed a BIM-based construction waste information management system (IMS) that provided accurate construction waste information and a detailed information estimation process and proposed a mathematical formula including several GHG emission factors [33].

Even though these studies give important references for using BIM in excavation projects, some problems limit excavated soil recycling and the BIM platform's potential functions. Currently, the main application of BIM mentioned above tends to be for single buildings' C&D waste management. However, BIM does not perform well for large-scale regional objects such as geomorphology, underground pipelines, and underground tunnels. Excavation projects involve collecting and using data on the geomorphology of the construction site, underground pipelines, and underground tunnels in the process of implementation. In this case, BIM and GIS need to be integrated to achieve these functions. GIS is a technology for collecting, storing, managing, computing, analyzing, displaying, and describing data about geographic distribution on the earth's surface (including the atmosphere) space [34]. GIS has the functions of acquiring, storing, displaying, editing, processing, analyzing, outputting, and applying spatial data. Topological data is provided by GIS, allowing for 3D analysis, geographical analysis, and queries such as calculating the distance between two places, computing routes, and determining the best site [35]. GIS collects and analyzes geographic data to visualize location-based applications [36]. The integration of BIM and GIS enables BIM to obtain information about surrounding conditions through GIS in the planning, design, construction, and recycling process. For example, basic information on topography, electricity, communications, and gas can be obtained from GIS. Measures can be taken to avoid these problems or protect the aforementioned infrastructures during the excavation project's planning, design, and construction. In this way, geographical information about the surrounding conditions becomes essential for building engineering information in BIM. Through a unified database, users of BIM can make use of information from GIS in addition to BIM's data. However, achieving the integration of BIM and GIS and improving the value of the use of both data is a significant difficulty for BIM+GIS applications. Yamamura proposes to carry out the integration of BIM and GIS, and first needs to coordinate conversion and data alignment, BIM and GIS models, terrain, and other multi-source data unified to a coordinate system, to achieve a variety of information alignment. The data mosaic, flattening, cropping, and other operations and processing achieve smooth data convergence texture stitching naturally [37]. El Meouche investigated multiple approaches to integrating BIM and GIS. However, he did not propose a system architecture to integrate the technologies [38].

Existing BIM and GIS software programs (Revit, Project Wise Navigator, SuperMap Beijing, China) for data transmission and the management of buildings project processes are efficient. They can better synthesize information from the excavation venture into a digital model and convey it in 3D graphics to each person concerned with the invocation of the model. The digital models of BIM and GIS are ordinarily up to date by using manually inputted applicable data. So updating and real-time invocation information from the rapidly changing construction site turns into an impossible mission. Relying only on BIM and GIS technologies cannot recycle the excavated soil well. Meeting the requirement for managing construction sites of the excavation project in real-time is essential in linking virtual digital models to reality to collect and exchange data. Being one of the advanced core technologies, the Internet of Things (IoT) can provide real-time data to BIM-GIS to link physical resources with virtual digital models [39]. Nowadays, the Internet of Things (IoT) has attracted the attention of academics, enterprises, and even government entities [40]. IoT is now being used in the construction industry to help with data collection and decision-making. It is an intelligent network comprising RFID (Radio Frequency Identification) tags, NFC (Near Field Communication) tags, and GPS (Global Positioning System) sensors [41]. The IoT technology, which automatically detects, controls, and programs objects [42], enables its surroundings to be connected and interact directly and indirectly. The IoT connects items to the Internet and uses that connection to allow remote monitoring and control of those objects. Thus, the spatial-temporal information of excavated soil can be collected in real-time to support construction management, transportation management, and recycling through IoT technology.

Nowadays, integrating GIS with BIM has become a trend for digital construction applications. As such, the real-time information about the construction site is inputted into the BIM-GIS digital model through IoT to form the essential information required for constructing the building. Moreover, the service-oriented architecture (SOA) is utilized to construct GIS-IoT-enabled BIM systems by mixing various web services [43]. Few research efforts on leveraging the integration of BIM in the C&D waste management process are relatively scarce compared to those utilizing BIM only, and almost none in excavated soil recycling. The excavation project involves five components in its implementation: planning; design; construction; transportation; and recycling. Information about individual buildings, geological features, hydrological environment, underground pipelines, construction capacity, transport capacity, and recycling must be integrated and updated throughout the excavation project. The existing single information technology is unable to meet these functional requirements. Thus, integrating BIM, GIS, and IoT is crucial for resolving such problems.

