Developing 3D Geospatial Model using Advanced Surveying System

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Abstract

This paper presents a new methodology to connect the surveying process directly with accurate geodatabase at 3D Geographical Information System (GIS) for any urban space without re-entering the surveyed data. This procedure conserves time and effort in studying and developing various urban projects whether current or extended. Additionally, the proposed approach is based on integrating the used surveyed systems with the appropriate geospatial surveyed software side by side using Building Information Modeling (BIM) for studying all details of the architectural objects into a geo-context. Accordingly, a dedicated proposed framework is proposed to develop the urban studies especially the development of the 3D geospatial models. The latter explores the importance of spatial relationships in surveying systems for different urban spaces that comprise a multilayer of analysis. Firstly, the spatial data of studied urban space is analyzed based on the database extracted from the surveyed systems used. Then, exporting this digitized data to ArcGIS software to build and analyze the urban space under study as a geospatial Model. Thus, the planner defines the required functions and urban needs that are be implemented in the study area. Secondly, using advanced geospatial surveyed software based on the concept of the highest reality and accurate database to link with the geospatial model. Finally, the last stage integrates the results obtained from the different surveyed systems and software used. Consequently, this paper introduces the effective contribution of the appropriate integrated system with an accurate geodatabase that redounds to taking appropriate planning decisions to develop or re-plan the presented urban project.

Keywords

3D Geographical Information System (GIS), 3D Cadastre, Spatial Relationships, 3D Geospatial Models, Surveyed Systems and Geospatial surveyed software.

1- Introduction

The high need for new advanced methods in surveying any urban site has opened up the scope of studying 3D geospatial models (Sadeghi-Niaraki and Choi, 2020). Various geospatial surveyed software is used to construct an orthophoto and 3D model of the surveyed region which results from error data of 3-5 m as DJI Phantom 4 Pro and DJI Mavic Pro software (Specht et al., 2020). Therefore, planners need to study and analyze the 3D geospatial models in depth that are done using the integration of BIM and 3D GIS models. 3D GIS model is a standard for modeling various urban sites, while the BIM model is the main reference for building objects and all details of the urban sites. Moreover; there are a range of users, local governments, urban planners, environmental agencies and utility companies, architects, and engineers who develop and utilize the increasingly sophisticated 3D geospatial models of the urban environment to plan and monitor various services (Wang et al., 2019). It is noteworthy to differentiate between surveyed systems and geospatial survey software that use BIM model which is obtaining more real photogrammetry with accurate results of 3D urban sites to be updated or extended or re-planned.

Firstly, a planner should define the total requirements of the site under study taking into account the existing infrastructure to be conserved if the site needs to be excavated. Secondly, the possible architectural projects which can be executed are determined by the designer. As well, there are many geostatistical and database techniques available to carry out the interpolations between surveying measurements and based 3D buildings (Watson et al., 2015). Recently, with highly accurate geometry, more considerable efforts are needed for the management of surveyed buildings with more details (semantic, attribute, material, temporal, and relationships) of the object and its sub-elements. This could be achieved using the developed Building Information modeling (BIM) technique in surveying systems that combine 3D modeling and information management (Yang et al., 2020).

Secondly, considering the surveying types as (a) Geometric model reconstruct the real entity with a holistic shape. (b) The semantic model recognizes and endows the meaning of the architectural elements. (c) The parametric model defines and alters the shape of the elements by parameters. (d) The information model builds a database with the attached attribute, material, and relationship information about the entity and its components as well as the 3D geometry (Barazzetti, 2016). Moreover, this research presents a newly developed surveyed system and geospatial surveyed software tool as ContextCapture to produce the 3D accurate models for every surveyed architectural and infrastructure project. Moreover, planner can add point clouds from laser scans results through surveying for more accuracy according to available funding for fine details, sharp edges, and geometric precision. Hence, the proposed or current urban spaces and their 3D buildings are most suited for development, where the analysis results are incorporated into the accurate geodatabase after using the surveyed systems and appropriate geospatial surveyed software. Nevertheless, none of these tools, software, and associated methods are used in the surveying field at the local level in Egypt with accurate depth excavation nor the types, quantity, and quality.

1.1. Statement of problem and motivations

Based on the above-explained considerations for surveying systems, the problematic of developing any current urban space, in particular, is mainly influenced by types of surveying and determination of the architectural functions based on geodatabase using ArcGIS software. Many researches have studied the same topic with different cases studies as geological surveying and heritage building information modeling based on surveying tools. But the main concern issues are the lack of accuracy and comprehensiveness of geodatabase due to uncovering the previously mentioned considerations entirely in the study alongside. In summary, the problematic of accurate surveying systems with quick data collection time is mainly influenced by two points, the type of surveying system and developing determination of the urban site under study. This issue also represents a motivation for the research work presented in this research, where the surveying system consumes time and effort with the accurate geodatabase.

