



Universidade de Brasília
Instituto de Ciências Humanas
Departamento de Geografia
Programa de Pós-Graduação em Geografia

UNIVERSIDADE DE BRASÍLIA
PÓS-GRADUAÇÃO EM GEOGRAFIA

MODELAGEM TRIDIMENSIONAL EM SIG DAS REDES DE ÁGUA E ESGOTO DO DISTRITO FEDERAL

Roberto Souza Borges

Tese de Doutorado

Brasília-DF: julho / 2025



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Orientador: Prof. Dr. Renato Fontes Guimarães

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Trabalho dedicado à minha família, cujo amor e apoio incondicional foram alicerces fundamentais ao longo dessa jornada acadêmica.



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RESUMO

A rápida urbanização e a alta densidade demográfica intensificam o uso do espaço subsuperfície, exigindo soluções mais eficazes para o planejamento urbano. A representação bidimensional (2D) das redes de infraestrutura enterradas tem se mostrado insuficiente diante da complexidade dos ambientes urbanos. Esta tese tem como objetivo modelar em três dimensões (3D) o cadastro técnico das redes de água e esgoto do Distrito Federal (DF), promovendo melhor representação e visualização das redes, prevenção de acidentes, identificação de erros cadastrais e integração com tecnologias emergentes como *Building Information Modelling* (BIM), a *Virtual Reality* (VR) e a *Augmented Reality* (AR). A pesquisa foi estruturada em três etapas: revisão do estado da arte da modelagem 3D de redes de saneamento; avaliação da qualidade dos dados espaciais existentes; e desenvolvimento de uma metodologia para automatização da geração de modelos tridimensionais. Os resultados demonstram que, mesmo com limitações nos dados originais, é possível construir modelos 3D confiáveis e de forma automática, contribuindo para a modernização dos cadastros técnicos e para a gestão eficiente da infraestrutura urbana. Conclui-se que a modelagem tridimensional é uma ferramenta estratégica para o saneamento público, com potencial de aplicação em outras áreas da infraestrutura urbana.

Palavras-chave: Infraestrutura Urbana; Rede de Esgoto; Rede de Água; Cadastro Técnico; Modelagem 3D.



ABSTRACT

THREE-DIMENSIONAL MODELLING OF WATER AND SEWAGE NETWORKS IN GIS IN THE FEDERAL DISTRICT - BRAZIL

Rapid urbanization and high population density have intensified the use of subsurface space, demanding more effective solutions for urban planning. The traditional two-dimensional (2D) representation of buried infrastructure networks has proven insufficient given the complexity of urban environments. This doctoral thesis aims to model, in three dimensions (3D), the technical cadastre of water and sewage networks in the Federal District, Brazil, enhancing network representation and visualization, accident prevention, error detection in cadastral records, and integration with emerging technologies such as Building Information Modelling (BIM), Virtual Reality (VR), and Augmented Reality (AR). The research was structured in three stages: a review of the state of the art in 3D modelling of sanitation networks; an assessment of the quality of existing spatial data; and the development of a methodology for automating the generation of 3D models. The results demonstrate that, despite limitations in the original data, it is possible to construct reliable and automatically generated 3D models, contributing to the modernization of technical cadastral records and the efficient management of urban infrastructure. It is concluded that 3D modelling is a strategic tool for public sanitation services, with potential applications in other areas of urban infrastructure.

Key words: Urban Infrastructure; Sewerage System; Water Network; Technical Cadastre; 3D Modelling.



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LISTA DE ABREVIATURAS E SIGLAS

2D	Duas Dimensões
3D	Três Dimensões
4D	Quatro Dimensões
AEC	<i>Architecture, Engineering and Construction</i>
AR	<i>Augmented Reality</i>
BEIM	<i>Built Environment Information Modelling</i>
BIM	<i>Building Information Modelling</i>
CAD	<i>Computer-Aided Design</i>
CAESB	Companhia de Saneamento Ambiental do Distrito Federal
DBMS	<i>Database Management System</i>
DF	Distrito Federal
DTM	<i>Digital Terrain Model</i>
ESRI	<i>Environmental Systems Research Institute, Inc.</i>
ET-EDGV	Especificações Técnicas para a Estruturação de Dados Geoespaciais Vetoriais
ETL	<i>Extract, Transform, Load</i>
GDF	Governo do Distrito Federal
GIS	<i>Geographic Information System</i>
GPR	<i>Ground Penetration Radar</i>
IDE	Infraestrutura de Dados Espaciais
IDE	<i>Integrated Development Environment</i>
IFC	<i>Industry Foundation Classes</i>
IMU	<i>Inertial Measurement Units</i>
INDE	Infraestrutura Nacional de Dados Espaciais
LADM	<i>Land Administration Domain Model</i>
LAS	<i>Land Administration System</i>
LiDAR	<i>Light Detection and Ranging</i>
LoD	<i>Level of Detail</i>
OGC	<i>Open Geospatial Consortium</i>
RRR	<i>Rights, Restrictions, and Responsibilities</i>
SDC	<i>Spatial Development Cycle</i>
SDI	<i>Spatial Data Infrastructure</i>
SGBD	Sistema de Gerenciamento de Banco de Dados
SIG	Sistema de Informação Geográfica
SIRGAS	Sistema de Referência Geodésico para as Américas
SQL	<i>Strutured Query Language</i>
TIN	<i>Triangulated Irregular Network</i>
ULA	<i>Underground Land Administration</i>
VR	<i>Virtual Reality</i>

1 INTRODUÇÃO

Na segunda metade do século XX, o Brasil passou por um intenso processo de êxodo rural, com milhões de pessoas migrando para as cidades em busca de melhores condições de vida, emprego e acesso a serviços (ALVES, SOUZA e MARRA, 2011). Esse movimento populacional contribuiu para uma urbanização acelerada, muitas vezes marcada pela ausência de planejamento adequado (MUSANTE, 2024). A rápida urbanização e a alta densidade demográfica obrigam o uso cada vez mais intenso do espaço subterrâneo que já não é usado apenas para proteção (em abrigos, refúgios e bunkers), para propósitos estratégicos e militares, para a prática religiosa ou para drenagem, mas também para abrigar túneis (rodovias, metrovias, ferrovias), estacionamentos, redes de água e esgoto, telecomunicações (telefonia, internet, tv a cabo) e energia elétrica, além do surgimento em todo o mundo da construção subterrânea de museus, shopping centers, teatros, entre outros (Zaini et al., 2015).

As escavações para implementação dessas infraestruturas podem causar acidentes e consequentes prejuízos difíceis de calcular. Muito pior do que o desperdício de água e os custos para recuperação das redes, os acidentes podem causar a perda de vidas. Além disso, a interrupção dos serviços resulta em perdas de arrecadação, os eventuais danos ao patrimônio de terceiros devem ser ressarcidos e danos ao meio ambiente podem resultar em multas e outras sanções por parte dos órgãos ambientais e de controle.

Para evitar acidentes na fase de obras, como a ampliação e pavimentação de ruas e rodovias, construção de viadutos e, posteriormente, durante as atividades de operação manutenção das redes de água, esgoto, drenagem, entre outras, é importante fiscalizar preventivamente as atividades em campo, analisar as interferências e informar adequadamente os executores sobre o posicionamento das redes no plano horizontal, eixos X e Y do plano cartesiano, e a profundidade, eixo Z (BALOGUN, MATORI e LAWAL, 2011; LIU e ISSA, 2012; ESEKHAIGBE, KAZAN e USMEN, 2020; WANG e YIN, 2022). A representação das infraestruturas enterradas em duas dimensões (2D) em plantas e mapas que tradicionalmente orientam os operários e fiscais, tem se mostrado ineficiente. Os mapas digitais tridimensionais (3D) informam corretamente aos trabalhadores de campos e auxiliam na compreensão do que está no subsolo (Yan et al., 2018). Chaaban, Darwishe e Kattabi (2019) observam que é crescente o interesse por mapas em três dimensões e destacam seu uso em emergências, gestão de desastres, verificações urbanas e nas redes de infraestrutura. Silva, Purificação e Carneiro (2018) acreditam que os mapas tridimensionais podem ajudar a disciplinar o uso dos espaços urbanos subterrâneos.

1.1 OBJETIVOS

1.1.1 Objetivo Geral

Esta pesquisa tem como objetivo geral modelar em três dimensões o cadastro técnico das redes de água e esgoto do Distrito Federal (DF). O cumprimento deste objetivo permitirá reduzir acidentes (com o repasse de informações corretas aos trabalhadores de campo), evidenciar erros no cadastro técnico, orientar as atividades de operação e manutenção das redes, facilitar análises de interferência e a integração do cadastro técnico com novas tecnologias, como o *Building Information Modeling* (BIM) e aplicativos de *Augmented Reality* (AR) e *Virtual Reality* (VR) para visualização de ativos enterrados.

1.1.2 Objetivos Específicos

A pesquisa tem os seguintes objetivos específicos:

- 1) Elaborar uma pesquisa bibliográfica, buscando o estado da arte da modelagem 3D de redes de água e esgoto;
- 2) Verificar se os dados espaciais que representam as redes de água e esgoto do DF possuem os requisitos mínimos necessários à modelagem 3D;
- 3) Estruturar e implementar um modelo para representação tridimensional das redes de água e esgoto, automatizando sua visualização como formas volumétricas em cena da web.

1.2 HIPÓTESE

A pesquisa parte da hipótese de que é possível visualizar em um modelo tridimensional uma rede originalmente construída em duas dimensões, desde que sejam realizados ajustes nos dados existentes e utilizada a combinação entre Sistema de Informação Geográfica (SIG) e sistema de banco de dados espaciais, permitindo a automatização do processo de conversão do cadastro técnico.

1.3 JUSTIFICATIVA

A pesquisa possui grande potencial para contribuir com a prestação do serviço público de saneamento com atualidade e eficiência, dois dos princípios fundamentais da

administração pública. A modelagem tridimensional é o que há de mais atual na gestão de cadastros técnicos de redes de água e esgoto. Os serviços serão mais eficientes com o uso dos modelos 3D para orientação dos serviços em campo, reduzindo ocorrências de rompimento de redes e consequentemente, prejuízo e interrupções dos serviços. A elevada dificuldade da modelagem de dados em três dimensões exige que, para que se torne usual, é necessário que se busque a automatização do processo de conversão do dado de duas para três dimensões (CHAABAN, DARWISHE e KHATTABI, 2019; CHAHINIAN et al., 2019; DU e ZLATANOVA, 2006; GUERRERO, ZLATANOVA e MEIJERS, 2013).

2 APRESENTAÇÃO

A pesquisa foi realizada em três etapas, com a produção de um artigo no final de cada uma, da seguinte forma:

1. O primeiro artigo apresenta o atual estado da arte da representação tridimensional de redes de água e esgoto. Foi revisada a bibliografia científica sobre a administração do espaço urbano subterrâneo. São mostradas as metodologias mais recentes e casos publicados em artigos científicos de modelagem tridimensional dessas redes no Brasil e em outros países.

2. O segundo artigo apresenta a pesquisa realizada com o intuito de avaliar o potencial de uso do cadastro técnico das redes de água e esgoto do DF para a modelagem tridimensional a partir dos dados espaciais existentes. O Centro da Cidade de Taguatinga, uma das principais regiões administrativas do Distrito Federal, localizada a cerca de 20 km do Plano Piloto de Brasília, foi escolhido como recorte espacial por ser um ambiente urbano complexo, onde constam as mais variadas feições representativas das redes. A pesquisa ajudou a entender como modelar redes de água e esgoto em três dimensões e os resultados mostram as dificuldades a serem enfrentadas para a modelagem 3D das redes do DF, como contradições entre entidades, ausência de atributos e atributos com valores incorretos.

3. O terceiro artigo apresenta uma metodologia inovadora para automatizar a geração de modelos tridimensionais a partir de dados bidimensionais. As feições que representam os arcos e nós das redes de água e esgoto no cadastro técnico, ganham automaticamente visualização em formas tridimensionais, incluindo os respectivos espaços de servidão. Essa abordagem permite que a visualização 3D ocorra de forma dinâmica, sem necessidade de modelagem manual.

Os dois primeiros artigos foram submetidos para publicação no periódico Engenharia Sanitária e Ambiental (ESA). O terceiro artigo foi submetido ao periódico Revista Brasileira de Recurso Hídricos (RBRH). Ambos os periódicos são indexados na plataforma *Web of Science* da Clarivate e classificados com conceito A no sistema Qualis da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). O primeiro e o terceiro artigos foram aprovados para publicação, enquanto o segundo encontra-se em processo de avaliação.

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**MODELLING WATER AND SEWAGE NETWORKS IN THREE
DIMENSIONS: A REVIEW AND THE BRAZILIAN CASE**

**MODELAGEM DE REDES DE ÁGUA E ESGOTO EM TRÊS DIMENSÕES: UMA
REVISÃO E O CASO BRASILEIRO**

ABSTRACT

Works in cities require attention to avoid disrupting underground installations in the excavations. Historically, workers orient themselves using maps and blueprints in two dimensions (2D) liable to errors in interpretation, which could be the cause of interruption of essential public services, accidents, and damages. A common source of damage is the lack of accurate information about the underground location and size of pipes to workers. Three-dimensional (3D) modelling allows visualization to be more informative, revealing details that would go unnoticed in two-dimensional modelling, adequately informing field professionals and helping to avoid accidents with utility networks. The present work aims to develop bibliographical research seeking the state-of-the-art 3D modelling of water and sewage networks. In addition to helping to fill the research gap that situates the Brazilian reality in the discussion about the use, ownership and management of underground urban space. The work seeks to understand the applicable rules and the role of each institution involved and to bring together methods and techniques for mapping, modelling, visualizing, storing, and sharing 3D spatial data representing water and sewage networks. The work guides for initiatives aimed at 3D modelling of water and sewage networks.

KEYWORDS

Network; Water; Sewage; 3D; Visualization; Modelling

RESUMO

A execução de obras em cidades exige atenção para evitar a rompimento de redes subterrâneas nas escavações. Historicamente, os trabalhadores se orientam utilizando mapas e plantas em duas dimensões (2D), passíveis de erros de interpretação, o que pode causar a interrupção de serviços públicos essenciais, acidentes e prejuízos. Uma fonte comum de danos é a falta de informações precisas sobre a localização subterrânea e o tamanho das tubulações para os trabalhadores. A modelagem tridimensional (3D) permite que a visualização seja mais informativa, revelando detalhes que passariam despercebidos na modelagem bidimensional, informando adequadamente os profissionais de campo e auxiliando na prevenção de acidentes em redes de serviços públicos. O presente trabalho tem como objetivo desenvolver uma pesquisa bibliográfica buscando o estado da arte da modelagem 3D de redes de água e esgoto. Além de contribuir para o preenchimento da lacuna de pesquisa que situa a realidade brasileira na discussão sobre o uso, apropriação e gestão do subsolo. O trabalho busca compreender as normas aplicáveis e o papel de cada instituição envolvida e reunir métodos e técnicas para mapeamento, modelagem, visualização, armazenamento e compartilhamento de dados espaciais 3D representativos de redes de água e esgoto. O trabalho orienta iniciativas voltadas à modelagem 3D de redes de água e esgoto.

PALAVRAS-CHAVE

Rede; Água; Esgoto; 3D; Visualização; Modelagem

1 INTRODUCTION

Large cities are constantly undergoing transformation, where new streets and buildings appear, and urban infrastructure is modified or expanded. The execution of each project requires caution so that excavations do not disrupt pre-existing underground installations. The public administration maintains technical cadastres to inform the location and characteristics of buried networks that are difficult to observe. Historically, workers access information from the cadastres through two-dimensional (2D) maps and blueprints, which could be misinterpreted when the networks are at the exact coordinates but at different depths (Du & Zlatanova, 2006). 2D models present information in a partial way, which can cause interruption essential public services, accidents, and losses (Balogun et. al., 2011; Esekhaigbe et. al., 2020; Liu & Issa, 2012). A common source of damage is the lack of accurate information about the underground location and size of pipes for maintenance workers (Liu & Issa, 2012).

Three-dimensional (3D) modelling allows a visualization that presents numerous advantages. It is more informative and reveals details that would go unnoticed in two-dimensional modelling (Yan et. al., 2019). The topological relationships between infrastructures are easily verified in all directions, not only in the horizontal plane but also in the vertical plane, facilitating interference analyses. 3D models help maintain the quality of the technical cadastres once they highlight spatial data errors and possible problems that occur during the data processing. The 3D modelling allows the integration of the technical cadastre in geographic information systems (GIS) with the Building Information Modelling (BIM) (Balogun et. al., 2011; Liu & Issa, 2012; Deng et. al., 2016; Liu et. al., 2017; Sharafat et. al., 2021; Wang et. al., 2019; Song et. al., 2017). Field professionals can be adequately informed, avoiding accidents in public services networks (Held et. al., 2004; Chong, 2006), including the visualization of underground installations by the workers in augmented reality (AR) and virtual reality (VR) applications (Soria et. al., 2018; Verbree et. al., 2004).