2.2. Research Gaps

The majority of previous research has discussed the potential use of BIM to reduce C&D waste (without excavated soil). Meanwhile, BIM has been shown to help with planning, scheduling, productivity, and waste-related expenses and materials. The digital modeling, visualization, simulation of construction, collaborative work, information processing, data management, processing, and mapping of BIM will significantly promote the effective implementation of project C&D waste management. However, the characteristics of excavated soil from excavation operations differ from C&D waste. The diversity of excavated soil makes it necessary to further subdivide them in the recycling process. There is a pressing need to incorporate computers and information technologies into excavating soil recycling; various technologies and standards need to be systematically structured efficiently to enhance communication and cooperation between participants. Based on the above literature review, it is evident that there is no research about BIM that has proposed a specific solution for excavated soil recycling for urban development, even though this is an essential field with a challenge for the cities to resolve. Thus, three observations can be summarized:

(1) There is a lack of a helpful operation system for excavated soil recycling. The operating system can integrate information from all stages of the excavation and transportation process [44] and simulate the relevant processes in construction through digital technology, which is a digital representation of the characteristics of construction entities such as shape, dimensions, materials, and functions. The system platform collaboratively manages information from government, developers, construction enterprises, transportation companies, and recycling facilities, considering the three processes of soil excavation, transportation, and recycling to achieve scientific and reasonable recycling for excavated soil;
(2) To arrange the many modules and applications into an integrated platform and define linkages and interactions among the modules and applications, the development and configuration of function services with such a system face challenges.
(3) A helpful operation platform for excavated soil recycling to explore cross applications in the knowledge of BIM, IoT technology, GIS, excavated soil recycling technology, and building construction. The platform collaboratively manages information from the government, developers, construction enterprises, transportation companies, and recycling plants, considering the links between soil excavation, transportation, and recycling.

3. BIM-GIS-IoT-Based Excavated Soil Recycling System

The BIM-GIS-IoT-based excavated soil recycling system is introduced in this section. Service-Oriented Architecture (SOA) is now a mainstream approach to integrating information technologies. Service composition, service discovery, model-driven application, loosely linked, and platform-independent are some of the SOA's unique features that enable information flow, adaptation, and scalability while keeping internal functioning for each service [45]. Therefore, The SOA is called "a set of components which can be invoked, and whose interface descriptions can be published and discovered" by the World Wide Web Consortium (W3C) [46]. SOA integrates the ability to invoke remote objects and functions, for example, services, with standardized mechanisms for dynamic and universal service discovery and execution, emphasizing interoperability [47]. The system architecture (Figure 1) for integrating applications within a BIM environment is developed to accomplish the following aims: To provide a wide range of potential applications interfaces. To keep the basic model lightweight and capable of supporting a variety of equipment and functions, which are its principal objectives.