It is noticed that some systems used surveying of 3D buildings with the full surrounding environment through integrating the information data with photogrammetric survey and Light detection and ranging (LIDAR) datasets or 3D cadastre technique which use various procedures for the surveying analysis in urban environments. Further, in archeology and architecture, 3D surveying and mapping sites are be performed by low-altitude image-based approaches (Mouget and Lucet, 2014). Also, there are many other surveying systems used in different fields, such as environment, emergency management, and traffic monitoring (Nex and Remondino, 2014). Further, geoinformation data and airborne remote sensing data have been used in surveying urban fields (Martín et al., 2015). Consequently, various studies have been used different kinds of photogrammetry processing software, such as Pix4D, Agisoft Photo scan, and 3DSurvey that produced the same results as 3D model or orthophoto (Alidoost and Arefi, 2017).

Besides, some studies presented the usage of 3D surveyed software to process the photogrammetry data since they can work with any drone device or any camera to develop real urban projects, make it fast and efficient at land surveying projects (Nex and Remondino, 2014). Also, there are some studies that presented the usage of drone devices in surveying systems that are navigated following flight plan and automatically capture images data for optimal 2D, 3D maps and models following the flight plan from the application by the method of the waypoint navigation system. A waypoint is a set of coordinates that identify a specific point in the physical space (Dean and Recht, 2021). Furthermore, there is another surveying system is called Grid Type flight plan which is one of the most widely used techniques of aerial survey for generating orthophotos or 2D and 3D maps (Alidoost and Arefi, 2017).

Nonetheless, all the above studies insufficiently considered the comprehensive process of surveying above and underground together in urban sites to avoid any problem that could be appeared when excavating as cutting any current cable or tubes. This problem motivates another alternative approach in this research for determining the surveying system with accurate results that are integrated with specialized software especially in Egypt at the local level based on spatial analysis.

1.2. Paper objectives and organization

In the light of the above-mentioned motivations, this paper introduces a new approach for using the integrated surveying system at a given urban space based on its needed services and developments. In addition to specifying the full site functions with each other that include the existing infrastructure and the 3D studied buildings. In this direction, a proposed framework is introduced for implementing the integrating method of surveying system and geospatial surveyed software. The implementation is organized in three ultimate stages as discussed hereinafter.

The first stage seeks identification of the urban fabric components in the urban space under study as a Geo-Model in ArcGIS software that is analyzed to identify the spatial data of the urban space and the needed services.

Whereas, in the second stage, applying the advanced surveying system on the defined urban space and importing this data to the geodatabase to be added in ArcGIS software. It contains the networks of roads and 3D buildings beside the surveyed data of infrastructure networks levels that are analyzed in ArcGIS software. This analysis is performed by using a spatial analysis tool, thereafter, the best-suited services are determined that site needed to be extended.

Finally, in the last stage, applying the geospatial surveyed software to obtain the infrastructure networks and compare their compatibility with road networks that are jointly gathered and inserted into the geodatabase in ArcGIS software. In summary, this paper proposes a new method based to be applied on the urban local level. This method depends on accurate results of surveying to save time and the efforts of planners. Besides, seeking to obtain appropriate decisions making for developing strategies that are related to the urban field.

In this way, planning of smart urban spaces is be enhanced without negligence of the necessary infrastructure with 3D buildings related to spatial analysis with the accurate geodatabase.

2- Methodology of the Paper

In this section, the research methodology is illustrated through the main steps adopted for the implementation of the proposed method.

- Step (1): Identification of the current urban space by surveying system as Vidente System in the site that includes all roads networks and 3D Buildings to assign all data as 3D Geo-Model in ArcGIS software.
- Step (2): Analysis of the spatial relations of 3D Geo-Model of the studied urban space using ArcGIS spatial analyst tool.
- Step (3): Using geospatial surveyed software as ContextCapture to detect the underground component that includes the infrastructure networks to avoid any damage for them.
- Step (4): It focuses on data gathering and insertion of the obtained results to the geodatabase in ArcGIS software, including the comprehensive study of the surveyed area both above and underground surfaces. The integrated procedures of the paper methodology are illustrated in Fig 1.