The advantages of 3D models have increased the interest in urban environment applications (Shiode, 2012) and in studies that address issues related to underground space, such as use, administration (Saeidian et. al., 2021; 2023) and ownership (Zaini et. al., 2015). Some of them explore the integration of digital technologies in the management of underground assets (Esekhaigbe et. al., 2020) including GIS/BIM integration (Liu et. al., 2017; Song et. al., 2017; Oti & Abanda, 2017) while others focus on data models (Kalogianni et. al., 2020; Aien et. al., 2017) and methods to determine the depth or map buried infrastructures (Ragade et. al., 2016; Wang & Yin, 2022; Metje et. al., 2007).

Some studies enrich the international debate by addressing the individual reality of a country, while some reviews compare different countries. The most part is about land use and its implications for underground space. There is a lack of reviews addressing specifically 3D modelling of water and sewage networks, essential infrastructures for health and quality of life in cities.

The present study aims to conduct a bibliographical survey seeking the state of the art in 3D modelling of water and sewage networks. The work helps to situate the Brazilian case in the international discussion about rules of use, appropriation and management of underground urban space, and the institutions' role. Furthermore, the study gathers methods and techniques for mapping, modelling, visualization, storage and sharing of 3D spatial data that represent water and sewage networks.

The next section of this article brings together research that approaches the legal, institutional, and technical aspects of underground space management worldwide and in Brazil, as well as how the topic is related to water and sewage networks. It then presents research that addresses the challenges of 3D modelling for water and sewage networks.

2 ADMINISTRATION OF UNDERGROUND SPACE

Managing resources that are below the surface is essential for sustainable urban development and maintaining a good quality of life in cities since it involves critical infrastructures (parking lots, roads, train, or subway tunnels) and facilities used to provide essential services (electricity, gas, drinking water, sewage, and telecommunications networks). Cartographic representation helps manage underground space by providing information about the location and characteristics of buried assets. Over time, 2D representation techniques have been used, but they have become inefficient with the increasing use of the underground. In contrast, 3D digital models are more suitable for answering legal issues, ownership, physical dimensions, location, and spatial relationships of infrastructures, including how they relate to aboveground areas (Saeidian et. al., 2021).

The spatial Development Cycle (SDC) includes underground management, where stages in an area or region pass through growth, transformation, and evolution over time. The Land Administration System (LAS) serves as the framework for the SDC, facilitating land use planning, land ownership registration, tenure security, purchase and sale transactions, and management information. LAS is essential for managing public service networks, logistics, transportation, military defence, construction projects, excavations, implementation of smart

cities, disaster management and emergency response (Saeidian et. al., 2021). Underground Land Administration (ULA) is part of the LAS, which refers to collecting and registering information, subdivisions, defining limits, and managing rights associated with underground assets (Kalogianni et. al., 2020). 3D ULA addresses using 3D models from legal, institutional, and technical perspectives (Saeidian et. al., 2021; Kalogianni et. al., 2020) responding to rapid urbanization and the search for sustainable urban development.

2.1 LEGAL ASPECTS

The legal aspects of ULA are related to the legal system applicable to the use of the underground space. The legal aspect of management focused on underground property dependent on 2D data causes damage to urban planning, disputes over underground space use, accidents, economic losses, delays, and interruption of works (Saeidian et. al., 2021). Adequate legislation should help prevent disputes for space, clarify the real extent of properties, and establish land rights, restrictions, and responsibilities (RRR). Rights are related to possession, use, transfer, and other privileges. Restrictions are associated with regulatory or contractual impediments arising from zoning and building codes and related to environmental protection. Responsibilities are the obligations related to compliance with regulations, conservation (of the property or assets) ensuring the safety of third parties and payment of taxes.

Paulsson & Paasch (2013) reviewed 156 conference papers and other publications written in English between 2001 and 2011 to analyse the areas of interest and the occurrence of legal aspects and trends in 3D property research. Many studies approached technical issues and technical cadastre to the detriment of legal issues. Among the studies that addressed legislation, most were on national laws. At the time, the authors noted the lack of international discussions and comparative legal studies, which could result in increased cooperation and standardisation of terminology.

About a decade later, the authors repeated the study (Paasch & Paulsson, 2021) comparing 530 publications. The findings revealed a rise in research on legal topics, though still significantly lower than other subjects, along with emerging subtopics such as 3D visualisation, BIM, and standardisation. Even studies on different issues should incorporate a legal perspective, emphasising international comparative research.

Despite the necessity to increase, it still conducted comparative studies showing different situations regarding the legislation applicable to 3D ULA, which varies according to the place. In some places, the legal system fulfils its role and can be a model to be followed by

others in which the legislation is sparse, incomplete and ambiguous, confronts public and private interests, does not support 3D models, and establishes rules for property on the surface that do not apply to the underground space. Some studies portray a country's situation that makes individual situations known or can be analysed together in comparative studies.

Comparative studies between Australia and New Zealand have identified similarities and differences in the legal, technical, and institutional aspects of 3D cadastre systems, particularly regarding the representation and management of RRR. These analyses have contributed to the development of harmonised frameworks and data models aimed at supporting a nationally integrated digital ecosystem for 3D cadastral data in both countries (Atazadeh; Olfat; Rajabifard, 2021; Atazadeh; Rajabifard; Olfat, 2023).

In the Brazilian context, the conceptual framework of territorial parcels and objects, as presented by Silva et al. (2023), offers a robust foundation for structuring multifunctional territorial cadastre systems. Their work emphasizes the spatial and geometric role of these entities in supporting urban policy implementation and municipal land governance, aligned with the national directives recently updated by the Ministry of Cities.

Zaini et. al. (2015) focus on the legal aspects of underground space ownership, addressing the depth that each infrastructure can reach and comparing the reality of Malaysia against countries with a greater tradition in managing the use of underground space, China, Finland, and Japan. The authors concluded that Malaysia has legislation that allows the use of underground space, but the country needs to define categories for land use based on depth ranges, as was done in the other countries studied, to facilitate planning for underground use and future development. For further future development of Malaysia's underground space, four improvements to the country's legal framework are recommended: clear definition of the extension of surface ownership on underground space, creation of separate agreements between surface owners and subsoil strata owners, issuance of land titles with specified depth, and appropriate zoning of underground space (Zaini et. al., 2017).

The legal aspects of China's 3D ULA are recurrently studied. Wenjun et. al. (2012) analysed local legislation in China, classifying it as separate, dispersed, and isolated, reporting the lack of integration and suggesting how to improve the Chinese underground urban space management system reasonably and sustainably. Xu (2014) shows that due to China's rapid urban growth, successive regulations related to underground space at the local level have been issued, with many advances but also many conflicting provisions requiring national legislation. Zhang et. al. (2017) discuss the property rights of underground space in China. Guo et. al. (2013) analysed the study case of the city of Shenzhen, China.

Karatas et. al. (2006) show that Turkey's cadastre law changed in 2005 to include spatial information databases, proposing an information system model that incorporates infrastructure data, highlighting the need for accurate spatial data and the importance of defining the relationship between infrastructure and properties for optimal planning.

In Korea, the current cadastral system does not cover the 3D registration of underground properties, which is essential for modern urban planning. Underground space objects do not accurately record their area and volume, which differs from the rights established by the corresponding occupied spaces. There is a lack of concrete standards and legal basis for underground space cadastral registration, with limitations in defining underground properties and difficulties in establishing easements, leading to double payments for underground spaces and disputes between landowners and underground space owners (Kim & Heo, 2019).

Croatia has had a functioning LAS for over two hundred years, but the lack of structured 3D data is an obstacle (Vučić et. al., 2020). Serbia shows a similar situation, where the land cadastre is based on 2D maps and procedures that do not support 3D registration and visualisation of underground plots or objects, especially in urban areas (Višnjevac et. al., 2018). Incorporating 3D data into land use management systems is essential to deal with overlapping rights at different depths. With low-cost investments, updating existing data and modernising land use management by upgrading technologies and making cadastres more efficient would be possible.

Regarding legal issues involving 3D space, comparative studies across different jurisdictions, including Brazil, demonstrate the urgent need for international standardization in the legal framework governing underground space. Kitsakis et al. (2016) highlight the complexity of integrating public law restrictions into 3D cadastral systems, emphasizing the challenges posed by vertically overlapping rights and the inadequacy of current 2D legal representations.

In the Brazilian context, Carneiro et al. (2012) provide a detailed analysis of the legal and institutional challenges associated with implementing a 3D Cadastre. Their study underscores the limitations of existing legislation and the need for adaptations to accommodate volumetric representations of property rights, particularly in urban infrastructure management.

Pacheco (2015) analysed the Brazilian reality and found an uncontrolled situation and a lack of public planning despite legislation for the occupation of the subsoil. The author studied federal regulations and identified regulations for the management of underground space in the cities of São Paulo, Rio de Janeiro, Belo Horizonte, and Porto Alegre. The regulations are often unaligned and put on opposite sides, such as private use and collective interest. The City Statute

of Brazil (Brasil, 2001) introduced surface rights, extending them to underground space use. However, according to the Civil Code of Brazil (Brasil, 2002) underground space and airspace use is subject to concession. Furthermore, according to the National Environmental Policy of Brazil (Brasil, 1981) underground space has the same legal nature as environmental assets, which limits private use. Brazilian legislation also includes specific rules for the protection of subsoil mineral resources (Brasil, 1967) and the preservation of natural underground cavities and archaeological sites (Brasil, 1990; 2022).

Naturally, collective interests overlap with individual rights. The right to private property cannot obstruct the offer of basic services, such as sewage collection or drinking water supply. The installation of networks may require expropriation. Furthermore, buffer zones or easements are established around the networks to prevent accidents, with limitations on activities and prohibitions on excavations. In Brasilia, the capital of Brazil, for example, the public and collective interests are prioritised in the concession rules for the use of land, underground space and airspace (Distrito Federal, 2008). The rights around water and sewage networks are restricted, demanding minimum soil coverage and minimum distances from the axis, which vary according to the network diameter. 3D modelling of these networks requires knowledge of local legislation for adequate representation, not only of the networks but also the easements, when applicable. However, legislation is not always clear on correctly representing easements in a 3D model, as it was designed considering a 2D view.

Legislative advances are needed to allow a clear 3D representation of utility networks and their easements, which new studies can support. However, the topic is present in a few approaches. Most international studies focus on parcels. In one of the rare cases that specifically address public services networks, it is possible to verify the characteristics of land use administration systems and the economic use of these infrastructures in Slovenia, China, Sweden, and Turkey (Bitenc, 2008).

While some topics remain rarely addressed in Brazilian legislation, such as the use of GIS for managing underground spaces, others are gaining increasing attention, notably BIM technology. Although GIS and BIM serve different purposes—GIS is primarily used for spatial analysis and territorial management, while BIM focuses on detailed modelling and lifecycle management of infrastructure—BIM has been expanding rapidly and is helping to plan infrastructures in a multidimensional way, offering many advantages. For utility networks, BIM provides a better understanding of underground installations and can assist in defining customers' connection points to water and sewage systems, among other benefits. In legal terms, BIM is becoming mandatory. Brazilian legislation, for example, requires the use of BIM

(Brasil, 2020) and defines the institutional arrangements to promote its dissemination (Brasil, 2019; 2024). However, this obligation applies only to works contracted by the federal public administration. Since sanitation services in Brazil are a municipal responsibility, and in some cases managed by state governments, making BIM mandatory for sanitation companies requires its inclusion in local laws.

Legislation defines the rights, obligations and restrictions of the actors involved in the management of underground space. The following section discusses the 3D modelling of water and sewage networks and requires knowledge of these actors and their relationships.

2.2 INSTITUTIONAL ASPECTS

Institutional aspects refer to the stakeholders involved in the 3D ULA. These are the owners, local government, public service providers, notaries, technology providers (information technology services, software, and tools) institutions that finance the construction of buildings and infrastructures, and those who build, operate and maintain the facilities. Institutional arrangements must protect rights and ensure sales or transfer transactions.

Before advancing in the development and use of the underground space, it is necessary to strengthen the administrative structure with a clear definition of the tasks and responsibilities of the involved. According to Saeidian et. al. (2021) institutional strengthening depends on overcoming some challenges, such as lack of institutional arrangements, lack of structure for surveying and registering underground assets, lack of clarity about the responsibility of departments and agencies in the coordinated and integrated management of underground space; reluctance to share data on underground assets due to commercial issues, political competition or safety concerns. Overcoming these challenges guarantees numerous benefits: new ways of harmonizing data; greater efficiency in designing and acquiring data; reduction of inconsistencies, losses, incompatibility and duplication of data; reuse of data in different phases of project implementation.

An adequate institutional environment requires, in each jurisdiction, the identification of institutions, users, political and public demands, financial and operational issues beyond the definition of responsibilities and standards for sharing and data security, concepts, terminology and semantics. These requirements are like those necessary for the proper functioning of Spatial Data Infrastructures (SDIs) and can overcome institutional challenges. Kalogianni et. al. (2020) consider that the system architecture required for a future web-based 3D LAS is aligned with

SDI best practices, focusing on spatial data collected once, maintained efficiently, and shared with multiple users and applications.

The integration of 3D LAS stakeholders through SDIs remains a glimpse of the possible future, once it is difficult to find, around the world, an example that it is already happening successfully. Important actors, such as notaries or private companies, do not use to participate in SDIs, as it happens in Brazil. Although the country has established SDIs at various levels, including corporate, local, state, and federal, these structures still require significant advancement to become truly effective in supporting underground space management. The lack of engagement from essential stakeholders and the limited interoperability between systems hinder the development of a cohesive and functional 3D spatial data ecosystem.

The Brazilian National Spatial Data Infrastructure (better known by its Portuguese acronym, INDE) aims to catalogue, integrate and harmonize geospatial data and its metadata produced or maintained by the various member institutions (Brasil, 2008; 2025). INDE promotes the standardization of geospatial data, facilitating sharing among different agencies and institutions. This avoids duplication of efforts and improves efficiency in collecting and updating information. Through INDE, information from various sources is organized and offered in a standardized and accessible manner. This is essential for professionals, researchers, companies and citizens who need to use spatial data in their activities. INDE data can be used in various contexts, such as urban planning, environmental management, agriculture, transportation, and security, among others. The availability of this information benefits the whole society. INDE uses Open Geospatial Consortium (OGC) standards to ensure interoperability and exchange of geospatial data and has adopted its own data models, established through Technical Specifications such as the ET-EDGV, which defines geometry and attributes of geospatial data and was developed by a specialized working group coordinated by the National Cartography Commission (CONCAR), with contributions from various federal agencies (Exército Brasileiro, 2018). Other specifications adopted by INDE include the ET-ADGV (for data acquisition), ET-PCDG (for geospatial data products), ET-CQPCDG (for quality control), and ET-RDG (for geospatial data representation), among others.

Beyond the INDE, at the national level, other spatial data infrastructures exist in Brazil at other levels. The Spatial Data Infrastructure of the Federal District is a good example of a SDI at the local level (SEDUH, 2016). This comprises technologies, policies, standards, and human resources necessary to acquire, process, consolidate, distribute, use, maintain, and preserve the geoinformation produced in the country's capital (Distrito Federal, 2020). Its main objective is to promote order in the generation, storage, access, sharing, dissemination, and use

of geospatial data, an essential tool for territorial management, urban planning, decision-making, and sustainable development of the region. Several agencies and institutions participate in the SDI of the Federal District, contributing to the provision and integration of geospatial information.

In general, is not common underground 3D data in the different levels of Brazil's spatial data infrastructures. Despite the existence of institutional arrangements that help manage land use, it is necessary to advance in the management of underground space. Specificities such as the existence of public service networks, the difficulties of excavations, and the need to coordinate planning and design actions for the construction of tunnels require a complex institutional arrangement, not always similar to those that manage the surface. The role of public service companies is important, but management involves many parties from the public and private sectors, with different interests to be reconciled.

SDIs can perform a crucial role in the sanitation sector, facilitating the integration between companies and other institutions involved in water resources management and infrastructure maintenance, providing significant benefits for the services. Generally, they provide access to satellite images and information about climate and water resources, allowing continuous monitoring of sensitive areas, such as water sources, environmental preservation areas and water bodies. This information helps to identify potential risks, such as pollution or deforestation, and to implement measures to protect water resources. Locating and mapping sanitation-related assets, such as treatment plants, distribution networks and water intake points, is possible at a local level. This data is essential for strategic planning, the expansion of water and sewage networks, decision-making and the facilitation of maintenance, optimization and efficient management of these assets. Researchers, academics and companies can use SDIs data to develop innovative solutions in the sanitation sector. This includes hydraulic modelling, environmental impact analysis and feasibility studies.

The Caesb, Environmental Sanitation Company of the Federal District, Brazil, present a successful case of using SDI in the sanitation sector. The company shares the technical cadastre of water and sewage networks with other local government agencies through the SDI of the Federal District. At the same time, it uses outside data such as digital terrain models (DTM) contour lines, watercourses, waterbodies, contour lines, road systems, lots, buildings, land data and many other environmental and urban planning geospatial data. Currently, the company is converting its utility networks from 2D modelling to 3D modelling, representing the first step for a 3D ULA in Brazil's capital, starting with the water and sewage networks, a movement to, in the future, model other urban infrastructures in three dimensions.

2.3 TECHNICAL ASPECTS

Technical aspects include selecting digital technologies, methods, models, and tools to develop the 3D ULA in each stage of the 3D data lifecycle: acquisition, registration, storage, management, visualisation, and sharing (Kalogianni et. al., 2020; Olfat et. al., 2021; Plale & Kouper, 2017). Increased research has provided advances in these stages, but many obstacles remain.