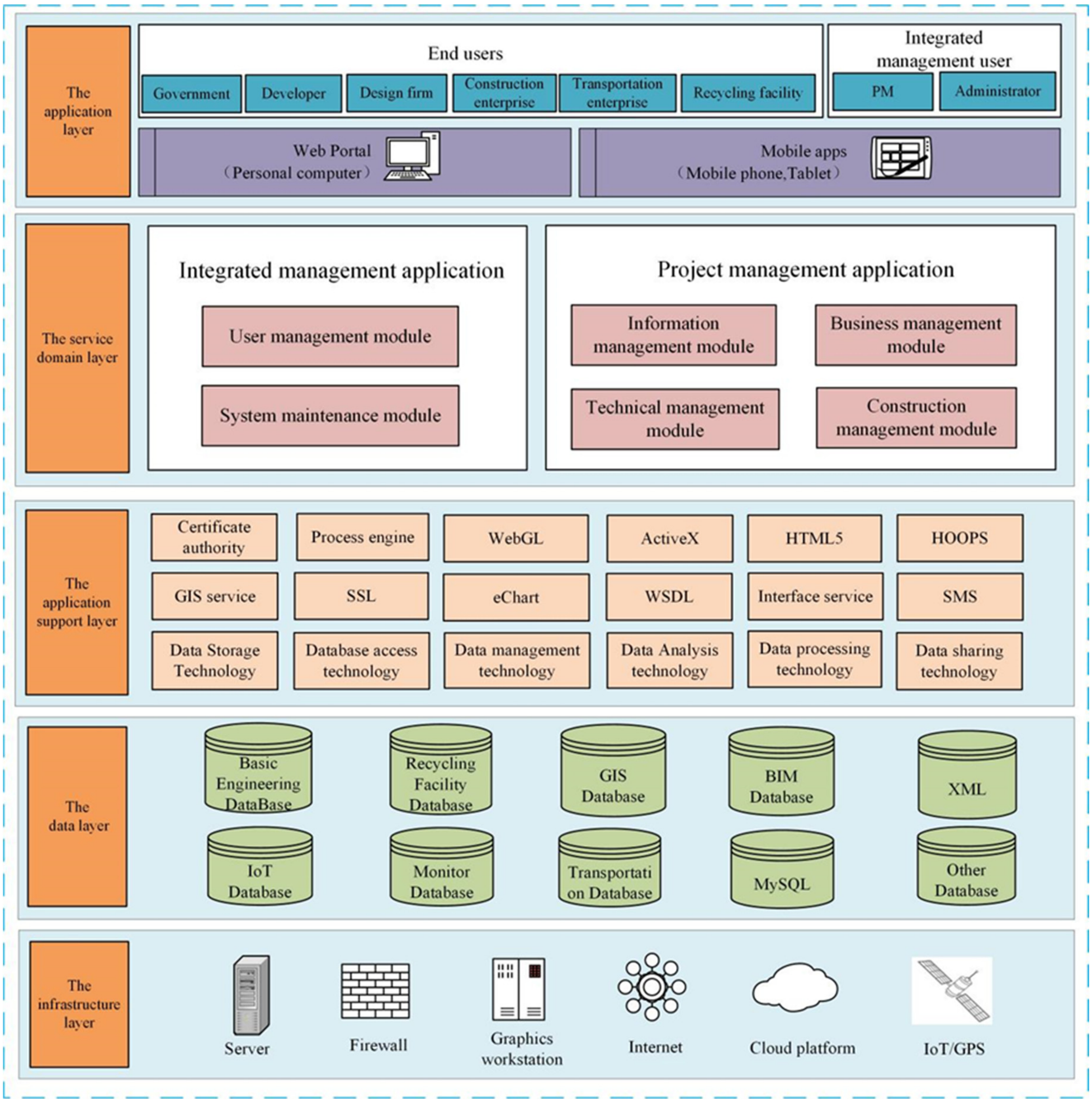

Figure 1. The overall framework of the BIM-GIS-IoT-based excavated soil recycling system.

In this paper, the BIM data were extracted into a GIS context to realize the integration of BIM with GIS. To avoid some essential details within the data being lost in the process [48], a unified building model (UBM) that encompasses both the IFC and CityGML models is used [49] to ensure data integrity. After that, the excavated soil recycling system architecture combines BIM, GIS, IoT, and SOA and adopts a C/S (Client/Server) and B/S (Browser/Server) hybrid model. With various SOA design components, loosely coupled web services integrate information from the BIM-GIS model with data from IoT networks. Meanwhile, the reusability of SOA services may provide a way for updating the parameters of BIM modeling using data from IoT sensors. On the one hand, the system gets data from IoT devices, while on the other, it performs creating/reading/updating/deleting activities in the data layer. Based on the technologies mentioned above, i.e., focus on the overall system architecture and highlighting the characteristics of service-oriented, this paper builds the excavated soil recycling system architecture by establishing a service model and dividing it into different layers.

The system adopts and realizes mutual access between various applications and services through functional module componentization and business process integration to realize data collection and management, information collection and sharing, and work collaboration in the whole process of excavated soil recycling, which can effectively avoid the problems of System Redundancy, slow response time, high maintenance cost, poor compatibility, fragile and easy to collapse [50]. With BIM as the core, the excavated soil recycling system architecture contains five layers: the application layer; the service domain layer; the application support layer; the data layer; and the infrastructure layer. The higher the layers in the system architecture, the more user-oriented it is; the lower the layers, the more infrastructure-oriented. The data requirements for integrated analysis were defined to provide relevant feedback while synchronously updating the modified basic model. Many types of analysis, such as the excavated soil's classification and quantity, require the integration of applications with different formats [51]. The research method reconfigures this exchange system by automating the data processing effort and making it an integral part of the exchange process. The system may create a mapping to the input data required by the application, or it may automatically convert the basic model to facilitate the specific analysis. The system architecture is intended to provide a fundamental digital construction model for excavated soil recycling, regardless of whether it is invoked by existing application software or a Program tailored to the demands of a specific organization or stakeholders.

3.1. The Infrastructure Layer

The infrastructure layer is the foundation for realizing all system functions and consists of servers, integrated security systems, graphic workstations, network systems, IoT devices, and GIS technologies [52]. This layer provides the required physical platform for numerous specialty areas.

3.2. The Data Layer

The data layer is located above the infrastructure layer and is the data center of the whole system architecture, containing primary data (main data that does not change with the fluctuation of the external environment, including basic project information, organization information, primary soil condition of project location, dictionary, IFC, WBS, etc.), BIM database, GIS database, MySQL, XML, IoT database, monitoring, and the identification database, transportation management database, recycling facilities database, other information data. The data layer provides the shared primary data and knowledge, which is called throughout the excavation project's whole process. This layer gives centrally accessible databases that could be accessed remotely, allowing stakeholders to collaborate and communicate more effectively. For recycling the excavated soil, this layer contains the applicable excavated soil's classification list and indices, which must be correctly mapped onto the excavated soil database and ontology for acquiring relevant excavated soil data from digital models. The quality of excavated soil quantification and prediction largely depends on the data collected [53] and the quality of data representation, and ease of knowledge extraction. Therefore, the database is kept up to date and repaired in real-time. The update of the database mainly relies on the collection, processing, and uploading of all kinds of data by all participants in the process of the excavation project development, which is the key for the system to ensure the accuracy and time of data and provide a strong guarantee for the integration and sharing of information.