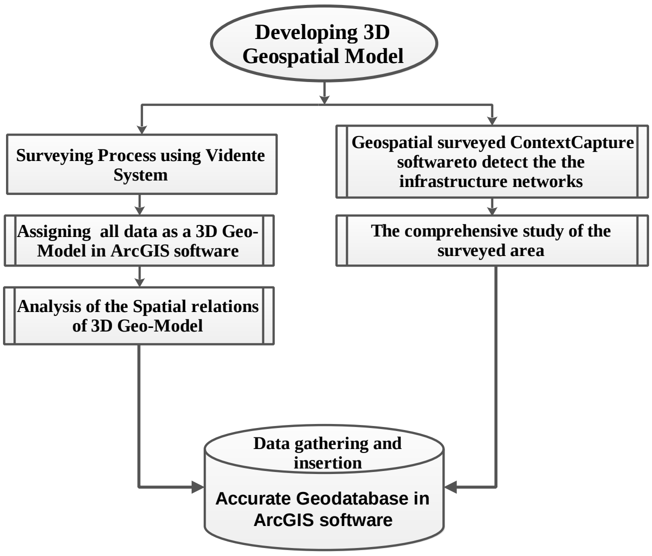

Fig 1. Flowchart diagram of the paper methodology.

3- Presenting Various Surveying System

The research presents the various surveying systems as 3D cadastre and Vidente System that used 3D GIS application in urban space to analyze it. 3D cadastre elaborates the details of the applications of 3D GIS from three aspects: 3D data and 3D modeling, 3D simulation, visualization, practice, and decision-making support.

3.1 3D Cadastre System

The 3D cadastral system detects the urban features which concern the urban planning, land resource, and real estate of municipalities, whether they are on, above, or below the earth's surface. Representing the geometry of 3D cadastral objects is done using 3D GIS to associate the semantics and transaction attributes. All 3D surveyed objects in urban spaces are assigned with spatial relationships as illustrated in Fig 2.

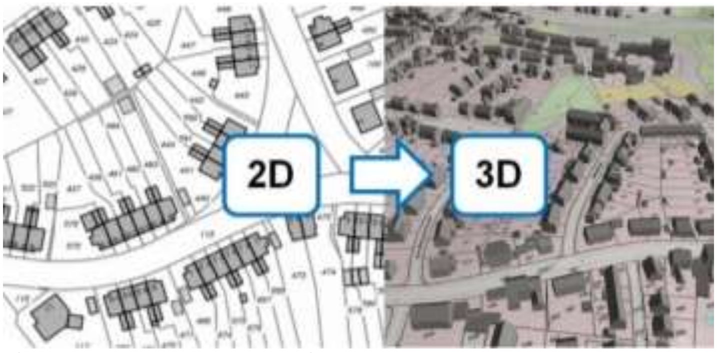

Fig 2. The transforming study from 2D data to 3D urban space of an urban space using 3D cadastre technique.
Source: www.gim-international.com/content/news/germany-s-progress-towards-a-multi-dimensional-cadastre (13/09/2021).

Moreover, the 3D cadastral system illustrates the detailed surveying areas using the infrastructure geodatabase by studying the following:

a. **Rapid Development:** It is mainly concerned with developing and utilizing the 3D urban space.

b. **Cadastral Management:** The study analyzes and visualizes various lands and other real estates. This is according to registering the legal status, attributes, and rights.

c. **3D Property Unit**: It is used in developing 3D urban management which is a comprehensive concept that integrates lands, 3D buildings with 3D data, parties (Ying et al., 2012).

The urban model depends on the study of the 3D cadastre data and 3D GIS data to define the specific geospatial model and its various urban features for achieving a comprehensive digital design of the 3D urban spaces as presented in Table 1 and Fig 3.

3D GIS	3D Cadastre
Studying 3D spatial data of: ▪ Admin Boundaries ▪ Roads ▪ Blocks ▪ Terrains	▪ 3D Boundary Points ▪ 3D Land Parcels ▪ 3D Buildings 3D Property Units

Table 1: The main features for studying the specific geospatial model with two integrated 3D GIS and 3D Cadastre objects.
Source: S. Ying, R. Guo, L. Li, and B. He, **"Application of 3D GIS to 3D cadastre in urban environment"**. in 3rd international workshop on 3D cadastres: Developments and practices, 2012, pp. 25–26.

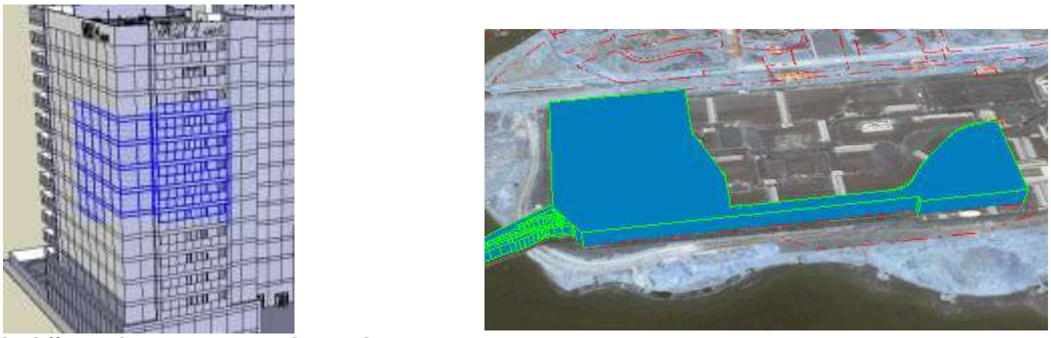

Fig 3. Studying the difference between 3D GIS and 3D Cadastre.
Left: Studying 2D, 2.5D, 3D physical shapes using 3D GIS.
Right: Studying closed volume of 3D space using 3D Cadastre as a 3D Geometric primitive.
Source: Ying, R. Guo, L. Li, and B. He, **"Application of 3D GIS to 3D cadastre in urban environment".** in 3rd international workshop on 3D cadastres: Developments and practices, 2012, pp. 25–26.