Among the wide range of possibilities, choosing digital technologies, tools, work methods throughout the data lifecycle, and information modelling systems is challenging (Oti & Abanda, 2017). Atazadeh et. al. (2021) compile a bibliography that simplifies the task by covering the technical aspects of 3D ULA, including 3D cadastres in other jurisdictions, data acquisition, modelling, storage, visualisation, validation, and analysis.

Regarding the choice of a data model, the Land Administration Domain Model (LADM) format is typically adopted, but the model is classified as inefficient for modelling underground assets, such as public service networks (Saeidian et. al., 2021). The format was the first successful attempt to create an international standard for land use administration. It is a conceptual model rather than a data product specification and is a descriptive rather than prescriptive standard, focusing on RRR (Lemmen et. al., 2015). Two prominent physical models are City GML, preferred by the geospatial sector, and IFC, which is widely adopted in the construction industry (Saeidian et. al., 2021). City GML (Geography Markup Language) was developed by the OGC and is an open-source format that allows the representation, storage and exchange of virtual 3D city models (Gröger et. al., 2012). IFC (Industry Foundation Classes) is an open format for 3D modelling buildings and managing buildings' lifecycle in the Architecture, Engineering and Construction (AEC) sector, promoting interoperability and efficient data exchange. Some studies seek to combine different formats to overcome limitations and have the best of each format. For example, Atazadeh et. al. (2018) combined the legal LADM and physical IFC formats. Becker et. al. (2012) analysed different geospatial utility network models: INSPIRE, IFC, ArcGIS network model and CityGML. There are also efforts to convert data from one format to another efficiently. It can, for example, facilitate GIS and BIM integration (Chen et. al., 2018; Hijazi et. al., 2009). Combining BIM and GIS data allows you to create 3D visual representations of pipelines, enabling analysis and decision-making in facilities management.

The integration of LADM and CityGML has been explored in Brazil by Costa (2016), who proposed a methodology for 3D cadastral modelling of buildings. Her work demonstrates

the feasibility of combining legal and physical data models to support spatial representation of individual property units, contributing to improved interoperability and urban management.

The integration between GIS and BIM technologies has been explored in scientific review articles, helping to overcome difficulties in sharing data and maintaining interoperability between tools. After reviewing the scientific literature on Built Environment Information Modelling (BEIM), Oti & Abanda (2017) concluded that interoperability is critical in choosing an environment information modelling system. The research by Liu et. al. (2017) concluded that semantic web technology is suitable for promoting BIM and GIS integration in a promising and widespread way. It allows effective information management in the various phases of a project's lifecycle. After reviewing 96 articles on BIM and GIS integration in the AEC industry, Song et. al. (Song et. al., 2017) concluded that this integration needs systematic theories and technologies for integration beyond the application of mathematical modelling methods, including spatiotemporal statistical modelling in GIS, simulation, and management 4D/nD (four or more dimensions) in BIM, it means, combine 3D geometric information with time information to visualise how the project will evolve over time.

Souza (2024) presents a case study involving GIS-BIM integration applied to improve the technical registration of gas distribution networks. This integration enhances spatial understanding, supports evidence-based decision-making, optimizes asset management, reduces conflicts and errors, and fosters standardization and interoperability across systems.

Saeidian et. al. (2021) point out the technical challenges to be overcome: geometric and topological differences between the surface ownership and buried assets, differences between data representing physical structures and data representing the space ownership, lack of data accuracy and integrity, difficulty to convert 2D data to 3D, lack of data to create 3D geometries, complexity in 3D modelling of certain elements of underground space (such as different depth demarcations, objects located at great depth, entrances or accesses to the subsoil, mineral resources, lighting, exhaust and ventilation data, among others) lack of standardisation of formats and data sharing protocols, use of different spatial reference systems, difficulty to integrate spatial and non-spatial data, diversity of storage media and representation modes.

Brazil faces particular challenges: the lack of data and the inadequacy of existing data. The data at the federal level were obtained on a small scale, incompatible with cadastral use and the management of underground space in the cities. At the local level, there is a lack of quality data. Few cities own resources to collect data, acquire software, and maintain qualified workers. Many cities have failed to make the technological transition from paper-based

technical cadastres to digital technologies. Geospatial data are often incomplete and rarely include, for example, the Z coordinate.

Public service providers face additional challenges. Many networks are underground, requiring more expensive mapping methods, which are among the most modern for collecting subsurface data and require greater investment. To enjoy all the benefits of 3D modelling of underground networks, choosing the appropriate tools in the initial phase and throughout the entire data lifecycle is necessary. The following section indicates the best practices for data acquisition, storage and management that favour visualising water and sewage networks in three dimensions.

3 3D MODELLING AND VISUALIZATION OF WATER AND SEWAGE NETWORKS

Implementing a 3D vision of the LAS requires the consideration of legal, institutional, and technological aspects (Kalogianni et. al., 2020). 3D modelling and visualization of water and sewage networks enrich the 3D ULA, covering all stages of working with 3D geospatial data, from production to sharing within best practices.

3.1 CRITERIA AND DIFFICULTIES FOR CREATING 3D MODELS

El-Hakim (2008) lists the criteria for projects that aim to create detailed and reliable 3D models of real-world objects, such as pipelines:

- Objects must have a resolution that is perceptible to the human eye;
- The accuracy of the final model's positioning should be compatible with the visualization application;
- Search for tools to automate data collection and modelling tasks so that the project can be completed in a reasonable time;
- The model must be efficient, without losing the desired details, but can be viewed interactively in the application's software and hardware;
- Projects must have low cost in general.

However, satisfying all the criteria is complicated, such as acquiring high-resolution data in a reasonable time or achieving high accuracy in automation at low costs, explaining the low dissemination of 3D models among companies (Balogun et. al., 2011). State-of-the-art underground facilities management systems (Esekhaigbe et. al., 2020) indicate that few U.S. utility operators produce 3D models. Although 3D visualization provides an accurate image of

underground infrastructure, minimizing accidents during excavation and preventing property damage, most U.S. companies only use GIS databases with 2D modelling, depth records, and other asset information. Therefore, the wider implementation of 3D modelling is limited by workers' lack of digital literacy and the high costs of acquiring and applying the technologies involved, which require overcoming the difficulties of disseminating 3D models of underground areas.

3.2 WAYS TO OVERCOME THE DIFFICULTIES

Scientific development is gradually finding ways to overcome difficulties and meet the criteria for building high-quality and low-cost 3D models.

3.2.1 Remote Sensing Methods

Excavating the entire system to determine the physical location of installations is impractical due to the high cost and time-consuming nature. However, new technologies allow us to probe the underground space like doctors probe the human body. Advances in remote sensing and GIS techniques for mapping buried utility networks have reduced mapping costs and provided higher resolution and positioning accuracy of spatial data (Ragade et. al., 2016; Yang et. al., 2023).

Methods such as Inertial Measurement Units (IMU), gyroscope-based systems and even the injection of markers into pipelines (such as radioisotopes that can be detected from the surface) are promising. However, Ground Penetration Radar (GPR) is the most cited instrument, and it is used in many cities worldwide (Yan et. al., 2018; 2020; Hashim et. al., 2010; Tao, 2013). Using existing 2D data and assessing where the Z-coordinate is needed is one way to reduce the cost of 3D modelling projects. Analyses can combine 2D and 3D data (Zhi et. al., 2019). GPR can be used to input the Z coordinate from prioritising preexisting data (Yan et. al., 2019).

Metje et. al. (2007) announced the development of a device for accurate and remote detection of public service networks. The device can combine three different detection technologies: GPR, low-frequency quasi-static electromagnetic fields, and acoustics (generally used for leak detection and network location). The authors conducted a literature review on these technologies. They verified how to optimise the techniques based on knowledge of the soil and the combination of technologies. The authors address the serious social, environmental,

and economic consequences of the inability to accurately and completely locate buried infrastructure without excavations.

GPR has proven effective in Brazilian applications, such as the COMPESA project documented by Santos (2022), which utilized GPR and geospatial technologies to enhance the technical cadastre of water and sewage networks. This approach exemplifies the potential of remote sensing for accurate subsurface mapping in urban environments.

3.2.2 Methods to Improve 3D Cadastre Management

As methods for mapping underground infrastructure have modernized, methods for recording, organizing, querying, and visualizing 3D data have also evolved, making cadastre management more efficient. 3D data models vary among jurisdictions that define their own data models, usually focusing on properties. Some models include buildings and utility networks, both above and below ground, but others do not. For example, the Z coordinate is not mandatory in Amsterdam, while in Chinese models, it has become mandatory (Du & Zlatanova, 2006). Furthermore, where the Z coordinate is mandatory, there are different ways of recording the value, for example, sometimes pipes receive their Z coordinate on the upper or lower generatrix, but other times on the centreline. The axial location is preferable because it facilitates buffer operations to assess legal distances to be observed and easements.

Pouliot et. al. (2015) warn that cadastre systems lack mapping of underground facilities and propose a model for these assets based on user needs. Aien et. al. (2017) reviewed and evaluated the most used cadastral data models for 3D applications, examining the management of legal (RRR) and technical aspects. The results can be used to improve existing models or develop new models geared towards the requirements of 3D cadastres. Some models are geared towards 3D data, but 4D cadastre models already exist, that is, 3D + time (Yan et. al., 2019; Döner et. al., 2008; Mittlböck et. al., 2021). Döner et. al. (2011) argue that the 4D model is viable in legal, organizational and technical aspects.

Some models assume the use of a database management system (DBMS). The technology offers greater data integrity because it supports manual or automatic inquiries to detect and correct inconsistencies, errors, and invalid data; ensures data curation, allowing the metadata, record and track of data lineage; enrich analyses with statistical techniques and data mining; supports the use of research tools, facilitating data access and recovery; allows integration with other databases and systems, producing robust analyses involving spatial and non-spatial data; preserves data for long-term storage; manages access, restricting data

according to the user profile, ensuring security and privacy. The database is presented as a promising solution for 3D cadastre, allowing centralized management and a correct record of legal determinations and obligations (Guerrero et. al., 2013), besides facilitating comparisons and analyses (Koch & Löwner, 2017).

The technical cadastres of sanitation providers' water and sewage networks sometimes need to be integrated with other company systems, such as commercial, financial, operational, asset management, and human resources management, among others. In addition, the integration of systems from external organizations with data from other urban infrastructures is necessary, recommending an IDE or the use of ETL (Extract, Transform, Load) tools that facilitate the extraction, transformation and loading of data between different databases, ensuring efficient and accurate communication between systems. The ETL technology is widely used to integrate other systems, extracting data from a database and converting it to formats accepted in the most diverse applications, such as CAD and BIM software, web applications, VR and AR applications, among others (Liu et. al., 2017).

3.2.3 Automatic 3D Visualization

A 3D visualisation can be complicated and time-consuming, but the human eye must perceive objects correctly. Some researchers are dedicated to automating this task.

Guerrero et. al. (2013) reported that it is challenging to visualise pipes and cables in 3D models because they are simple and narrow objects that cover large geographic areas and are made of many segments. This situation has not changed with more modern visualisation tools because the technical limitation is intrinsic to visualising line-type spatial data in scenes amidst large-volume shapes. The authors suggest that, in 3D modelling, lines be replaced by volumetric shapes, such as cylinders or triangular meshes. Other authors share the idea of replacing the lines and points representing the segments and nodes of public service networks for cylinders or other shapes in 3D visualisation (Du & Zlatanova, 2006; DÖNER et. al., 2011; Chaaban et. al., 2019; Santos et. al., 2013). However, it seems inappropriate to store 3D shapes in the database. Du & Zlatanova (2006) argued that storing parametric shapes in a database is time-consuming, costly, and unjustified, even with current DBMSs. A more efficient approach keeps points and lines in the database while attributes generate 3D shapes automatically or “on the fly” (Du & Zlatanova, 2006; Guerrero et. al., 2013; Chaaban et. al., 2019; Chahinian et. al., 2019).

Algorithms or functions in Computer-Aided Design (CAD) and GIS software enable dynamic 3D modelling (Du & Zlatanova, 2006). Nowadays, the same methods for dynamic visualisation in CAD are possible in BIM software. At that time, the authors said that GIS did not provide solutions for the 3D modelling of piping, but it has changed in recent software versions.

3.2.4 Improving the performance of 3D models

3D models need to perform well to replace maps and blueprints effectively. Assessing the scene cannot take too long, and the navigation must be easy and fluid, without frequent errors. The latency of the network influences these factors, and the processing capacity of the devices used to access the models plays a fundamental role, more powerful devices can manipulate complex models more efficiently. However, it is also necessary to seek a balance between the expected level of detail (LoD) and the performance of the 3D model beyond the use of an appropriate symbology, which allows a clear and accurate visualisation without overloading the available resources.

Sometimes, a high level of detail is applied to models unnecessarily, as the details will not be perceived when viewed on small scales. It is appropriate that high levels of detail be reserved for models that represent infrastructure in small areas and that will be viewed at a large scale. Applying a high level of detail is unnecessary for models in larger areas, which will be viewed at small scales. For cadastre purposes, low LoD models are sufficient (Deng et. al., 2016). In addition, the high level of detail can impair the immediate interpretation of the visualised object, making communication less effective.

Symbol selection influences performance in 3D maps, as geometric symbols improve user experience, scale transitions, and simplify modelling, making them more effective than highly realistic representations and enabling clear communication of infrastructure networks (Santos et. al., 2013).

3.3 SHARING 3D MODELS

The final stage of the work process for creating 3D models of underground networks is sharing, in which the 3D scene reaches the user for viewing and analysis of the facilities. Various publishing and consumption methods and tools are chosen according to the availability of resources and stakeholders' expertise. Liu & Issa (2012) proposed a method that helps overcome the lack of workforce skills. The process explores the integration of GIS and BIM to

create 3D models of underground facilities, especially for use by workers without GIS and CAD knowledge, for consultation before maintenance activities, such as excavations. Regardless of the sharing methodology, it is important to use interoperable formats, whether computer files, internet services or web scenes, for desktop applications or mobile devices.

3.4 BEST PRACTICES OF 3D MODELLING OF WATER AND SEWER NETWORKS

Table 1 summarises best practices for 3D modelling water and sewer networks at each data lifecycle stage.

Table 1

Best practices of 3D modelling of water and sewer networks in each step of the data lifecycle.

Step	Challenge	Actions	Instruments Possible
Planning	Improving the work processes of sanitation companies with 3D modelling of networks	Evaluate existing data, clearly define objectives and requirements, define technical requirements and draw up an action plan	Infrastructure or ecosystem of existing 2D data and 3D modelling techniques
	Legal compliance	Analyze how to adapt existing data to a 3D model in accordance with needs, standards and applicable legislation	Legislation applicable to the jurisdiction
		Define the easements	Regulations applicable to the jurisdiction
		Identify the ownership of the properties on which the networks are located	Urban cadastre
	Alignment with institutional aspects	Identify stakeholders and RRR	Legislation, institutional arrangements and SDIs
	Data model compatible with needs, objectives and available resources	Develop a conceptual and logical model of the network	LADM, IFC, City Engine, Utility Network Foundations among others.
	Capable team to produce, analyse and use 3D data	Empower team	Peopleware and training techniques
Enrichment or data production	Leverage existing data	Digitize paper-based networks, convert data CAD, process existing data or import data from nearby features to geometric or semantic adjustments.	Existing cadastre, scanners, database or geoprocessing techniques, CAD and GIS softwares (e.g., AutoCAD, ArcGIS, QGIS).
	Produce missing data with quality and accuracy in accordance with established objectives	Collect data in field	Measuring equipment (e.g., GPS, LiDAR, Georadar)

Storage	Database design	Design and execute physical database modeling	Database Management Systems (e.g., PostgreSQL, Oracle, SQL Server)
	Data availability and integrated systems without redundancy	Organize, standardize and implement adequate data management	Database inquiry and queries, ETL tools, among others.
	Secure storage	Create users with access levels according to the roles they play, define data backup and recovery policies and routines	Database management techniques
Use	Reliable and updated spatial data	Update and maintain network records. Promote data cleansing through archiving, reusing or eliminating obsolete data.	System of cadastre manage (e.g., ArcFM, Utility Network Foundations, Giswater
	Rapid implementation and low-cost 3D models	Automate the conversion of network nodes and lines into three-dimensional shapes	Geometry and attributes of spatial data, such as networks location (X, Y), depth (Z), diameter, material and time. GIS, CAD, BIM softwares and web scenes.
	Good performance in viewing 3D models	Choose the level of detail and symbology in a balanced way and use resources with greater technological performance.	High latency networks and high-performance devices.
	Use of spatial analysis in different work processes	Promote interference analyses with networks, land analyses, environmental analyses, among others.	Analysis software (e.g., ArcGIS, QGIS and others),
Sharing	Collaboration between institutions with granted rights to access and use data	Publish data on internet services	Internet service sharing platforms (e.g., ArcGIS Enterprise, GeoServer, among others)
	Systems interoperability	Use protocols that allow easy use by other institutions	Open and interchangeable data sharing standards (e.g., OGC)
	Accessible 3D models	Allow use by workers who are not highly skilled in 3D visualization and specialized software (e.g., GIS, CAD, and BIM)	Web scenes, VR and AR applications.