3.3. The Application Support Layer

In the application support layer, the complementary services are located in the UDDI (Universal Description Discovery and Integration) service registry through WSDL (Web Services Description Language) files through the service bus [54], which provides stable and reliable technical support for the BIM-GIS-IoT-based excavated soil recycling. It includes authentication and authorization, the process engine, the search engine, interface service, GIS service, data storage technology, data access technology, data management technology, data analysis technology, data processing technology, data sharing technology, WebGL, ActiveX, HTML5, HOOPS, and eCharts and other related technologies. The application support layer establishes open BIM standards to guarantee system compatibility and data transparency. There are additional spreadsheet formats for the cost analysis of the excavation project, generic component models–OBJ, Material Library File (MTL), Polygon File Format (PLY), and soil classification (SC)–and software-specific models in this layer (rvt, pln, dng) [55]. The application support layer is an integrated environment that provides a unified application support service interface for all upper-layer module components to realize the integration of the module components, reduce the coupling between applications, and facilitate the expansion and deployment of the system. The application support layer's main services consist of the reading or writing of data from or to the data layer.

3.4. The Service Domain Layer

The service domain layer specifies ideas and functions developed on top of the application support layer to analyze and simulate all elements of the excavation project, mainly including excavated soil analysis and management. This layer mainly realizes the specific functions of the system. It provides management module components to the access layer for invocation according to the demand and authority, including two parts: integrated management application and project management application. The project management application includes four modules: information management module, technology management module, construction management module, and business management module; the integrated management application consists of two modules: user management module and system maintenance module. In addition, the service domain layer enables intelligent decision-making by extending the parametric properties of objects to obtain numerous elements of excavation projects such as cost, scheduling, and visibility. The applications in this layer allow for schedule preparation, automatic quantity surveying, cost calculation, and economic evaluation throughout the excavation project. After the initial work plan is prepared, these applications can adjust the work arrangement during the project and automatically complete the arrangement and combination of processes to ensure that the overall project schedule is completed on time. Through the automatic quantity calculation function of BIM, a high-precision bill of quantities for each scheme is prepared within a short period, followed by cost calculation of the corresponding scheme using the latest price information in the database and economic evaluation based on the magnitude of the economic return on the capital invested. At the end of the above process, the system will make a judgment and formulates a decision based on the conditions (Social benefit/Economic benefit/Schedule). The service domain layer serves as a platform for stakeholder interactions, document management, and information sharing. It is the operation layer for users to query and upload all kinds of information and data. It provides users with a corresponding access interface based on different permissions and makes displays and reminds them of all kinds of information instructions and queries.

3.5. The Application Layer

The application layer is the uppermost layer, through which different stakeholders could enter into the services domain layer. The application layer divides users into end-users and integrated management administrators, where end-users mainly consist of project-related personnel from the government, developers, construction companies, transportation companies, and waste recycling facilities. End-users can access the system and obtain and upload relevant information according to their authority, although they cannot change the data and information related to the system. The integrated management users are mainly the project managers and system managers of the construction unit, who mainly maintain and upgrade the system, backup and restore, and view all operations and information records of each participant, among which the project manager also needs to validate and approve the access rights of the relevant personnel of each participant and the programs proposed in the system. In case of significant changes in the project environment, the integrated management administrators can modify and delete the system-related information only with the authorization of senior management. This layer contains the entrance of BIM applications, which provides access to the services domain layer through web interfaces. Wired and mobile applications provide access to this layer on devices like personal computers, mobile phones, and tablet computers.

4. The Modules and Main Functions

According to the entire process of recycling excavated soil, the functional requirements of different users in the three stages of excavation, transportation, and recycling are fully considered, and the service domain layer of the BIM-GIS-IoT-based excavated soil recycling system is divided into an integrated management application and a project management application, which contains six modules (shown in Figure 2). The data is shared among the six modules.

Figure 2. The modules and main functions of the BIM-GIS-IoT-based excavated soil recycling system.

4.1. User Management Module

The User management module mainly includes three functions: user basic information; user registration/logout; and user rights management, which is accessed and managed by the integrated management administrator. The integrated management user registers users according to the list of project participants submitted by each stakeholder and provides accounts with corresponding privileges to the corresponding staff according to their relevant basic information. The integrated management administrator also modifies or cancels their accounts when the user information changes. Access control, intrusion prevention, denial of service (DoS) protection, and other security features are provided by this module [56], scalability and management models, and visible user licenses and agreements.

4.2. System Maintenance Module

The system maintenance module consists of seven functions: workflow setting; network information interface; collaborative platform management; system log management; system update and upgrade; system expansion; and secondary development platform, which is accessed and managed by an integrated management administrator.

4.3. Information Management Module

The Information management module consists of nine functions: basic project information management; model browsing; and display; information query; information upload; information review; information summary; information storage; information deletion; and the information prompt.

4.4. Technical Management Module

The technical management module consists of ten functions: excavated soil classification; BIM model creation and management; GIS model creation and management; model integration; BIM-based soil volume calculation; excavation-fill balancing; excavated soil transportation scheme; drawing review and modification; construction simulation; and IoT management; and all users can access and manage the corresponding parts according to their authority.