-3D Modeling of Cadastral objects

The modeling depends on integrated steps to build an accurate 3D cadastre urban space as follows:

a) Precise geometrics of consistent topological relationships.
b) Modeling each 3D volume cadastral object by 3D geometry.
c) Presenting the precise boundary of property units and their 3D location.
d) The accurate visualization of the 3D cadastre illustrates the distributions of occupations, partitions of land space, and urban space to give clear ideas for users or to support decision-making for the government as shown in Fig 4 (Peters and van Kolfschoten, 2020).

Fig 4. Visualizing of cadastral objects of 3D land space and 3D buildings of the 3D City of Berlin.
Source: www.virtualcitysystems.de/en/references (16/09/2021).

3.2 The Vidente System

The system presents the 3D visualized data models over video footages of underground infrastructure networks on handheld devices in real-time as virtual excavation tools. These tools like spatial Augmented Reality display (AR) that integrates with Esri ArcGIS® software. Also, the system performs accurate global localization and poses tracking of virtual objects with the physical objects in real-time (Carmichael et al., 2012). Planners can use the Vidente System such as in water and sewage utility systems that are operated by their authorities according to updating geodatabase on daily basis. Moreover, this system enables planners to store, analyze the geospatial data on-site and take their planning decisions, especially in urban expansion projects, taking into account the infrastructure, without damage. Also, Vidente System detects the environmental problems of the urban infrastructure networks to solve and upgrade them by accurate defining X, Y, and Z. Given the aforementioned, Vidente System enables planners to expand the initial path beneath the ground, pull various cables for water lines, electricity, the telephone of fiber optic cables and lines by X-Ray visualization views beneath the ground. Besides, intersecting the ray from a "virtual laser pointer" with the Digital Elevation Model (DEM) by reducing interruption to traffic as illustrated in Fig 5.

Fig 5. Using Vidente System in generating the 3D underground infrastructure networks via handheld AR device at average depth from 3.0 to 4.0 m.

Source: Carmichael, G., Biddle, R., Mould, D., 2012. Understanding the power of augmented reality for Learning, in: E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education. Association for the Advancement of Computing in Education (AACE), pp. 1761–1771.

4- Presenting a Geospatial Surveyed Software

The second part of the study is concerned with geospatial surveyed software as ContextCapture using an available group of modules under study. Using ContextCapture enables planners to use ordinary photographs to cost-effectively produce the 3D models of the most challenging conditions for every infrastructure project via smartphone camera to capture images. For additional accuracy, adding point clouds from laser scans results in fine details, sharp edges, and geometric precision. Furthermore, creating and using 3D models of any scale, from objects measuring a few centimeters to entire cities according to the image resolution. Thus, this geospatial surveyed software provides the precise real-world context for design, construction, and operations decisions throughout the lifecycle of projects as presented in Fig 6.

Fig 6. Producing 3D geospatial model of reality mesh model using ContextCapture software.

Source: www.architosh.com/2018/10/bentley-acquires-agency9-to-help-them-realize-digital-twin-for-every-city/ (17/09/2021).

Moreover, the surveyed data then is accessed and shared the richly photo-textured 3D models of existing conditions in any CAD or GIS workflow on desktop and mobile devices in many formats. This aids cities and towns in visualizing the urban infrastructure assets, represented in GIS data, terrain surveys, and BIM models for buildings in an accurate georeferenced database. In addition, the planner also uses ContextCapture software with Point Clouds that are be enriched, segmented, classified, and combined with engineering models. Then, the ContextCapture Editor's capabilities are advanced 3D modeling, cross-sectioning, brake lines, and ground extraction to model as-built conditions quickly and efficiently. As a result, the planner improves the point-cloud evaluation and produces more accurate engineering models, animations, and renderings for a presentation. Besides, producing and working with Large, scalable terrain models created from many sources including point clouds, brake lines, raster digital elevation models, and existing triangulated irregular networks. Scalable terrain models are always up to date, as they synchronize with the original data sources. This adds value through a global, current, integrated representation of all geodatabase that can perform analysis using a variety of display modes as shown in Fig 7.