4 CONCLUSIONS

This review identified the best practices in each part of creating 3D models of water and sewage networks based on legal, institutional, and technical aspects, as well as understanding the specificities of the Brazilian reality. The review recommends considering legal elements when identifying the ownership of the properties where the networks exist and their respective easements, allowing the list and apply rights, restrictions and responsibilities,

considering the real right of use, the prevalence of the public interest, regulatory frameworks, contracts, zoning, construction and environmental protection standards.

Legal aspects are closely linked to institutional aspects. Enforcement of legislation is facilitated by identifying the stakeholders involved, their tasks and responsibilities. It is important to train the workforce to work with 3D models and find ways to facilitate visualization for the end user. It is necessary to choose a 3D cadastre data management model or adopt the model established for the respective jurisdiction, in addition to respecting data sharing and security standards, concepts, terminology and semantics.

Considering the technical aspects, best practices to create 3D models of water and sewage networks suggest storing the data in a database management system, with the nodes and segments of the networks represented by points and lines but visualized as cylinders and other volumetric shapes automatically. The 3D visualization of spatial data should contain at least the location (X, Y), depth (Z coordinate preferably representing the axial line of the pipes) and diameter, as well as complementary material and current situation (time or fourth dimension). The modelling can use pre-existing 2D data, while missing data can be obtained through mapping, subsurface survey, and geoprocessing techniques compatible with the expected accuracy of the model or by importing them from nearby resources. Spatial data should be shared as internet services, with 3D scenes accessible in web browsers, VR, and AR applications. Effective scene manipulation and communication rely on a balanced level of detail and symbology to ensure good performance. Data extraction and export to various file formats can be done using ETL tools.

The analysis of the Brazilian situation indicates specificities in relation to legal and institutional aspects, such as compliance with the rules and standards established to participate in INDE and IDEs at other levels, following the ET-EDGV rules when defining a data model, using the spatial reference system established for the jurisdiction based on the SIRGAS 2000 datum. For networks of Federal Government institutions, compliance with legislation related to BIM is required. In the Brazilian case, 3D models can help to comply with the concession of underground space use.

For future research, it is advisable to create a 3D model that materializes the results of the bibliographic review and that serves as guidance for initiatives aimed at the three-dimensional modelling of water and sewage networks.

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Table 1
Best practices of 3D modelling of water and sewer networks in each step of the data lifecycle

Step	Challenge	Actions	Instruments Possible
Planning	Improving the work processes of sanitation companies with 3D modelling of networks	Evaluate existing data, clearly define objectives and requirements, define technical requirements and draw up an action plan	Infrastructure or ecosystem of existing 2D data and 3D modelling techniques
	Legal compliance	Analyze how to adapt existing data to a 3D model in accordance with needs, standards and applicable legislation	Legislation applicable to the jurisdiction
		Define the easements	Regulations applicable to the jurisdiction
		Identify the ownership of the properties on which the networks are located	Urban cadastre
	Alignment with institutional aspects	Identify stakeholders and RRR	Legislation, institutional arrangements and SDIs
	Data model compatible with needs, objectives and available resources	Develop a conceptual and logical model of the network	LADM, IFC, City Engine, Utility Network Foundations among others.
	Capable team to produce, analyse and use 3D data	Empower team	Peopleware and training techniques
Enrichment or data production	Leverage existing data	Digitize paper-based networks, convert data CAD, process existing data or import data from nearby features to geometric or semantic adjustments.	Existing cadastre, scanners, database or geoprocessing techniques, CAD and GIS softwares (e.g., AutoCAD, ArcGIS, QGIS).
	Produce missing data with quality and accuracy in accordance with established objectives	Collect data in field	Measuring equipment (e.g., GPS, LiDAR, Georadar)
Storage	Database design	Design and execute physical database modeling	Database Management Systems (e.g., PostgreSQL, Oracle, SQL Server)
	Data availability and integrated systems without redundancy	Organize, standardize and implement adequate data management	Database inquiry and queries, ETL tools, among others.
	Secure storage	Create users with access levels according to the roles they play, define data backup and recovery policies and routines	Database management techniques

Use	Reliable and updated spatial data	Update and maintain network records. Promote data cleansing through archiving, reusing or eliminating obsolete data.	System of cadastre manage (e.g., ArcFM, Utility Network Foundations, Giswater
	Rapid implementation and low-cost 3D models	Automate the conversion of network nodes and lines into three-dimensional shapes	Geometry and attributes of spatial data, such as networks location (X, Y), depth (Z), diameter, material and time. GIS, CAD, BIM softwares and web scenes.
	Good performance in viewing 3D models	Choose the level of detail and symbology in a balanced way and use resources with greater technological performance.	High latency networks and high-performance devices.
	Use of spatial analysis in different work processes	Promote interference analyses with networks, land analyses, environmental analyses, among others.	Analysis software (e.g., ArcGIS, QGIS and others),
	Collaboration between institutions with granted rights to access and use data	Publish data on internet services	Internet service sharing platforms (e.g., ArcGIS Enterprise, GeoServer, among others)
Sharing	Systems interoperability	Use protocols that allow easy use by other institutions	Open and interchangeable data sharing standards (e.g., OGC)
	Accessible 3D models	Allow use by workers who are not highly skilled in 3D visualization and specialized software (e.g., GIS, CAD, and BIM)	Web scenes, VR and AR applications.

THREE-DIMENSIONAL MODELLING OF WATER AND SEWER NETWORKS: CASE STUDY IN THE CENTRE OF TAGUATINGA, FEDERAL DISTRICT – BRAZIL

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**THREE-DIMENSIONAL MODELLING OF WATER AND SEWER NETWORKS:
CASE STUDY IN THE TAGUATINGA DOWNTOWN, FEDERAL DISTRICT –
BRAZIL**

**MODELAGEM TRIDIMENSIONAL DE REDES DE ÁGUA E ESGOTO: ESTUDO DE
CASO NO CENTRO DE TAGUATINGA, DISTRITO FEDERAL**

ABSTRACT

In recent decades, billions of people have migrated to cities seeking better employment, education, and quality of life. Urban infrastructure has grown more complex to ensure essential services in limited spaces. Cities are becoming more vertical and intensively using underground areas. Two-dimensional (2D) technical cadastres are no longer sufficient. To avoid excavation accidents and ensure service continuity, spatial data must be analysed in three-dimensional (3D) models. Although 3D data usage is increasing, 3D technical cadastres remain underutilised. This research evaluates whether spatial data representing water and sewer networks in the Federal District, Brazil, meet minimum requirements for 3D modelling. A 3D visualisation of a network extract was created in a web-based map in Geographic Information System (GIS) using data from downtown Taguatinga, containing representative characteristics of water and sewer networks of various sizes. Results show that, with some adaptations, existing data support 3D models that identify errors, improve cadastre quality, analyse infrastructure overlaps, and enable technologies like Building Information Modelling (BIM) in managing underground facilities, offering value to decision-makers and public managers.

KEYWORDS

Water Network, Sewer System, Technical Cadastre, 3D

RESUMO

Nas últimas décadas, bilhões de pessoas migraram para as cidades em busca de melhores oportunidades de emprego, educação e qualidade de vida. A infraestrutura urbana tornou-se mais complexa para garantir serviços essenciais em espaços limitados. As cidades estão se tornando mais verticalizadas e utilizando o subsolo de forma intensiva. Os cadastros técnicos bidimensionais (2D) já não são suficientes. Para evitar acidentes em escavações e assegurar a continuidade dos serviços, os dados espaciais devem ser analisados em modelos tridimensionais (3D). Embora o uso de dados 3D esteja em expansão, os cadastros técnicos 3D ainda são pouco utilizados. Esta pesquisa avalia se os dados espaciais que representam as redes de água e esgoto no Distrito Federal, Brasil, atendem aos requisitos mínimos para modelagem 3D. Foi criada uma visualização tridimensional de um extrato da rede em um mapa online baseado em Sistema de Informação Geográfica (SIG), utilizando dados do centro de Taguatinga, local que possui feições representativas de redes de água e esgoto em diferentes tamanhos. Os resultados mostram que, com algumas adaptações, os dados existentes permitem a criação de modelos 3D que podem ajudar na identificação de erros, melhorar a qualidade do cadastro, analisar sobreposições de infraestrutura e viabilizar tecnologias como o *Building Information Modelling* (BIM) na gestão de instalações enterradas, o que pode ser valioso para os tomadores de decisão e gestores públicos.

PALAVRAS-CHAVE

Rede de Água, Rede de Esgotamento, Cadastro Técnico, 3D

1 INTRODUCTION

Looking for better job opportunities, education and quality of life, billions of people have migrated from the countryside to the city in recent decades. With the population explosion and the increased demand for space, services and resources, the desired quality of life would not be possible in the most disputed neighbourhoods of large cities without verticalization. Buildings with the functions of housing, commerce, leisure and offices are built increasingly taller, optimizing the use of urban land, but also requiring more complex urban infrastructure networks to guarantee services such as water supply, sewer, energy, public lighting, gas, drainage, transportation and telecommunications for a large number of people in a reduced space. At the same time the underground space began to be more intensely used by public service networks, train stations, tunnels, parking lots, walkways, shopping centres (Saeidian et al., 2022; 2023), among others.

Underground urban infrastructure, however, cannot be easily observed. Traditionally, field workers who intervene in underground networks access the technical cadastre through two-dimensional (2D) maps, that is, they locate the networks through pairs of coordinates on the X and Y axes of the Cartesian plane. However, technological advances and the popularization of mobile devices allow the visualization of the cadastre in three dimensions (3D), so that spatial data, as long as they are properly prepared, can also be analysed in depth, with an additional axis, the Z axis, presenting numerous advantages. 3D spatial data are more informative and easily reveal details that could be unnoticed in two-dimensional modelling (Yan et al., 2019). This may be the reason for many accidents involving network ruptures in infrastructure works, since the 2D models normally used present the information in a partial way (Balogun et al., 2011; Esekhaigbe et al., 2020; Liu & Issa, 2012), which can result in misinterpretations (Du & Zlatanova, 2006). Thus, 3D visualization can help reduce accidents (Held et al., 2004; Chong, 2006) and indicate errors in registration and data processing. 3D modelling enables more advanced spatial analyses of underground infrastructure networks, which is becoming essential in increasingly complex urban environments.

Despite the benefits, the 3D modelling requires changes in work processes throughout all spatial data lifecycle (Kalogianni et al., 2020; Olfat et al., 2021), from field surveys, through data storage, processing and analysis, to presentation and sharing (Olfat et al., 2021; Plale & Kouper, 2017). Thus, the adoption of 3D modelling is hampered by the natural resistance against changing work procedures, uncertainties about the possibility of using existing data, and the lack of methodologies for converting 2D to 3D data.

This research contributes to overcome the challenges of adopting 3D modelling, using spatial data of the urban infrastructure networks in the Federal District, a state in Brazil that houses the country's capital, Brasilia. The study aims to assess whether the spatial data representing the Federal District's water and sewer networks meet the minimum requirements for 3D modelling. The existing cadastre was built to be viewed in two dimensions, but with some adaptations, it may be possible to present the same data in three dimensions. This would save time and money, since existing data would be used instead of having to conduct new large field surveys to provide the Z coordinates to the cadastre. The work, initially limited to water and sewer networks may, in the future, stimulate 3D modelling other urban infrastructure cadastres of the Federal District.

2 MATERIALS AND METHODS

Although three-dimensional modelling was not initially planned, the cadastre was gradually enriched with attributes useful for 3D visualization, such as bottom and lid elevations, generatrix elevations, depth, and pipe diameter. The adequacy of these attributes for 3D modelling was assessed, leading to adaptations in existing spatial data to enable visualization of networks in three dimensions. The study utilized spatial data from the downtown area of Taguatinga, one of the principal administrative regions of the Federal District, located approximately 20 kilometres from Brasília's Pilot Plan. Despite its limited geographic extent, this urban environment is notably complex and features a wide array of representative elements of water and sewer infrastructure. The area includes high-diameter water and sewer pipelines as well as networks of varying diameters, making it an ideal setting for testing and evaluating whether the cadastre's attributes and structural organization are adequate to support three-dimensional modelling. The study area and the local networks are shown in Figure 1.

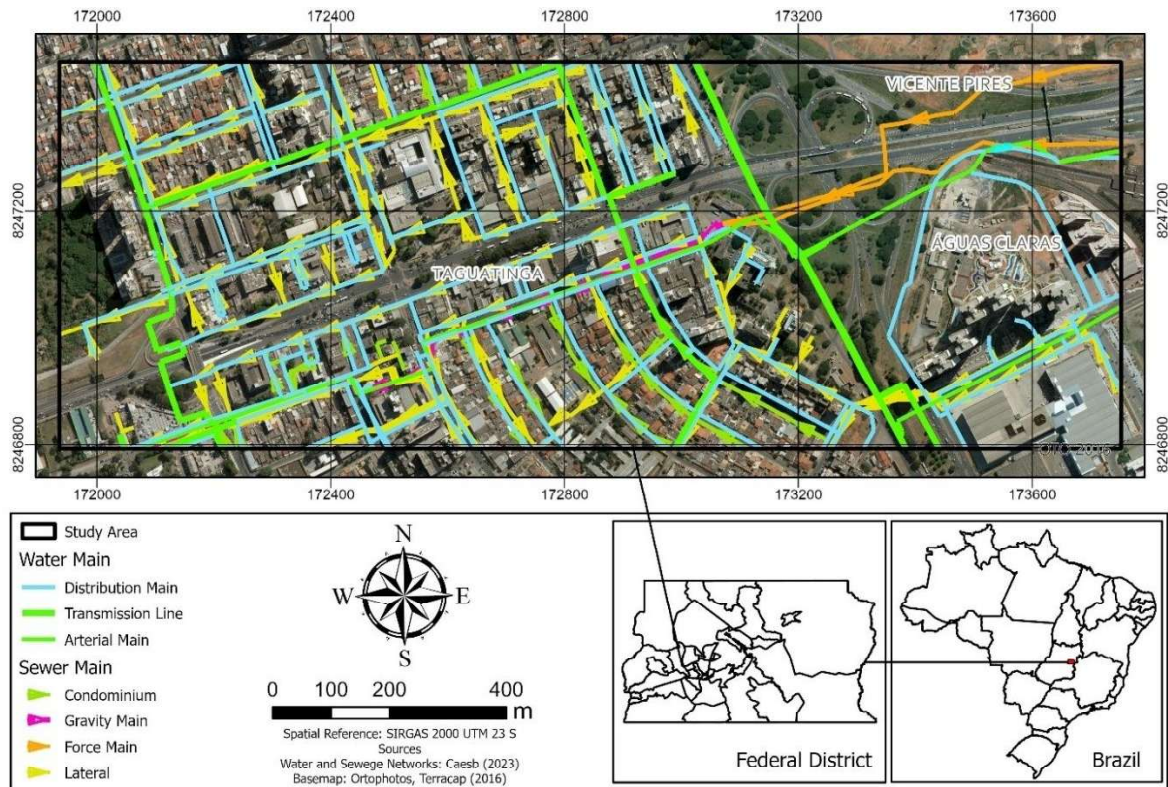


Figure 1 - Study Area

Source: by the authors

The underground infrastructure analyzed in this study is part of the technical cadastre maintained by the Environmental Sanitation Company of the Federal District (CAESB), using a spatial database system based on Microsoft SQL Server 18 with ArcSDE technology, and managed through ArcMap 10.6 software (developed by Environmental Systems Research Institute, Inc. – ESRI) and ArcFM plugin (Schneider Electric). In order to not compromise the integrity of the cadastre during the research, data from study area was extracted and stored in a local file geodatabase. Were used spatial data representing pipes, junctions, devices, and topographic points from water and sewer networks. Pipes are tubes where passe fluids represented by line-type spatial data. Junctions are parts that interconnect pipes, such as tees, elbows, crosses and couplings, represented by point-type spatial data. Devices are junction boxes and manholes, in addition to structures that house equipment such as valves, air release valves and hydrants, also represented by point-type spatial data. The topographic point marks the location where ground penetrating radar (GPR) or other measurement and prospecting methods confirmed the positioning of the network, junction or device. In locations where there is a greater concentration of topographic points, the networks have more precise vertical positioning. Yan et al. (2019) suggest integrating preexisting data with new data collected using GPR to build a 3D cadastre.

The modelling and structure of the data as used by the company were preserved, without the concern of adopting a preestablished conceptual or physical model of space management and 3D modelling, and without requiring acquisition of new software or plugins besides those in use at the company. The transition to the 3D model must be low-cost in order to be accepted (Balogun et al., 2011).

The ArcGIS Pro 3.2.2 software was used for editing and processing the data, composing and publishing the 3D web map. The 3D Analyst extension was necessary to assign the Z dimension. Initially, the Z coordinate values were inserted into each of the features that make up the information plans used. The vector data was then converted into solids as multipatch feature to allow the visualization of the networks in 3D web map.