4.5. Construction Management Module

The construction management module consists of ten functions: technical interpretation of design intention; construction management; dispatch list management; monitoring and identification; safety management; progress management; quality management; truck dispatching management; material management; sampling and feedback; and all users can access and manage the corresponding parts according to their rights.

4.6. Business Management Module

The Business management module consists of seven functions: bidding; bid opening and assessment; bid award notification; contract management; economic analysis and evaluation; decision-making; and integrity management; and all users can access and manage the corresponding parts according to their authority.

5. The Workflow for Excavated Soil Recycling

The workflow of the BIM-GIS-IoT-based excavated soil recycling system is shown in Figure 3. Based on the on-site investigation and engineering geological investigation report, the design firm draws up relevant design drawings according to the requirements of the developer; after the drawing review, the construction enterprise sets up the digital platform, creates a BIM 3D model, and translates it into GIS format through IFC; then the integrated digital model will be tested for coordination. After inputting the basic information about the excavation project, the recycling facility, the construction enterprises, and the transportation company, the integrated digital model will automatically formulate the plan for the excavated soil recycling process simulation. The entire simulation recycling process includes excavated soil classification, construction simulation, recycling facility selection, excavation-fill balancing simulation, truck dispatching simulation, benefit and cost comparison, and automatically checking whether there are unreasonable or error processes; if the whole simulation process is running smoothly with no error, the result will be submitted, as a recycling plan for excavated soil, to the project managers from the developer, design firm, and construction enterprise for review. After the recycling plan is approved to be carried out, the project manager of the construction enterprise will issue the approved plan to each participating party. All the project members will consult the recycling plan to carry out construction.