Fig 7. Precise real-world context with reality modeling for design and construction workflows using ContextCapture software.
Source: www.architosh.com/2018/10/bentley-acquires-agency9-to-help-them-realize-digital-twin-for-every-city/ (17/09/2021).

5- Studying of the 3D Proposed Geospatial Model

3D proposed geospatial model supports a more efficient, productive, and collaborative design workflow that depends on the integration steps which are executed using various data sources as survey, geospatial information in ArcGIS. Moreover; designed data of 3D BIM models from Autodesk 3ds Max® software based on the integration between surveying system and 3D ContextCapture software that has been created through the following integrated steps:

a) Capturing the 3D real model using Vidente System that includes all surveys data (point properties, position on photos, and positioning constraints) which are exported to an XML format that imported in the accurate geodatabase at ArcGIS software as seen in Fig 8. So, it is obtained geo-referenced map in accurate x and y coordinates that connect to the current geodatabase as a geospatial model.
b) Visualizing the 3D geospatial context using 3D ContextCapture to capture the infrastructure data, so it is possible to access the underlying data by selecting the classified reality mesh as illustrated in Fig 9.
c) Integrating the geospatial information and BIM are achieved at semantic level with the interoperability of the urban data from the infrastructure step to execute the buildings as presented in Fig 10.
d) Obtaining 3D Proposed Geospatial models that include semantic information and spatial relationships of building elements and urban data in a defined urban space by inserting the geodatabase from ContextCapture software to ArcGIS software with accurate Geodatabase as seen in Fig 11.

Hence, this sequence is executed by supporting all phases of design according to all detailed urban and architectural constraints required for the proposed urban project.

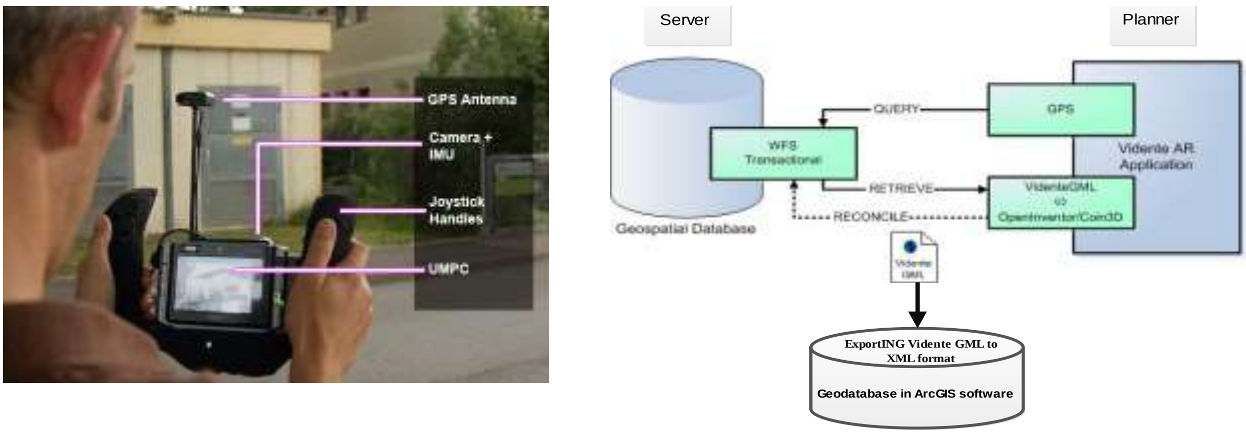

Fig 8. Using Vidente System to survey defined urban site, then converted the output data to an XML format in accurate geodatabase at ArcGIS software.
Source: Researcher.