To assign the third dimension to the geometries, semantic data from the network cadastre were used, applying different strategies to compensate for missing attributes. While some point-type features contained elevation values, others had their elevations imported from the nearest topographic point via spatial union. In cases where data were insufficient, the surface elevation was used as lid elevation for devices. Once elevation values were assigned to all points, they were transferred to the connected lines, with long sections divided at each passing point for better adjustment. The field calculator then combined the different elevation attributes to generate Z coordinates, ensuring accurate axial positioning of pipes and junctions. It was used the following formulas:

$$\text{Axial Elevation} = \text{Surface Elevation} - [\text{Depth} + (\text{Diameter}/2)] \text{ or}$$

$$\text{Axial Elevation} = \text{Upper Generatrix Elevation} - (\text{Diameter}/2) \text{ or}$$

$$\text{Axial Elevation} = \text{Lower Generatrix Elevation} + (\text{Diameter}/2)$$

These were the formulas to insert the bottom elevation of the inspection wells and junction boxes of the network's devices as Z coordinates:

$$\text{Bottom Elevation} = \text{Lid Elevation} - \text{Depth or}$$

$$\text{Bottom Elevation} = \text{Surface Elevation} - \text{Depth or}$$

$$\text{Bottom Elevation} = \text{Upper Generatrix Elevation} - \text{Diameter or}$$

$$\text{Bottom Elevation} = \text{Lower Generatrix Elevation}$$

It was used the diameter value of the largest pipe that touches the device. Fields were created specifically to store the resulting values, which were used to parameterize the "Feature To 3D By Attribute" tool. The tool added the Z coordinate to the points and to the initial and final vertices of the lines, inferring the values of the intermediate vertices. The inferred values may not correspond to the real value, but these values are close to the real ones, as most of the networks are shown in the 3D web map in the expected position.

Three-dimensional solids were created by the “Buffer 3D” tool, parameterized with the radius of the pipes (Diameter/2) to convert the lines into cylinders and points into spheres, with twice the diameter, leaving the junctions visible in the 3D web map. Cylinders were also used to represent the sewer network devices but constructed using another process. Firstly, the points were converted into polygons with circular shape. The polygons were obtained with a buffer operation at a value of 0.5 m. Then an extrusion corresponding to the depth (difference between the lid elevation and the bottom elevation) was applied. For the water network devices, a step was added. Using the “Feature Envelope to Polygon” tool, squares were created around each of the circles obtained in the buffer operation, which, after extrusion, took on the appearance of cuboids, the real shape of the concrete boxes that house the manoeuvring devices. Simple shapes were chosen for their ease of construction, adaptability to different junction types, and compatibility with various network sections, regardless of duct orientation. Additionally, they offer better performance. While realistic symbology provides fine details that may not be distinguishable at most scales, geometric symbology is simpler to render, requires fewer computational resources, and enhances cartographic communication (Santos et al., 2013). For cadastral purposes, low level of detail (LoD) models are sufficient, as high levels of detail are unnecessary when not essential to the analysis. Cadastres in Geographic Information System (GIS) typically span large areas. Excessive detail can negatively impact 3D model performance (Deng et al., 2016). Figure 2 shows the visual result of the application of this methodology.

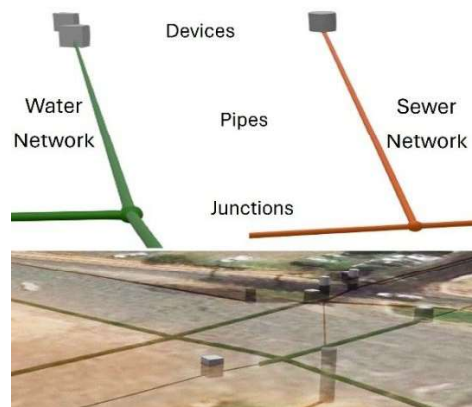
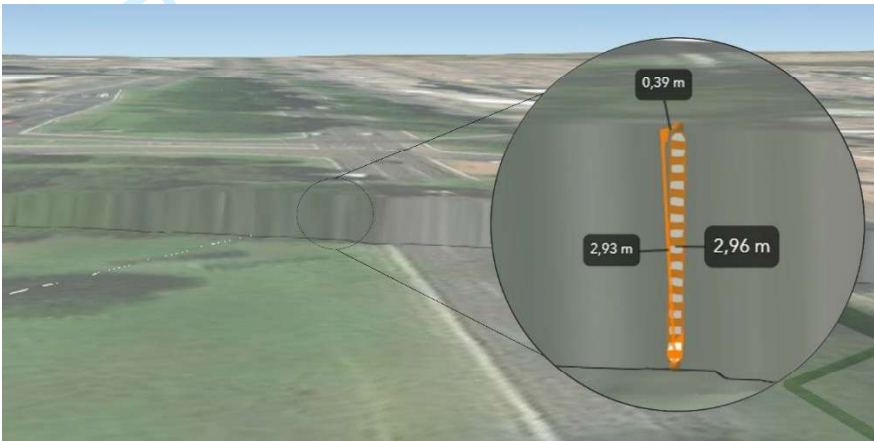


Figure 2 – Visual Result
Source: by the authors

Some of the spatial data used in this study were obtained from the Geoportal of the Spatial Data Infrastructure of the Federal District (SEDUH, 2023). The Geoportal is a public platform that provides free and open access to geospatial information produced by various government agencies. It offers datasets covering themes such as health, education, environment, infrastructure, land use, and urban planning. The platform is updated frequently and includes

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4
5 181 metadata catalogs and geoservices that support decision-making and technical analyses. In this
6 182 research, data related to buildings, vegetation, and terrain elevation were accessed through the
7
8 183 Geoportal to complement the technical cadastre and enhance the accuracy of the 3D modelling.

9
10 184 A Digital Terrain Model (DTM) for all Federal District's urban areas was produced in
11 185 the year of 2016, obtained through Light Detection and Ranging (LiDAR). This is the newest
12 186 data. The use of this reference surface was extremely important, because it allowed for an
13 187 adequate adjustment to the data from the CAESB technical cadastre, differently what would be
14 188 obtained using the standard reference surface of the ArcGIS platform (which has lower
15 189 accuracy). In the study area, these surfaces have an elevation difference of almost three meters,
16 190 as shown in Figure 3.



191
192 Figure 3 - Difference Between Reference Surfaces
193 Source: by the authors

194 Under the reference surface was positioned a mosaic of orthorectified aerial
195 photographs of the Federal District's urban areas, for the year of 2016, obtained in the same
196 survey of the DTM used.

197 To facilitate viewing and sharing, the 3D web map was published as shown in Figure
198 4, using ArcGIS Enterprise 10.9.1 and Portal for ArcGIS 10.4. The online environment used
199 ESRI's World Imagery basemap service. It is advisable to invest in map servers that allow the
200 publication of 3D web maps on the internet (Kamal & Ibrahim, 2013; Zhao et al., 2019).
201 Atazadeh et al. (2023) warn, there is a need to use data sharing standards that guarantee
202 interoperability between software.

203 The network web services, published as feature services, were accessed by the
204 Infraworks 2019 software through the Autodesk Connector for ArcGIS, in order to verify
205 whether the spatial data produced in GIS were compatible with Building Information Modelling
206 (BIM) systems. Liu et al. (2017) suggest the promoting BIM and GIS integration through the
207 internet service. These technologies complement each other facilitating analysis and decision-

making in facility management (Liu & Issa, 2012; Song et al., 2017; Sharafat et al., 2021; Wang et al., 2019).

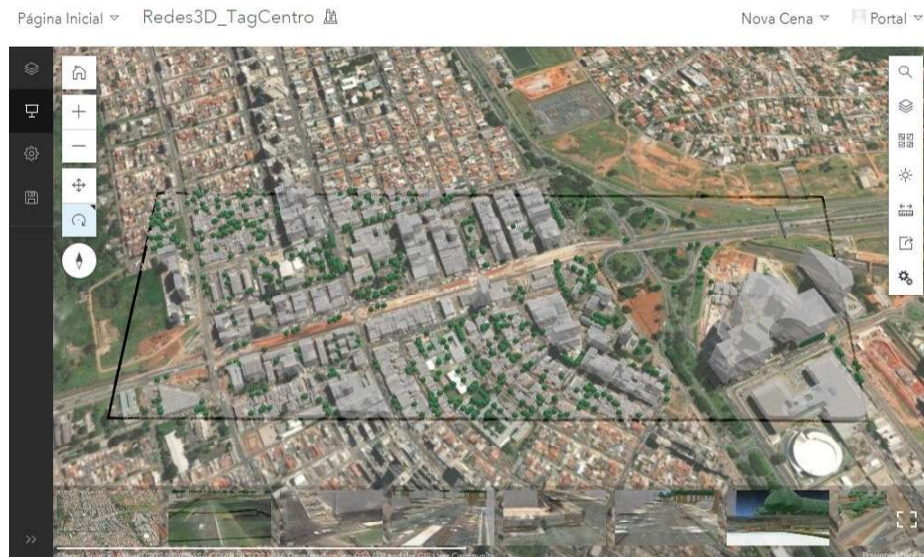


Figure 4 - 3D web map published on the internet
Source: by the authors

3 RESULTS AND DISCUSSION

Any errors in data recording stay evident in 3D modelling. In the manhole highlighted in Figure 5, for example, the difference between the registered bottom and lid elevations exceeds six meters. The overestimated lid elevation value occurred due to a typing error. Errors like this is not easily perceived in 2D visualization but is evident in 3D modelling.

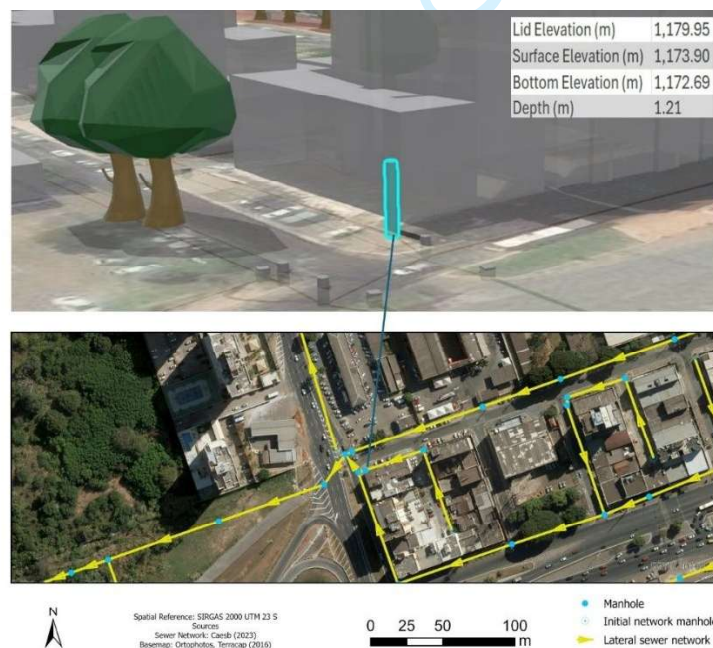


Figure 5 - Ease of Viewing Registration Errors
Source: by the authors

Most of the networks were correctly positioned below the reference surface, at the expected depth, as shown in the topographic profile in Figure 6, made in the Create Chart/Profile Graph functionality of ArcGIS Pro. However, as shown in the inset, some irregularities were identified in the representation of the sewer network that do not correspond to reality, because they would impede the flow by gravity. The 3D modelling reflected the incorrect recording of the network depth values.

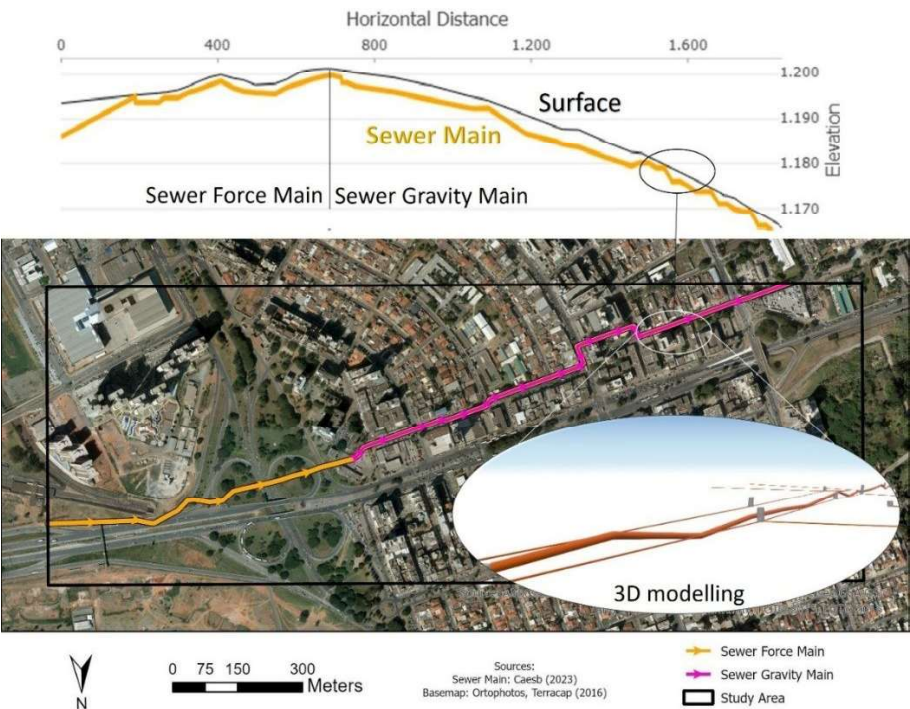


Figure 6 - Positioning of the Network on Reference Surface
Source: by the authors

In Figure 7, the sewer network appears approximately one meter above the reference surface on the entire avenue and adjacent streets, another example of the improper positioning of the sewer network due to errors in the registration.

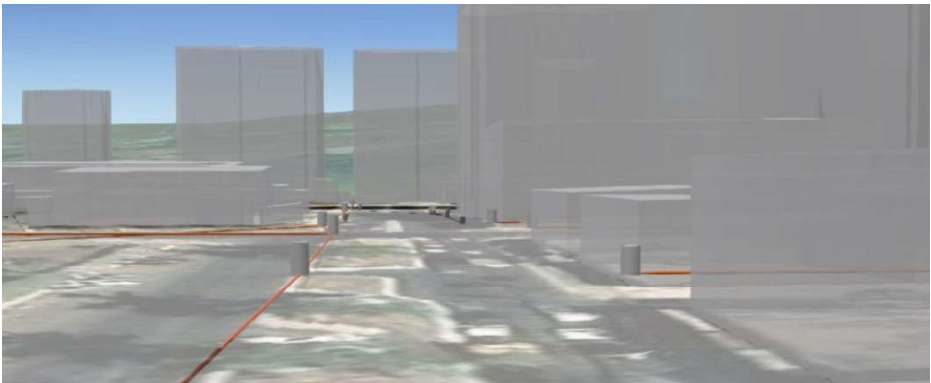


Figure 7 - Positioning of the Sewer Network Above Reference Surface
Source: by the authors

The topographic profile shown in Figure 8 confirms that the local sewer network elevation values are incorrect, as can be seen in the three-dimensional modelling. Analysis of

the attributes revealed errors in the topographic survey in this place, giving the sewer network elevation above surface unduly.

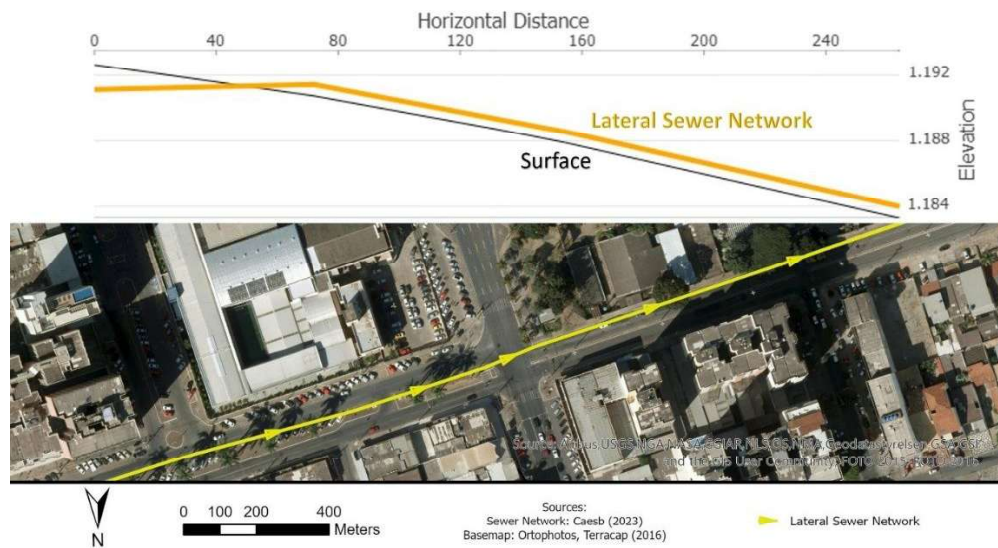


Figure 8 - Section of the Sewer Network with Incorrect Elevations
Source: by the authors

During data processing to produce the 3D web map, most network segments already contained diameter values among their attributes. In a few cases where this information was missing, the diameter was mistakenly imported from the nearest topographic points. This led to processing errors, as the most appropriate approach would have been to retrieve the diameter from the closest network segments. The 3D visualization made it easy to detect these discrepancies, as shown in Figure 9, and the processing methodology was subsequently corrected.



Figure 9 - Pipes with Incorrect Diameter
Source: by the authors

To overcome the limitations of 2D registration, it is common to use resources such as annotations on blueprints and maps, contour lines, elevation points, altimetric profile, among others. CAESB created a specific feature class called “overpass connection” represented as arcs to indicate which network is at a higher elevation in situations where two segments intersect, taking an additional concern for recording spatial data. In 3D registration, the network that passes over is easily perceived, as shown in Figure 10.