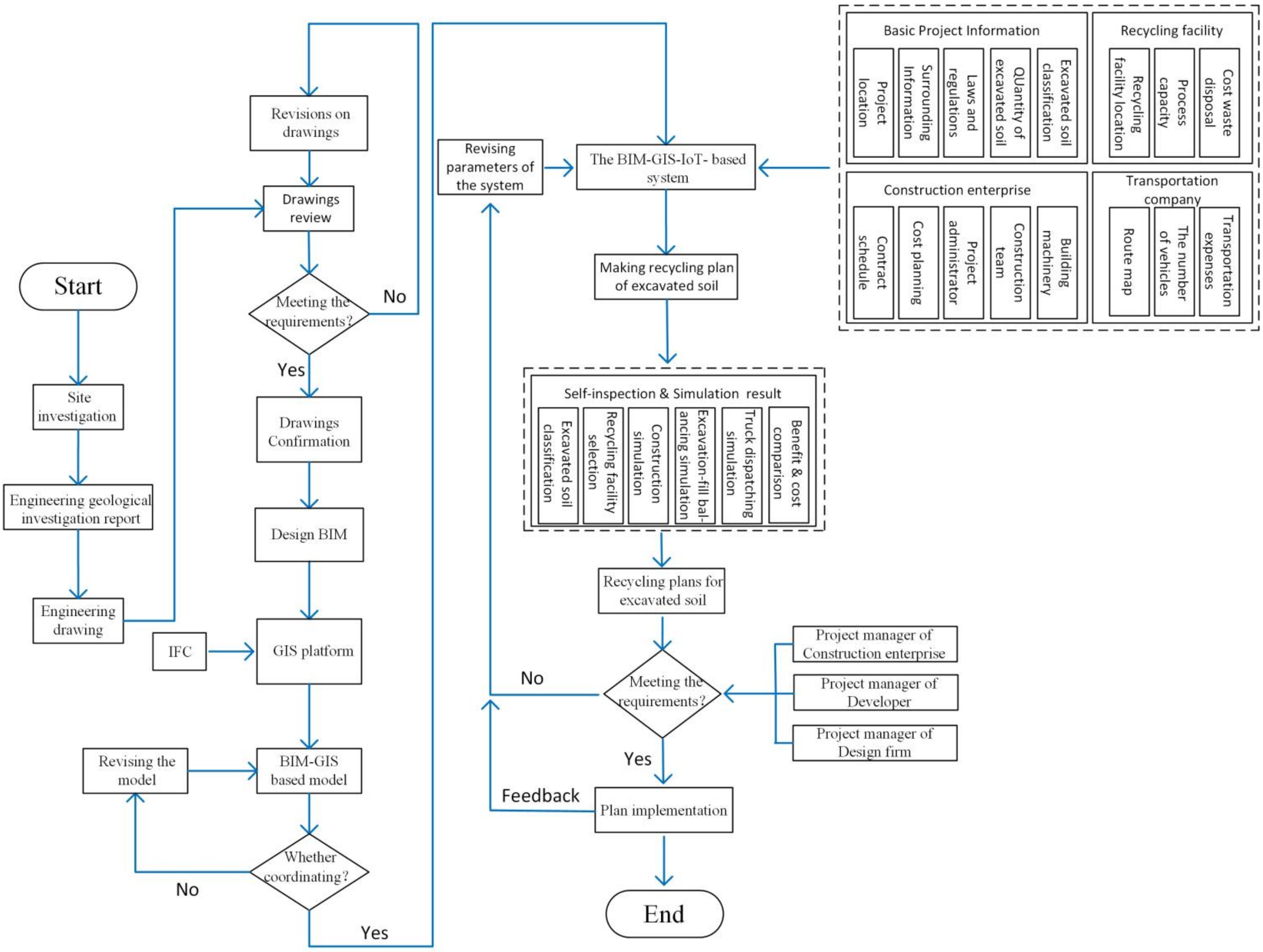

Figure 3. The workflow of BIM-GIS-IoT-based excavated soil recycling system.

The IoT technology is mainly used for the identification and feedback of excavated soil during transportation out of the construction site, so that excavated soil of different compositions can be efficiently delivered to recycling plants or landfills where the excavated soil could be appropriately recycled (seen in Figure 4). The recycling plants then upload the excavated soil reception information (vehicle information, soil composition, quantity of soil) to the system for feedback in real-time. Then, the recycling system confirms and adjusts project schedules and contract performance based on transportation and recycling data. In implementing the recycling plan phase, the BIM-GIS-IoT-based system collects and feeds the site information in real-time and automatically judges whether there is a significant change. If there is a significant change, the process will return to the excavated soil recycling plan phase to adjust the recycling plan and repeat the above simulation, approval, delivery, and implementation process, and if there is no change, the project is completed, and the process finished.

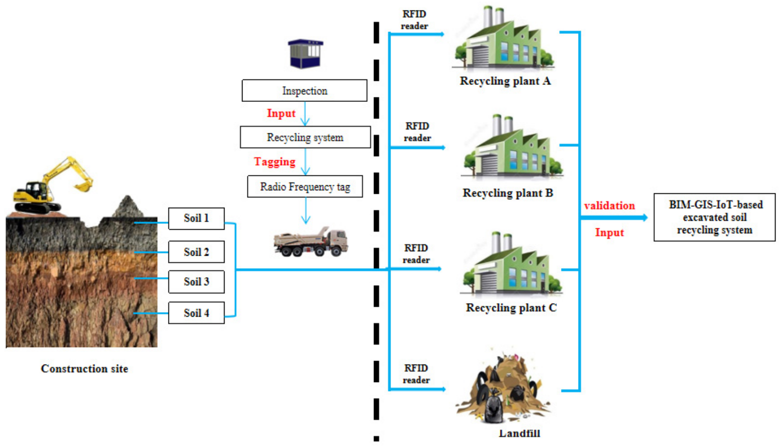

Figure 4. The application of IoT technology in the excavated soil recycling system.

6. Case Study

The case study offered in this section is an excavation project in Shenzhen, China. It is intended to confirm the viability of the given BIM-GIS-IoT-based excavated soil recycling system and validate it, considering its efficiency for managing and controlling excavated soil recycling. The BIM model was created by Revit (Autodesk Revit). The excavation project has a site area of 15,539.46 m^2, a building height limit of 150 m, and a total construction area of 103,000 m^2. The project has a two-story basement and an excavation depth of 13 m. Three hundred twenty-three thousand two hundred twenty-one tons of excavated soil will be transported and landfilled from the construction site. If the excavated soil does not recycle, a 50,503 m^2 (Height 4 m) landfill will be required, and approximately USD 10,148,226 will be paid (USD 31.4 per tons of residue for landfill and transportation costs) [57–59]. Thus, the demand for the considerable landfill area and high tipping costs make it feasible to recycle the excavated soil using recycling systems. Figure 5 shows BIM integration with GIS and the associated information and data invocation after the integration process.

After integrating BIM with GIS, the BIM-GIS model will be tested for coordination. Supposing there are no errors in the digital model, the basic information about the excavation project, the recycling facility, the construction enterprises, and the transportation company will be inputted into the model. According to an analysis of the geological report, the excavated soil at a depth of 5–10 m was rich in sand and gravel, totaling approximately 100,000 t. Recycling Plant A could pay USD 10/ton (including transportation cost) for this sand and gravel and only receive 2000 t per day; recycling Plant B would charge USD 5/ton (including transportation cost) yet could receive 5000 t per day. The project schedule requires 20 days to complete the soil excavation within this area; the system automatically schedules a recycling plan for part of the excavated soil, as shown in Table 1. The recycling plans for three different scenarios are given in Table 1. When specific conditions are provided, the system can automatically decide which recycling option to use.

Table 1. Recycling plans for the excavated soil at the depth of 5–10 m.