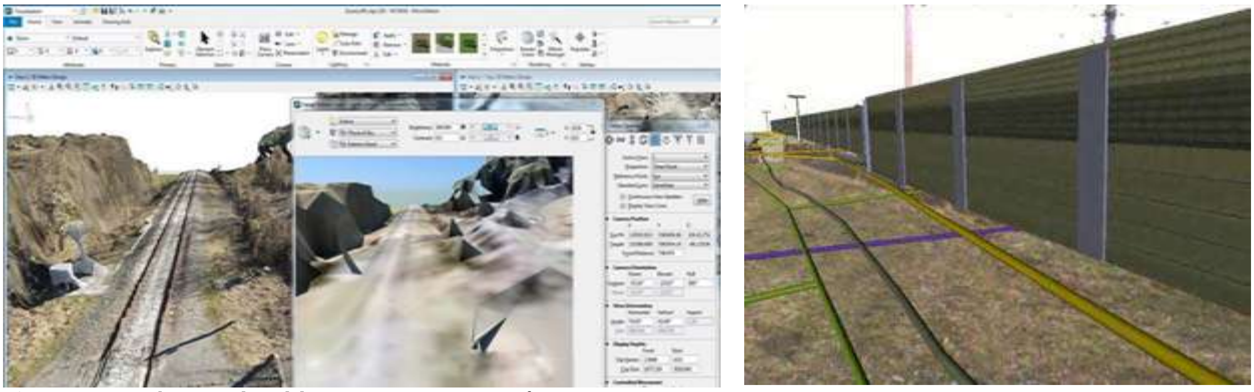

Fig 9. Capturing the 3D real model using ContextCapture software.
Right: Capturing the whole site in the real world that converted to the Geospatial model with all accurate database.
Left: Snapshot of the augmented live video captures the railway with underground current infrastructure.
Source: http://www.freesoftwarefree.com/bentley-context-capture-center-4-4-with-crack/ /(17/09/2021).

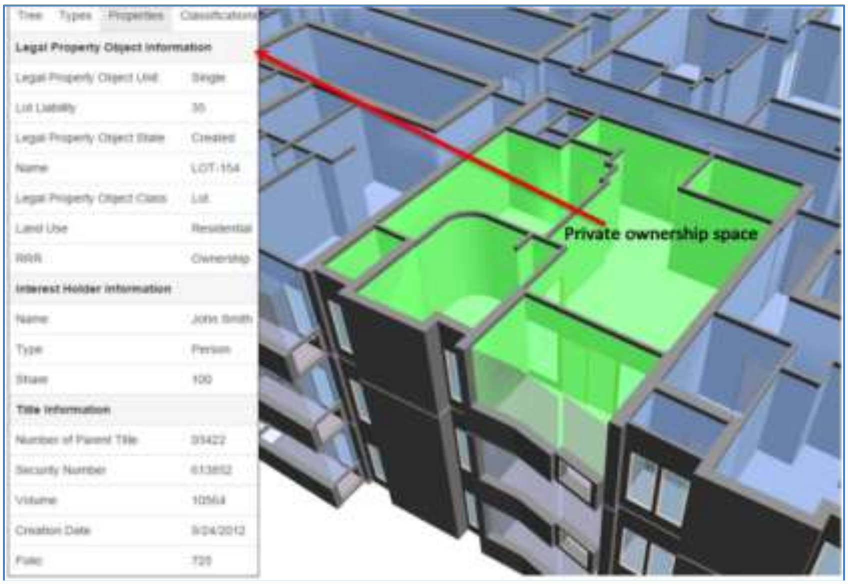

Fig 10. Designed data in 3D BIM models depends on the integration between surveying system and 3D ContextCapture software. On the left, a list of attributes of the private ownership space.
Source: (Atazadeh et al., 2016)

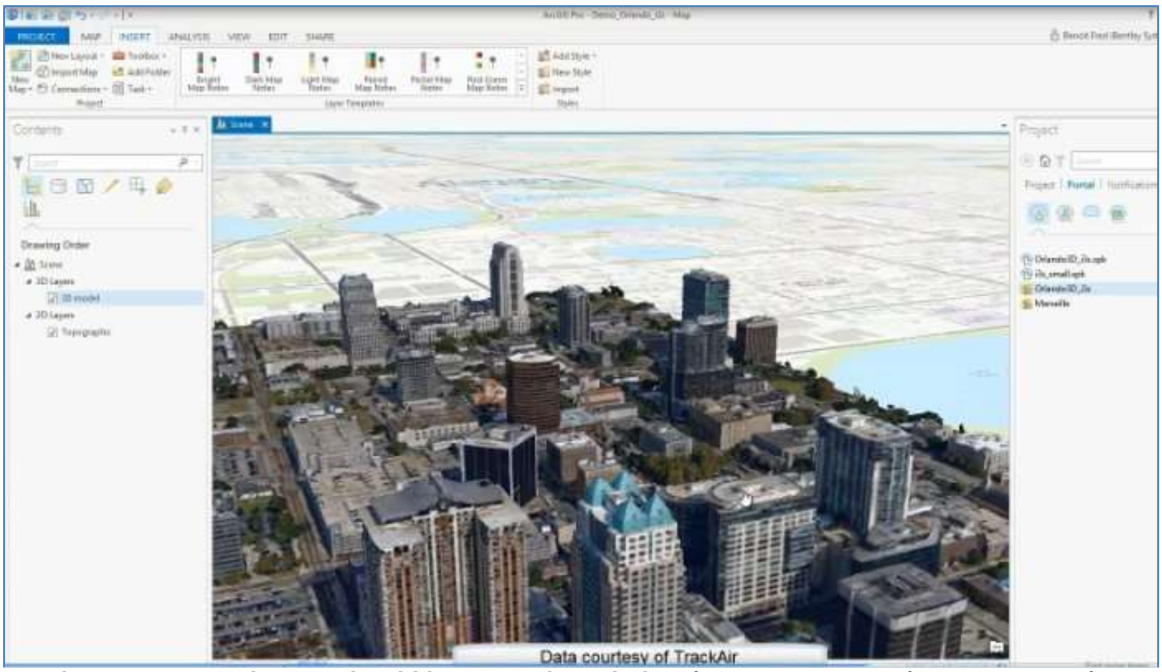

Fig 11: Obtaining 3D Proposed Geospatial model by inserting the geodatabase from ContextCapture software to ArcGIS software with accurate Geodatabase.
Source: www.linkedin.com/pulse/bentleys-contextcapture-now-supporting-esri-i3s-3d-scene-john-taylor/ (17/09/2021).