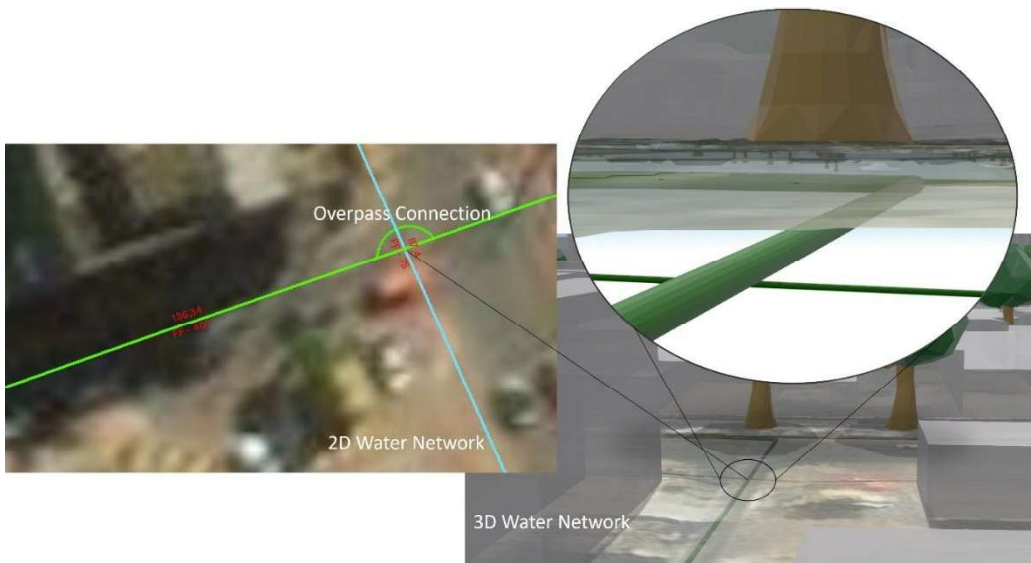


Figure 10 - Crossed Networks in 2D and 3D
Source: by the authors

Buildings, still in the construction phase and, later, when they start operating, need to be connected to public service networks. Sometimes, the project of the surrounding networks must be changed to maintain the quality of services after the increase in demand. Therefore, there must be integration between information about the project and the surrounding environment. BIM gathers a set of detailed information about buildings from the design and construction phase to operation and maintenance (Liu & Issa, 2012). Technical cadastres that gather information about the surrounding environment use GIS. Three-dimensional GIS modelling is necessary for integration with BIM, adequately informing how the building should connect to urban infrastructure networks. Figure 11 shows an example of GIS/BIM integration in the study area.



Figure 11 - Example of GIS/BIM Integration
Source: by the authors

The 3D visualization networks in Taguatinga downtown were automatically constructed in Infravworks, from the internet service. Some studies develop methods for automating the process of converting 2D data to 3D (Chaaban et al., 2019; Du & Zlatanova, 2006). Automation is important because it prevents work processes from becoming overly complex, repetitive and expensive in the production of 3D visualization.

To be useful, a 3D model needs to present a good performance in the visualization in the field. In the Taguatinga networks model, data visualization through internet browser presented significantly better performance than in ArcGIS for desktop. In addition, navigation commands are simpler, and the response speed of the commands was faster, making manipulation of the 3D web map easier. This may be because the data is hosted on servers, instead of directly accessing the database, as in the desktop tool. Thus, the 3D web map proved to be more suitable if the use is restricted to simple spatial visualization and analysis. Visualization through internet browsers democratizes access to data that would otherwise be restricted to desktop use, with specialized software and restricted to a few professionals. It is necessary to facilitate the visualization of networks by field teams (Liu & Issa, 2012), who do not always have the technical knowledge necessary to interpret maps and blueprints or to use CAD, BIM and GIS tools. To reach better results is recommended mobile internet networks that offer good latency, high processing and memory capacity of the devices.

4 CONCLUSIONS

The three-dimensional modelling of water and sewer networks in Taguatinga downtown provided valuable insights into the advantages of 3D spatial data. The research demonstrated that existing cadastral records can be leveraged to generate 3D models, provided certain improvements are made to enhance accuracy and usability. Compared to traditional two-dimensional maps, charts, and blueprints, the 3D representation offers superior precision, enabling field workers to analyse infrastructure in greater detail.

To be effective in real-world applications, a 3D model must perform well in field visualization. Smooth navigation and clear interpretation of spatial information are essential to support operational teams and decision-making processes. This approach facilitates the detection of errors in cadastral records, enhances interference analysis between underground networks, and enables integration with advanced technologies such as GIS and BIM.

The model developed confirmed that CAESB's corporate spatial data infrastructure is capable of supporting three-dimensional modelling and visualization of water and sewer

networks. For broader implementation across the Federal District, it is essential to optimize existing data, software, and infrastructure.

Inaccuracies such as network segments positioned above the terrain were immediately evident through 3D visualization, which proved to be an effective diagnostic tool. This capability allows the Technical Cadastre team to promptly identify and correct such anomalies, improving data reliability. Moreover, the use of 3D modelling in future data submissions from contractors will enhance quality control by enabling more accurate evaluations prior to integration into the corporate database.

Specific field surveys will be necessary to correct errors and improve the vertical alignment of network components. It is also crucial to distinguish features with Z elevations measured directly in the field from those derived from topographic points, ensuring greater representational accuracy. Increasing the number of topographic points and refining their classification will further improve model precision.

Several methodological refinements are recommended to enhance the 3D modelling process. These include segmenting lines at junctions to better represent network nodes, inserting junctions at branches, curves, and directional shifts to enable precise vertical alignment, and incorporating buffer zones or easements to indicate restricted excavation areas, thereby improving safety for field teams.

To facilitate the transition from a 2D to a 3D cadastral system, the implementation of automated dynamic visualization through spatial database queries is recommended, ensuring real-time updates and consistency. Publishing the dataset as a feature service will enable broader access via 3D web maps and integration with BIM, augmented reality (AR), and virtual reality (VR) applications, fostering seamless collaboration across teams. The adoption of interoperable formats is fundamental to ensuring compatibility with various software systems and strengthening institutional efforts in underground space management.

As the research progresses, it becomes evident that implementing a three-dimensional technical cadastre offers strategic advantages that extend beyond sanitation infrastructure. By enabling detailed spatial representation, including elevation profiles, pipe diameters, and connection nodes, the model supports more accurate analysis of topological relationships among subsurface and surface urban infrastructures, such as electrical conduits, telecommunications lines, and stormwater systems. This integrated spatial understanding enhances the capacity of public managers to anticipate conflicts, optimize maintenance schedules, and plan infrastructure expansions with greater precision. In the context of the Federal District, characterized by rapid urban growth and complex utility networks, the

adoption of this model represents a foundational step toward the modernization of technical cadastres and the rationalization of underground utility management, potentially serving as a replicable framework for other metropolitan regions in Brazil.

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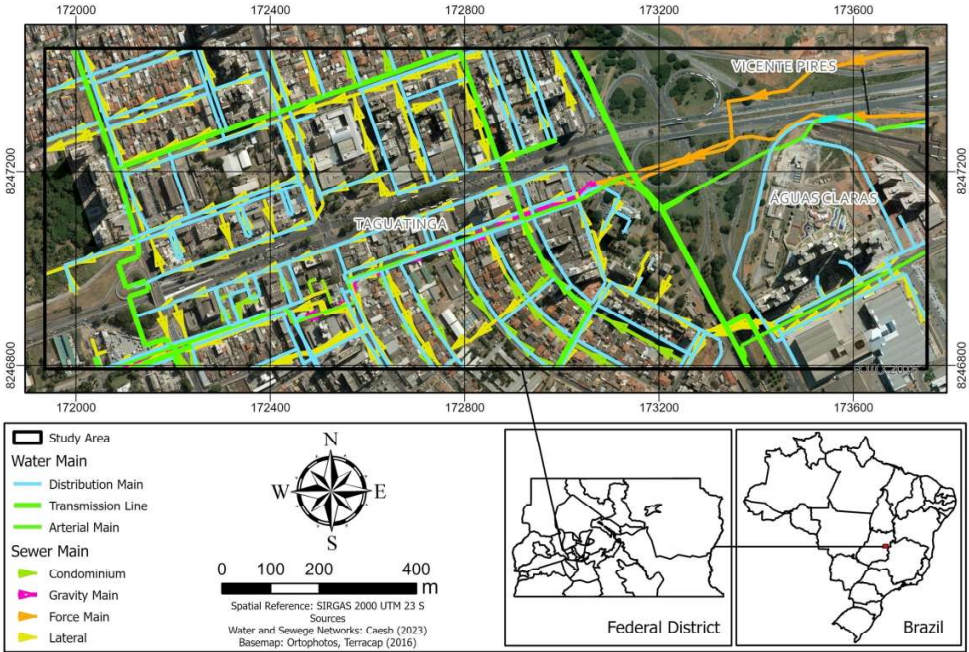


Figure 1 - Study Area

200x135mm (300 x 300 DPI)

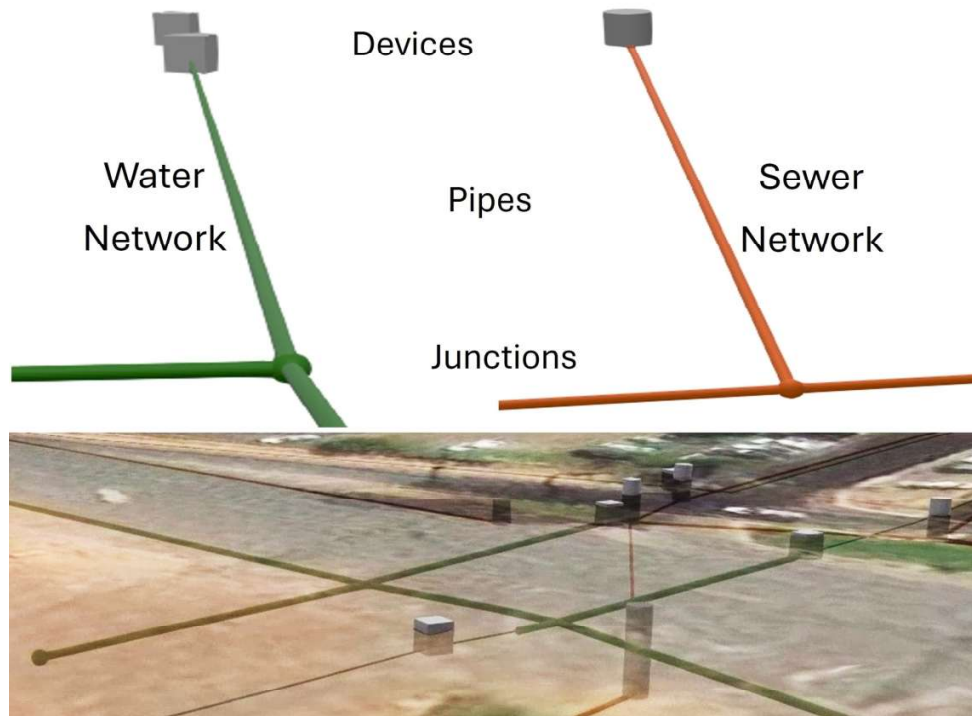


Figure 2 – Visual Result

173x130mm (300 x 300 DPI)

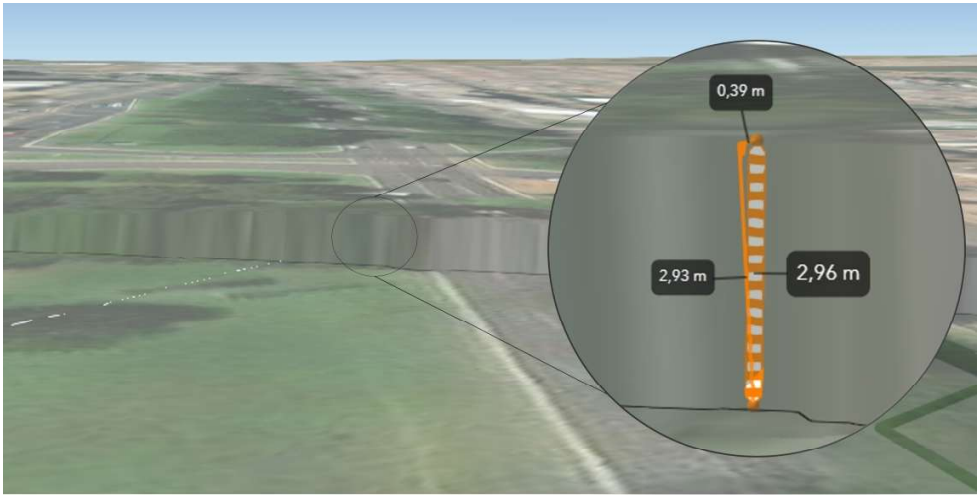


Figure 3 - Difference Between Reference Surfaces
289x176mm (300 x 300 DPI)

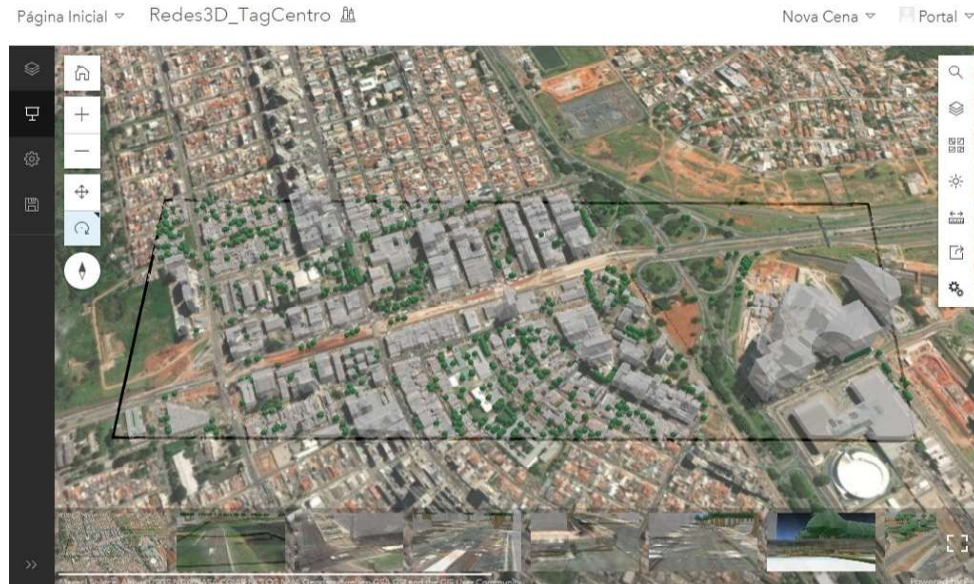


Figure 4 - 3D web map published on the internet

270x166mm (96 x 96 DPI)

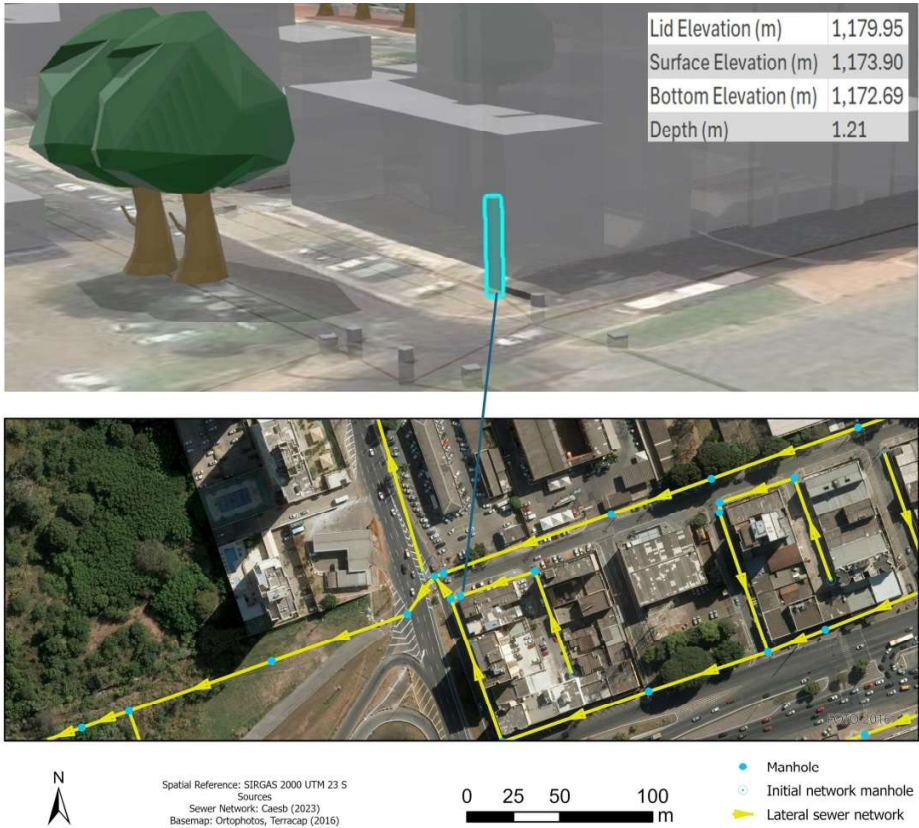


Figure 5 – Ease of Viewing Registration Errors
209x180mm (300 x 300 DPI)