Item	Plan A	Plan B	Plan C
	Shortest Construction Period	**Lowest Cost**	**Completed on Time**
Recycling plant A	Receive 2000 t/d	Receive 2000 t/d	Receive 2000 t/d
Recycling plant B	Receive 5000 t/d	Receive 0 t/d	Receive 3000 t/d
Construction period	14.29 d	50 d	20 d
Cost	−71,450 US$	1,000,000 US$	100,000 US$

The application in the technical management module will automatically carry out the formulation of the plan for the excavated soil recycling process simulation and simulate the whole recycling process. The entire simulation is shown in Figure 6. By recycling the excavated soil from the above excavation projects, USD 3,239,717 in cost reductions were achieved by adopting an on-time completion strategy given by the BIM-GIS-IoT-based excavated soil recycling system.

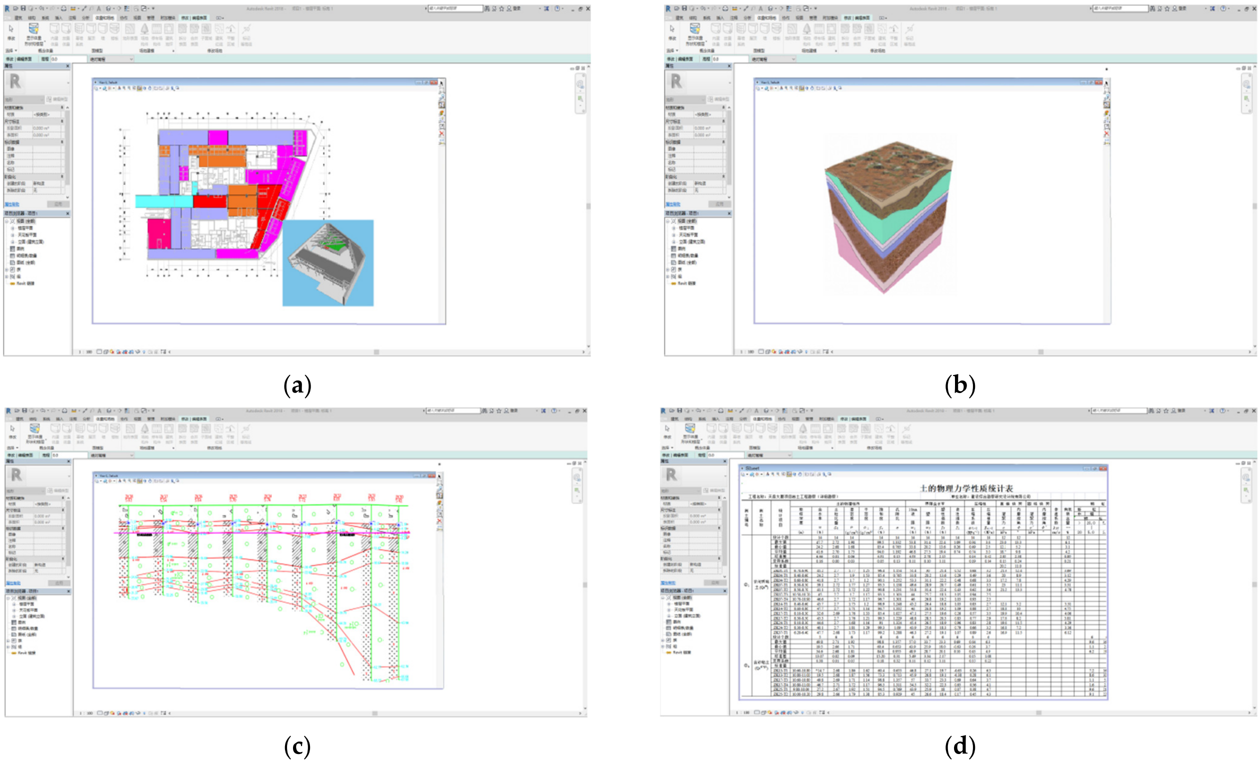

Figure 5. Models developed for the case study: (**a**) creates a BIM 3D model; (**b**) an integrated BIM model (architectural, Shapes, dimensions, and materials) with GIS through IFC; (**c**) the invocation of a geological report in the BIM model; and (**d**) the invocation of soil properties uploaded in a BIM model.