From the analysis, it is found that integrating the surveyed system and geospatial surveyed software presents the accurate results of 3D urban sites to be updated, or extended or replanned without any damaging especially the current infrastructure. Furthermore, the time and efforts of planners are conserved because any urban space is surveyed easily and then imported its data to the accurate geodatabase in ArcGIS software to be stored and updated.

6- Proposing Framework for developing the 3D Geospatial Models

Developing the 3D geospatial models depends on two factors: spatial information database, the accurate surveyed system with using advanced geospatial surveyed software. The spatial information is based on a GIS database that has extensive functionality and analytical capability of multiple queries features which are linked to geodatabase from the ContextCapture software. The latter is built on-site in real-time and depends on Ortho-photos that measure, store, and record the urban surveyed data. The proposed framework illustrates the development of a 3D geospatial model for various current or the proposed urban projects. This process requires many steps that depend on each other to generate a smart 3D geospatial model from the construction of a 3D GIS model that integrates with the surveyed data from Vidente System and ContextCapture software to analyze and evaluate the 3D geospatial models. So that planners directly reflect the captured data input onto the model which significantly reduces the time and cost of constructing the proposed product by studying the following integrated steps that depend on data structure connection as illustrated in Fig 12.

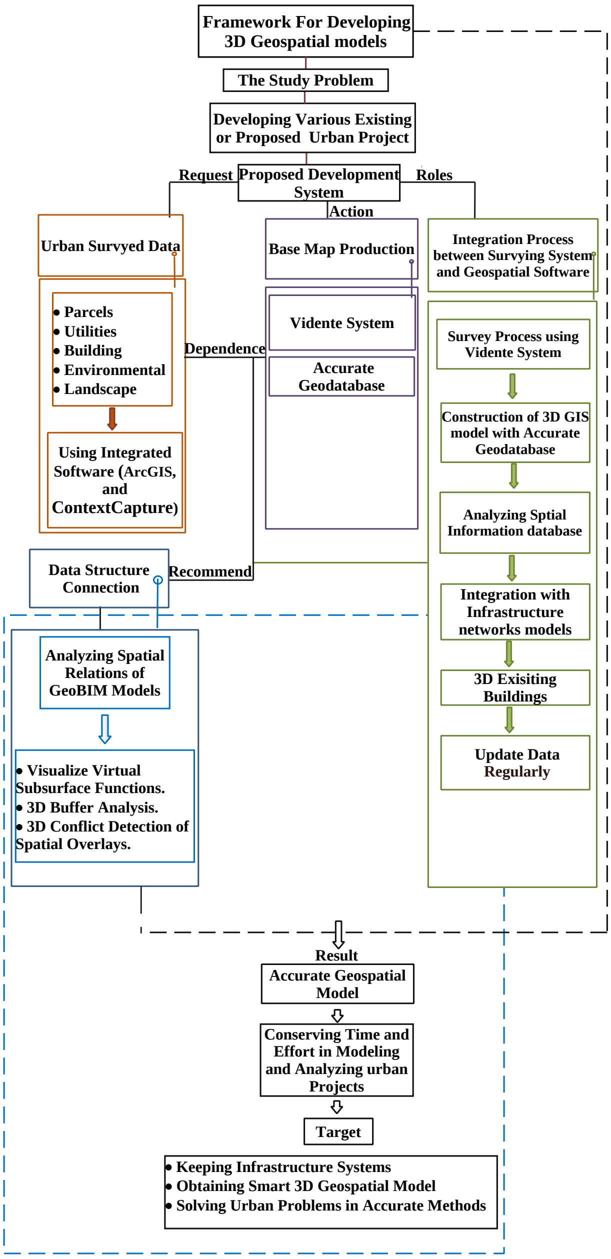

Fig 12: The Suggested Framework for developing 3D Geospatial models.
Source: Researcher.