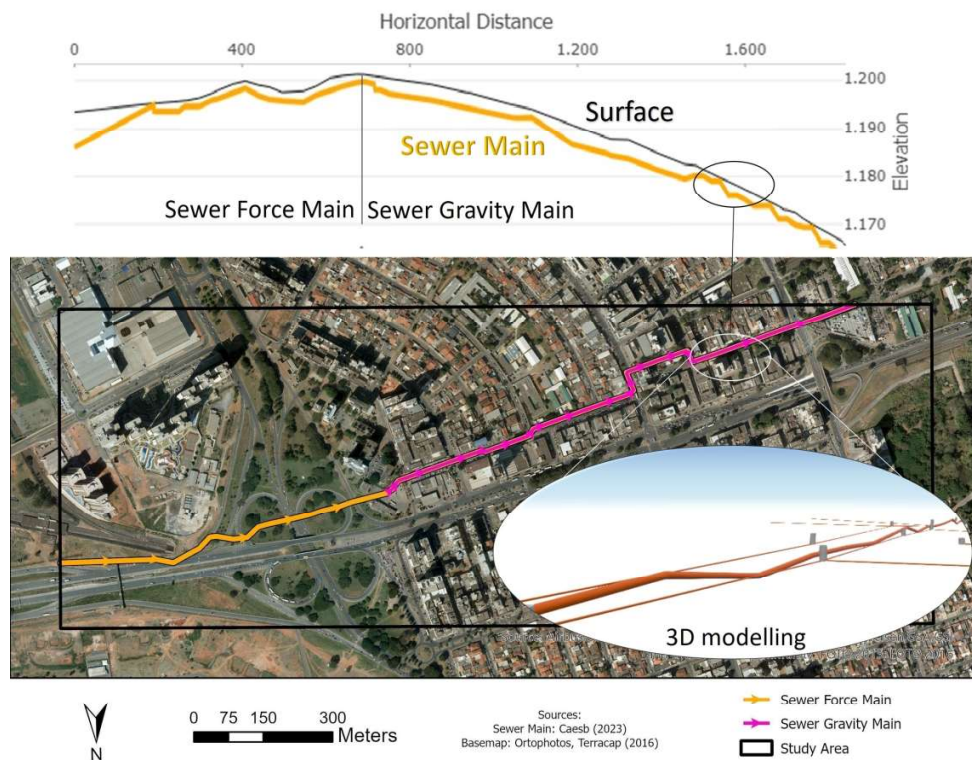


Figure 6 – Positioning of the Network on Reference Surface

209x164mm (300 x 300 DPI)

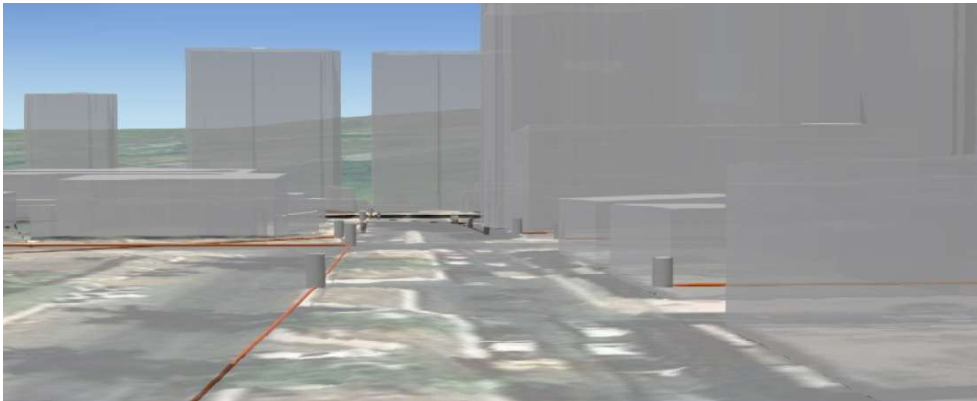


Figure 7 – Positioning of the Sewer Network Above Reference Surface

234x95mm (120 x 120 DPI)

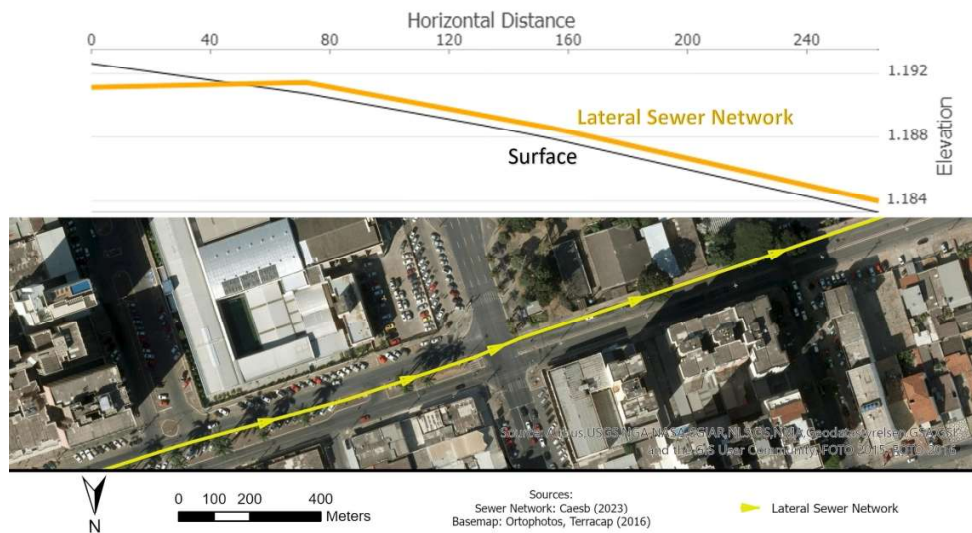


Figure 8 – Section of the Sewer Network with Incorrect Elevations

209x114mm (300 x 300 DPI)



Figure 9 – Pipes with Incorrect Diameter
126x55mm (96 x 96 DPI)

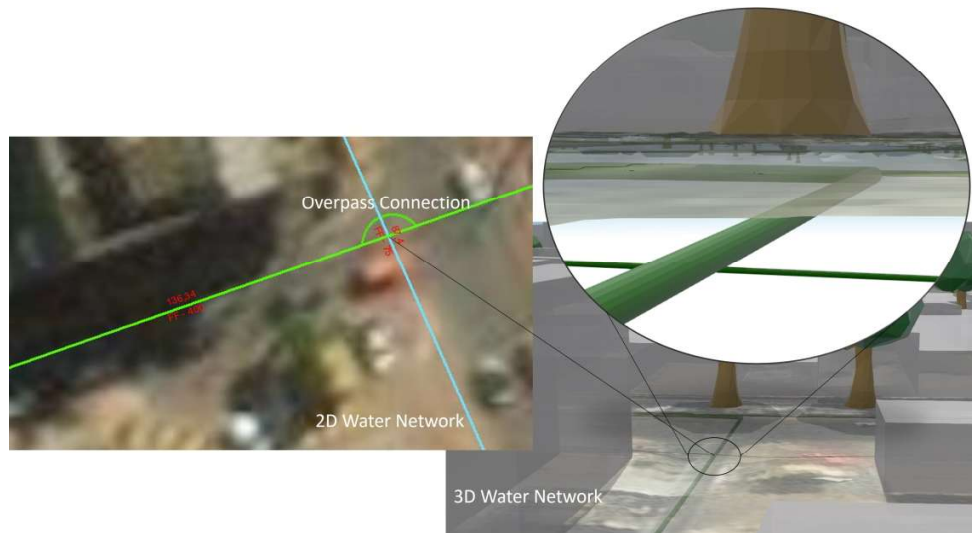


Figure 10 - Crossed Networks in 2D and 3D

315x170mm (300 x 300 DPI)



Figure 11 - Example of GIS/BIM Integration
252x170mm (300 x 300 DPI)



**Automated 3D visualization of water and sewer networks in
GIS: a methodological approach applied to the technical
cadastre of the Federal District, Brazil**

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Keyword:	Water Network, Sewer System, Technical Cadastre, 3D

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AUTOMATED 3D VISUALIZATION OF WATER AND SEWER NETWORKS IN GIS: A METHODOLOGICAL APPROACH APPLIED TO THE TECHNICAL CADASTRE OF THE FEDERAL DISTRICT, BRAZIL

VISUALIZAÇÃO 3D AUTOMATIZADA DE REDES DE ÁGUA E ESGOTO EM SIG: UMA ABORDAGEM METODOLÓGICA APLICADA AO CADASTRO TÉCNICO DO DISTRITO FEDERAL, BRASIL

ABSTRACT

This study presents a methodology for the automated production of three-dimensional (3D) models based on two-dimensional (2D) technical cadastres of water and sewage networks. The approach was applied to real data from the Environmental Sanitation Company of the Federal District (CAESB), demonstrating its practical feasibility. The proposed methodology can be adopted by sanitation companies worldwide, contributing to the improvement of technical record management, the planning of new networks, and the maintenance of infrastructure near existing systems, helping to prevent accidents, losses, and interruptions of essential services. Furthermore, the approach facilitates conflict analysis, communication among technical teams, and decision-making processes. The results demonstrate the potential of the methodology to enhance spatial understanding of the networks and support planning and maintenance strategies. Finally, the generated models enable integration with emerging technologies such as augmented reality (AR), virtual reality (VR), and Building Information Modelling (BIM), expanding possibilities for visualization and analysis.

KEYWORDS

Water Network, Sewer System, Technical Cadastre, 3D

RESUMO

Este trabalho apresenta uma metodologia para a produção automatizada de modelos tridimensionais (3D) a partir de cadastros técnicos bidimensionais (2D) de redes de água e esgoto. A abordagem foi aplicada a dados reais da Companhia de Saneamento Ambiental do Distrito Federal (CAESB), demonstrando sua viabilidade prática. A metodologia proposta pode ser adotada por empresas de saneamento em diferentes partes do mundo, contribuindo para o aprimoramento da gestão de cadastros técnicos, o planejamento de novas redes e a manutenção de infraestruturas próximas aos sistemas existentes, prevenindo acidentes, perdas e interrupções de serviços essenciais. Além disso, a abordagem facilita a análise de conflitos, a comunicação entre equipes técnicas e a tomada de decisões. Os resultados demonstram o potencial da metodologia para ampliar a compreensão espacial das redes e apoiar estratégias de planejamento e manutenção. Por fim, os modelos gerados permitem a integração com tecnologias emergentes, como realidade aumentada (RA), realidade virtual (RV) e *Building Information Modelling* (BIM), ampliando as possibilidades de visualização e análise.

PALAVRAS-CHAVE

Rede de Água, Sistema de Esgoto, Cadastro Técnico, 3D

INTRODUCTION

Most water and sewer networks are buried and invisible to the naked eye, making technical records essential for safe excavation and infrastructure interventions. Traditionally, field teams rely on printed two dimensional (2D) plans (Du & Zlatanova, 2006), which often fail to convey network depth and overlapping components, increasing the risk of misinterpretation, service disruptions, and even serious accidents (Balogun et al., 2011; Esekhaigbe et al., 2020; Liu & Issa, 2012). To mitigate these risks, sanitation companies maintain technical cadastres that include not only location and depth, but also attributes such as pipe diameter, material, hierarchy, and installation date. Compared to 2D representations, three dimensional (3D) models offer a more comprehensive and intuitive understanding of spatial relationships, helping to prevent damage, losses, and interruptions to essential services (Held et al., 2004; Chong, 2006).

Many companies still rely on blueprints, charts, or paper maps stored in archives and physical map libraries. With the rise of microcomputing, some companies transitioned to digital cadastres in Computer-Aided Design (CAD) formats, primarily viewed on monitors and printed for field access. Today, the combined use of Geographic Information System (GIS) and spatial database system offers the most effective solution for managing technical cadastres (Döner et al., 2011; Guerrero et al., 2013; Koch & Löwner, 2017).

Spatial database system organizes and protects data, enabling access control, versioning, and integration with internal and external sources. This structure enhances analytical capabilities and, when combined with GIS tools, supports online map publication and 3D data visualization. The production and application of 3D representations present a series of technical and practical challenges at every stage of the spatial data life cycle (Kalogianni et al., 2020; Olfat et al., 2021). Field data collection requires sophisticated and costly equipment, such as laser scanners and depth sensors, which are often complex to operate. The challenges intensify when acquiring underground data, necessitating remote sensing technologies like Ground Penetrating Radar (GPR), Inertial Measurement Units (IMU), gyroscope-based systems, or even the injection of traceable markers into pipelines, such as radioisotopes, that can be detected from the surface (Yan et al., 2018; 2019; Hashim et al., 2010; Tao, 2013). Processing tasks, including filtering, correction, segmentation, analysis, information extraction, and visualization, demand highly skilled professionals and advanced hardware and software with substantial processing capacity (Guerrero et al., 2013; Liu & Issa, 2012).

Given the numerous challenges in this field, researchers are increasingly focused on addressing issues related to the use of three-dimensional models (Paulsson & Paasch, 2013; Paasch & Paulsson, 2021). Advances in research continue to raise expectations that the production, storage, retrieval, and visualization of 3D data will become more efficient and accessible. Consequently, the costs associated with implementing 3D modelling projects are expected to decrease. El-Hakim (2008) emphasizes that, for 3D modelling projects to be feasible and widely adopted, they must maintain low implementation costs while meeting essential criteria for reliability and practicality. These include perceptibility of objects to the human eye, positional accuracy aligned with the intended purpose, interactive visualization without loss of detail, and execution within a reasonable timeframe.

Meeting all these criteria simultaneously presents a challenge, as achieving high levels of detail and accuracy can be both time-consuming and costly, which accounts for the limited adoption of three-dimensional models (Balogun et al., 2011). Even in developed countries such as the United States, most public service providers continue to rely on 2D spatial data. The broader adoption of 3D modelling is primarily hindered by insufficient worker training and the high costs associated with acquiring and implementing the required technologies (Esekhaigbe et al., 2020).

Automation has become a key driver in advancing the 3D modelling of public service networks, which remains a complex task due to the challenges of ensuring accurate human perception, particularly when visualising narrow, segmented features such as pipes and cables that extend across large geographic areas. Guerrero et al. (2013) highlight the difficulty of representing such features in scenes dominated by volumetric shapes, suggesting the use of cylinders or triangular meshes instead of simple lines. This approach is supported by other authors (Du & Zlatanova, 2006; DÖNER et al., 2011; Chaaban et al., 2019; Santos et al., 2013), although storing 3D shapes directly in databases is considered inefficient. Du & Zlatanova (2006) argue that parametric shape storage is costly and unjustified, even with modern Database Management Systems (DBMS). A more efficient strategy involves keeping points and lines in the database while generating 3D shapes dynamically or “on the fly” (Du & Zlatanova, 2006; Guerrero et al., 2013; Chaaban et al., 2019; Chahinian et al., 2019). Advances in CAD and GIS software now support this dynamic modelling, and while GIS previously lacked solutions for 3D piping, recent developments have addressed this gap (Du & Zlatanova, 2006).

Chaaban et al. (2019) proposed a semi-automatic method using ModelBuilder and ArcScene to generate 3D representations of sewage and drainage systems. Du and

Zlatanova (2006) automated 3D modelling by integrating DBMS and CAD tools for real-time visualization, while Guerrero et al. (2013) used database queries to dynamically convert network elements into 3D geometries rendered in web-based scenes. Zhao et al. (2019) introduced a JavaScript-based approach for online 3D conversion and publication. Despite their contributions, these methods face limitations such as the need for manual updates, restricted accessibility to specialized software, performance issues in real-time rendering, and lack of detailed cadastral attributes for accurate representation.

This study proposes a methodology for automating the 3D visualization of water and sewer networks based on existing 2D records, addressing limitations in spatial understanding inherent to traditional representations. By simplifying model updates and reducing the need for specialized professionals, the approach enhances operational efficiency. The resulting 3D models support the evaluation of water supply interruptions and the analysis of network interference with other urban infrastructures. Additionally, they offer cognitive advantages by improving users' spatial perception of network layouts, contributing to more informed decision-making. The scientific contribution lies in advancing data-driven strategies for managing water infrastructure, with direct applications in planning, maintenance, and risk prevention within the field of water resources. The methodology employed is outlined below.

MATERIAL AND METHODS

The core of the proposed methodology lies in the automation of the conversion process from two-dimensional (2D) technical cadastre data to three-dimensional (3D) models. This automation was achieved through the development of custom scripts and tools that process spatial attributes, calculate elevation values, and generate 3D geometries without manual intervention. Although the full algorithmic implementation spans over 40 pages and is not included in this article, the workflow and logic are summarized to highlight the key steps and decisions involved.

The methodology developed for 3D visualization of water and sewer networks enables the publication of interactive 3D online map accessible through standard internet browsers, without requiring specialized software. These visualizations are designed to be intuitive and usable even by professionals who do not work with GIS or Architecture, Engineering, and Construction (AEC) platforms. This approach addresses key usability challenges and expands access to spatial information, supporting broader adoption and operational efficiency. The proposed methodology aligns with best practices for 3D modelling of water and sewer networks, as outlined by Borges et al. (2025a).