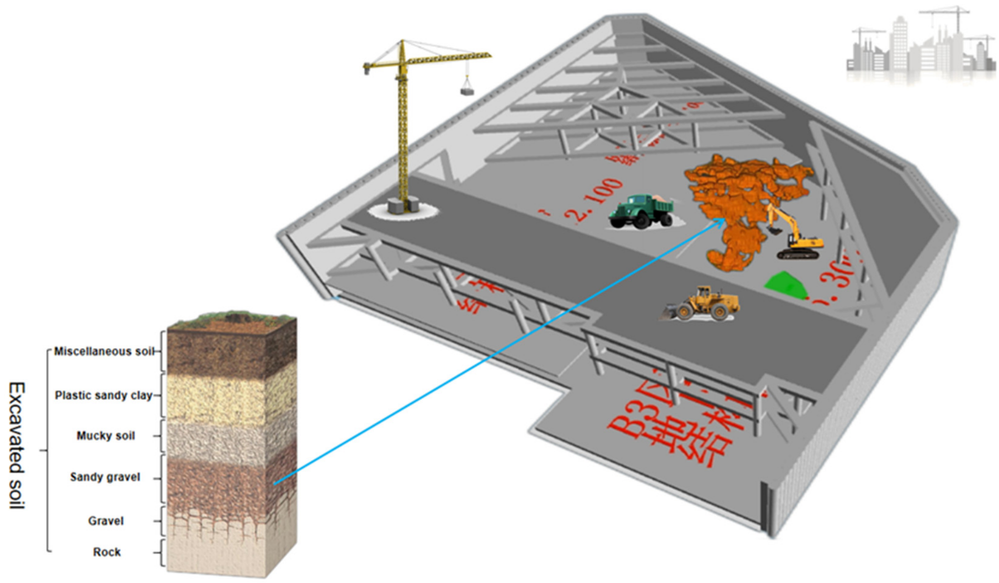

Figure 6. The simulation of excavated soil recycling process.

7. Discussion

Due to the traditional recycling methods for excavated soil lacking the ability to use the complete project information collected by the participants fully, a new reliable system based on BIM is proposed for excavated soil recycling in this paper. The conceptual framework for a BIM-GIS-IoT-based recycling system discussed in this research comes from the pressing problem of excavated soil. It avoids the disadvantages of the traditional excavated soil disposal method, which ignores recycling but focuses on solely minimizing construction costs or shortening the construction period. The BIM-GIS-IoT-based system enables smooth communication between project participants in construction processes for the entire excavation project life cycle. They can obtain accurate information about the project and upload their information for looking up, downloading, analysis, editing, and development in the BIM-GIS-IoT-based system.

The volume calculation function in the application of the system will automatically calculate and count the excavated soil volume transported out. The system could estimate the cost of different excavated soil recycling solutions and compare each solution. Due to different recycling facilities lacking uniformity in the recycling process, and technology, their recycling capacity and stacking capacity of excavated soil are also different, and some recycling facilities specify that only a specific type of excavated soil could be received. In contrast, others could recycle all types of excavated soil. Under the premise of meeting the schedule and cost control, the system automatically prepares the excavated soil recycling plan with minimizing social and economic costs for the excavation project according to the classification of soil, disposal charge, and transportation cost of each recycling facility. The recycling plan is based on being beneficial for all stakeholders. Firstly, the construction plan is optimized. The excavation sequence of the excavation project is designed with the multi-objective linear planning model for the in-site excavation-fill balancing plan and the excavated soil transportation plan to meet the requirements of different recycling facilities. Then, the information module will send the optimized plans to the developer, design firm, and construction enterprise for review. If the construction and recycling plans above are approved to be carried out, the business management module will start a process of biding-bid, opening-bid, assessment-bid award notification to realize the plans. After the relevant contract of the plans is signed, the integrated management administrator uploads the contract information into the system to save.

Excavated soil recycling companies recently faced up to the fact that the recycling industry is losing money at astounding rates, with recycling facilities incapable of handling the deluge of excavated dirt in a timely enough manner to generate profits [60]. Thus, many recycling plants have been shut down for economic reasons. Recycling for excavated soil has certainly seen positive repercussions for the environment, however, recycling the wrong way creates headaches and losses of profit for all stakeholders. With the dramatic impact of excavated soil on the environment, the government, developers, design firms, construction enterprises, and recycling companies may have to find a better way to handle all of the excavated soil it produces or receives. The loss of money of excavated soil recycling is primarily due to extensive management of the soil in the recycling industry—which means the no recycling plans from the source in the excavation project. The excavated soil without sorting cripples the economics of recycling. The process to sort the excavated soil at recycling facilities diminishes its profitability, increasing the cost of recyclables and discouraging many businesses from reusing recycled materials [61]. It can be believed that the BIM-GIS-IoT-based excavated soil recycling system can better handle the above problems to promote the whole C&D waste reusing and recycling industry.

8. Conclusions

The value of recycling excavated soil has been proved to significant in the face of pressing realities. After discussing the disadvantage of the current excavated soil disposal methods, we have developed an excavated soil recycling system based on BIM technology. The system is intended to provide a fundamental digital construction model for excavated soil recycling, regardless of whether it is invoked by existing application software or a program tailored to the demands of a specific organization or stakeholders. It makes excellent use of the rich information stored in digital information models, may create a mapping to the input data required by the application, or automatically convert the basic model to facilitate the specific analysis. This system can not only serve as an excavation project simulation tool before construction, but also serve as a tool to recycle the excavated soil and cost evaluation. This paper demonstrates the modules and functions of the excavated soil recycling system in detail. With BIM and relevant information technologies being primarily developed worldwide, it is expected that BIM will be increasingly used for excavation projects. This BIM-GIS-IoT-based excavated soil recycling system would be used universally to resolve the urgent question of too much-excavated soil for megacities worldwide.

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