7- Recommendations

A. Using the proposed surveying system is a huge challenge for the governments to manage 3D land space using accurate geodatabase using ArcGIS software which needs the support of 3D advanced surveying systems.
B. Supporting the 3D integrated visualization of entities above, and underneath the earth's surface supports comprehensive urban studies.
C. Integrating ContextCapture software with an advanced surveying system is ideal for urban and infrastructure projects throughout the design, construction, and operations of any urban project. This procedure reduces the cost and time for capturing and increasing the accessibility of reality data throughout projects and among enterprise stakeholders.
D. Presenting a new vision for studying the benefit of integration between BIM and 3D GIS models into a geo-context to develop various urban projects which have been applied in important fields such as urban planning and virtual city especially for future studies.
E. Proposing a new framework develops the urban studies as 3D geospatial models to analyze the GeoBIM models accurately.

8- Conclusion

This research has introduced an effective integration between advanced surveying system and accurate geospatial surveyed software to develop the 3D urban models spatially at the local level in Egypt. The produced model is a new method that improves the urban planning field. Moreover, the outcome of this research achieved two ultimate advantages. Firstly, creating a Geo-Model is efficient to be analyzed spatially using ArcGIS software. Secondly, studying more architectural details with aiding of 3D BIM model in a GeoBIM model that is implemented through an integrated Autodesk 3ds Max model and ArcGIS software is very helpful for planners in the comprehensive study of urban projects. Also, analyzing the infrastructure networks with architectural 3D buildings through all analyses of 3D GIS model using ContextCapture software leads to accurate results with more realism. Finally, the obtained results are incorporated into the geodatabase directly without re-entering any data which conserving time consuming and costs to study the urban project under study. In this context, applying the proposed method optimally enhances the planning of future urban spaces or replanning the existing ones without any defects or causing any damage to the current infrastructure concerning spatial analysis. Moreover, the proposed framework of an integrated system is contributed in resolving the issues of urban data according to the proper characteristics of planning which is used at a local level because the traditional methods in inserting data from the real sites lack accuracy. Further; the proposed framework makes a comprehensive planning process of 3D geospatial models' studies that support the expert urban planners to develop the urban needed functions and update the long-term urban strategies which lead to boost the design process, and analyses on the urban scale.

References

Alidoost, F., Arefi, H., 2017. COMPARISON OF UAS-BASED PHOTOGRAMMETRY SOFTWARE FOR 3D POINT CLOUD GENERATION: A SURVEY OVER A HISTORICAL SITE. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences 4.
Atazadeh, B., Kalantari, M., Rajabifard, A., 2016. Comparing three types of BIM-Based Models for managing 3D ownership interests in multi-level buildings.
Barazzetti, L., 2016. Parametric as-built model generation of complex shapes from point clouds. Advanced Engineering Informatics 30, 298–311.
Carmichael, G., Biddle, R., Mould, D., 2012. Understanding the power of augmented reality for Learning, in: E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education. Association for the Advancement of Computing in Education (AACE), pp. 1761–1771.
Dean, S., Recht, B., 2021. Certainty equivalent perception-based control, in: Learning for Dynamics and Control. PMLR, pp. 399–411.
Martín, A.M., Domínguez, J., Amador, J., 2015. Applying LIDAR datasets and GIS based model to evaluate solar potential over roofs: a review. energy 2015, Vol. 3, Pages 326-343. https://doi.org/10.3934/energy.2015.3.326
Mouget, A., Lucet, G., 2014. PHOTOGRAMMETRIC ARCHAEOLOGICAL SURVEY WITH UAV. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences 2.
Nex, F., Remondino, F., 2014. UAV for 3D mapping applications: a review. Applied geomatics 6, 1–15.
Peters, C., van Kolfschoten, T., 2020. The site formation history of Schöningen 13II-4 (Germany): Testing different models of site formation by means of spatial analysis, spatial statistics and orientation analysis. Journal of Archaeological Science 114, 105067.
Sadeghi-Niaraki, A., Choi, S.-M., 2020. A Survey of Marker-Less Tracking and Registration Techniques for Health & Environmental Applications to Augmented Reality and Ubiquitous Geospatial Information Systems. Sensors 20, 2997.
Specht, M., Specht, C., Mindykowski, J., Dąbrowski, P., Maśnicki, R., Makar, A., 2020. Geospatial modeling of the tombolo phenomenon in Sopot using integrated geodetic and hydrographic measurement methods. Remote Sensing 12, 737.
Wang, H., Pan, Y., Luo, X., 2019. Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. Automation in Construction 103, 41–52.
Watson, C., Richardson, J., Wood, B., Jackson, C., Hughes, A., 2015. Improving geological and process model integration through TIN to 3D grid conversion. Computers & Geosciences 82, 45–54.
Yang, X., Grussenmeyer, P., Koehl, M., Macher, H., Murtiyoso, A., Landes, T., 2020. Review of built heritage modeling: Integration of HBIM and other information techniques. Journal of Cultural Heritage.
Ying, S., Guo, R., Li, L., He, B., 2012. Application of 3D GIS to 3D cadastre in urban environment.