The development and validation of the methodology relied on spatial data from the technical cadastre of the Environmental Sanitation Company of the Federal District (CAESB), which contains water and sewer network information. The cadastre is maintained within ArcSDE technology, managed using Microsoft SQL Server Management Studio 18, ArcGIS Pro 3.3, ArcGIS Enterprise 11.1, Portal for ArcGIS 10.4 and ArcGIS Workflow Manager. ArcGIS platform software was developed by Environmental Systems Research Institute, Inc. (ESRI). The cadastre includes data covering the Federal District and a small portion of the neighbouring state of Goiás, as illustrated in Figure 1.

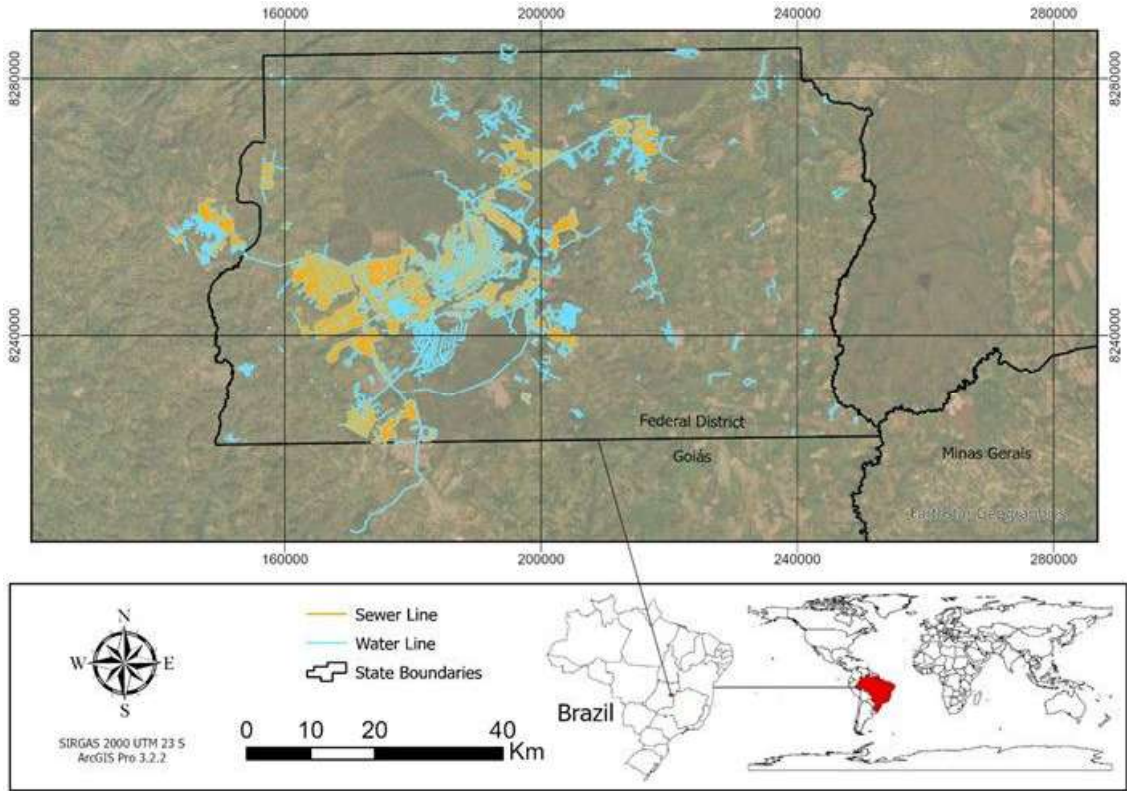


Figure 1. Coverage of the used spatial data. Sources – Sewer and Waterline: CAESB; State Boudaries: IBGE; Basemap: ESRI Imagery web service.

Since 2024, the data model has adhered to the guidelines of the Utility Network Foundation, incorporating adaptations to accommodate the constraints of preexisting spatial data and the company's operational framework. The model is highly complex, encompassing numerous classes and attributes. To fulfil its objective, this research focused solely on the classes necessary for 3D network visualization and the attributes that enable this functionality, rather than utilizing the entire cadastre. Figure 2 illustrates the 2D model classes employed in this study.

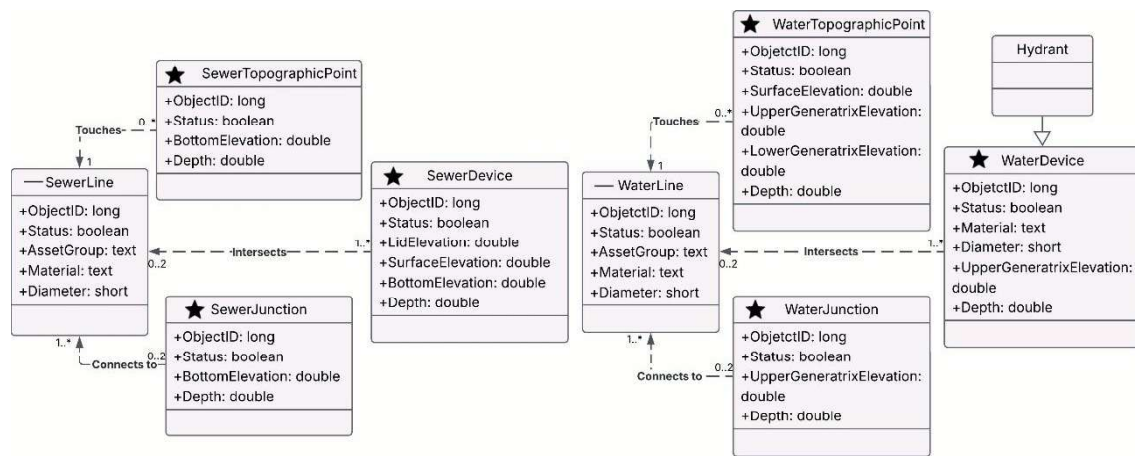


Figure 2. Technical cadastre classes used in the research

Due to the challenges associated with 3D data modelling, CAESB continues to rely on 2D representations. However, as Borges et al. (2025b) highlighted, existing data can be adapted to enable 3D visualization. To ensure data security, accuracy, consistency, traceability, and auditing of modifications, the technical cadastre incorporates topological rules and a structured process for editing, validation, and approval across multiple user levels. For the purposes of this research, it was not necessary to adopt the full complexity of the Utility Network Foundation data model, nor other widely used standards such as CityGML, common in GIS applications, or IFC, prevalent in AEC software. Instead, a simplified, custom data model was developed, focused on the attribute classes essential for 3D visualization, allowing for greater performance during data processing while maintaining compatibility with both GIS and AEC platforms. The new dataset, along with the input data, is stored in the ArcGIS Geodatabase structure within a Microsoft SQL Server database. To support 3D visualization, a dedicated dataset was created and automatically populated with spatial data imported from the technical cadastre. Additionally, a specific class was developed to enhance the visualization of hydrants, derived from the water network device records. Figure 3 presents the classes and attributes used in the 3D visualization.

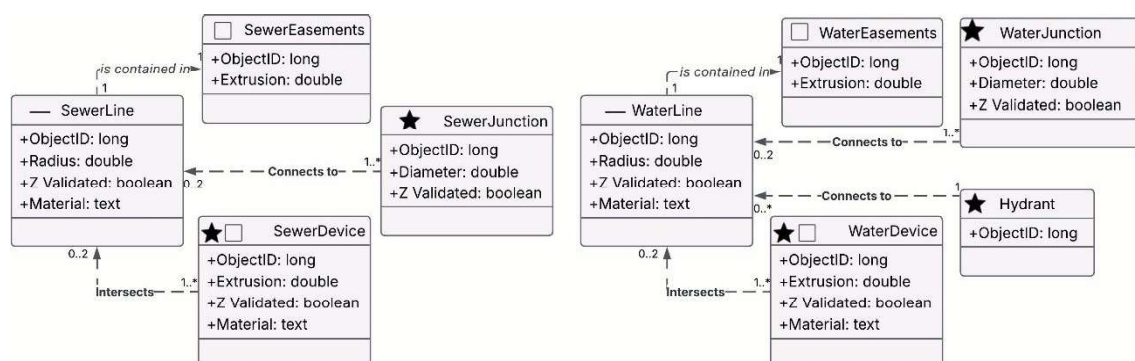


Figure 3. Classes used in the 3D visualization

Lines represent pipes, while junctions are point-based spatial data that depict components connecting pipes, such as tees, elbows, and crosses. Devices are also point-

type data, used to represent junction boxes, manholes, and structures housing equipment such as registers and pressure relief valves. Hydrants, originally part of the water network, are designed for fire suppression. Topographic Points indicate locations where network positioning has been confirmed through measurement or prospecting methods, such as GPR.

The automation process includes: extraction of relevant attributes from the 2D cadastre; elevation assignment using digital terrain models (DTMs); SQL-based spatial data enrichment; and generation of 3D primitives based on predefined rules. These steps are executed through integrated Python and SQL scripts, ensuring consistency, scalability, and repeatability across large datasets.

All classes, both in the 2D cadastre and in the 3D dataset, are stored as Geometry-type features. In the 3D dataset, pipes, junctions, and hydrants retain their geometric primitives as lines and points. Devices, however, are published as web services that can take the form of either points or polygons, depending on the specific visualization and analysis needs they are intended to address. In AEC software, such as AutoCAD Civil 3D or InfraWorks, it is common to employ libraries of predefined three-dimensional shapes that replace points in visual representations. Similarly, in GIS platforms, three-dimensional shapes can be generated by extruding polygons.

Elevation data, including the lid, terrain, and bottom elevations of devices, as well as the depth and elevations of junctions and the pipes' generatrix, can be used to determine Z coordinates. However, because such data is not required for 2D visualization, it is absent from most original features. To address this gap, a tool was developed in Python to automatically import elevation values from a digital terrain model (DTM) and assign terrain and lid elevations to features lacking these values. The terrain elevation is used as the lid elevation since, in most cases, the lid is positioned flush with the surface. In this study, the same raster dataset was utilized as the reference surface, serving as the elevation baseline for the 3D dataset. Figure 4 illustrates the DTM, where areas enclosed within the yellow polygons were mapped at a scale of 1:1,000, while the remaining areas were mapped at a scale of 1:10,000.

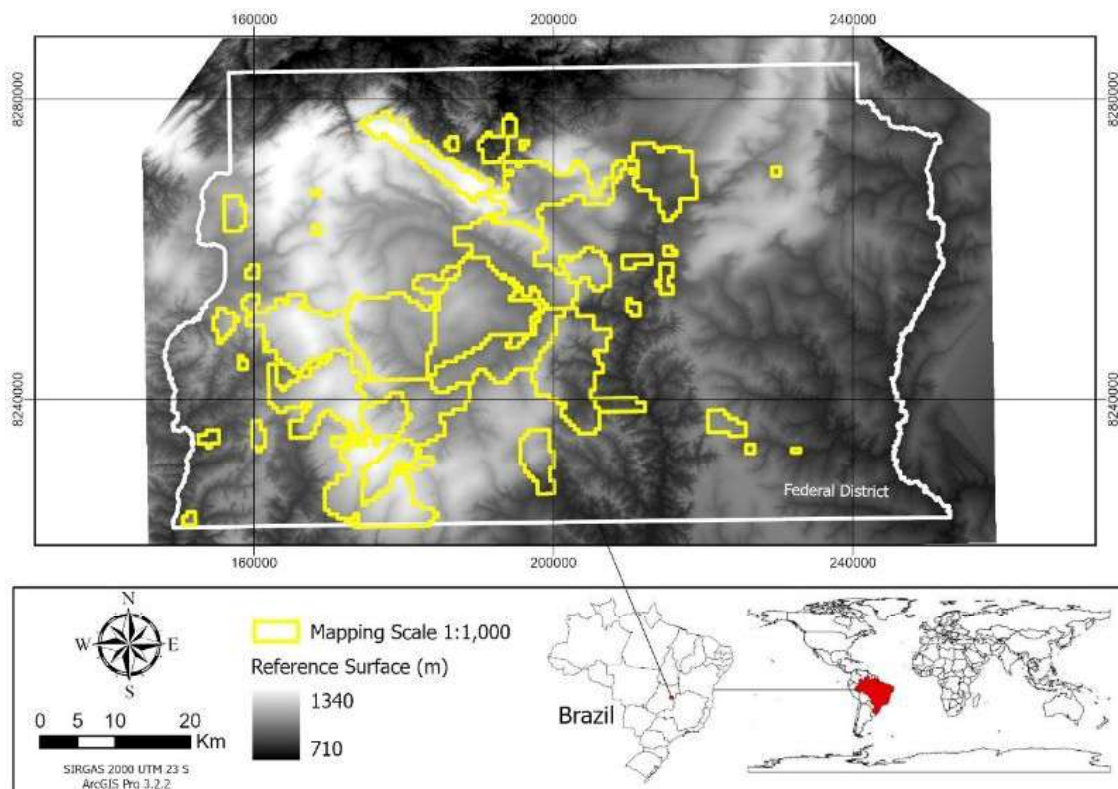


Figure 4. DTM reference surface. Sources – Mapped areas in scale 1:1,000 and DTM: Terracap. Federal District Boudaries: IBGE.

The developed tool also executes scripts developed in Structured Query Language (SQL) within the spatial database system to share existing data among nearby features or import it from the Topographic Point class. These scripts calculate the Z coordinate, populate the attributes required for 3D visualization, and generate easements. Creating or vectorizing objects in three dimensions is inherently complex, making automation based on spatial data attributes essential for efficient 3D visualization. The data import and processing workflow is summarized in Figure 5.

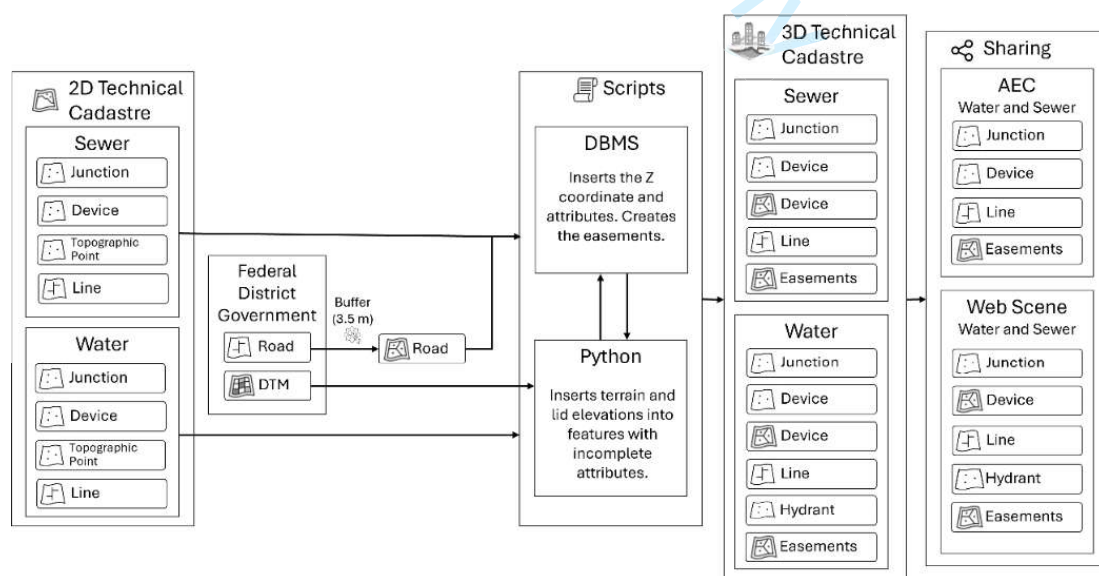


Figure 5. Data import and processing workflow

The Z coordinate is calculated and assigned to each vertex of the features, including the axis elevation of pipes and junctions, as well as devices' lid elevation. Despite their similarities, water and sewage networks exhibit distinct differences arising from both technical and regulatory requirements, as well as from the specific methodologies employed in the construction of their respective cadastres. As a result, the script used for modelling is not identical for both systems; instead, it has been adapted to accommodate the particularities of each network in the development of their respective 3D representations.

Easements are designated buffer zones surrounding the networks to ensure accessibility and safety during installation, maintenance, repairs, and inspections, preventing undue interference. Additionally, they restrict vegetation growth and construction activities that could obstruct or damage the infrastructure. CAESB's regulations for water network easements are summarized in Table 1.

Table 1. Easements for water networks

Diameter (mm)	Material	Covering* (m)	Offset ** (m)
Until 150	PEAD/PVC, PB JE	0.80	1.50
	FF, FOFO	0.60	
Above 150 until 200	PEAD/PVC, PB JE	0.80	2.00
	FF, FOFO	0.60	
Above 200 until 250	PEAD/PVC, PB JE	0.80	
	FF, FOFO	0.85	
Above 250 until 300	All	1.10	5.00
Above 300 until 350		1.25	
Above 350 until 400		1.50	
Above 400 until 1500		2.00	

Source: CAESB *From upper generatrix **For both sides from the network axis

Table 2 presents the regulations for sewage system easements. According to these guidelines, sewer networks receive greater coverage when passing beneath public roads. To define which sections of the sewage networks are located under roadways, a 3.5-meter buffer was applied to spatial data from the Federal District Government representing the road system, resulting in 7-meter strips, the average road width. Additionally, CAESB mandates that other urban infrastructures maintain a minimum clearance from the lower generatrix: 0.3 meters for water networks with diameters under 400 mm and 0.5 meters for diameters of 400 mm or greater. For the sewage system, the required minimum distance corresponds to the diameter of the network.

Table 2. Easements range for sewer networks

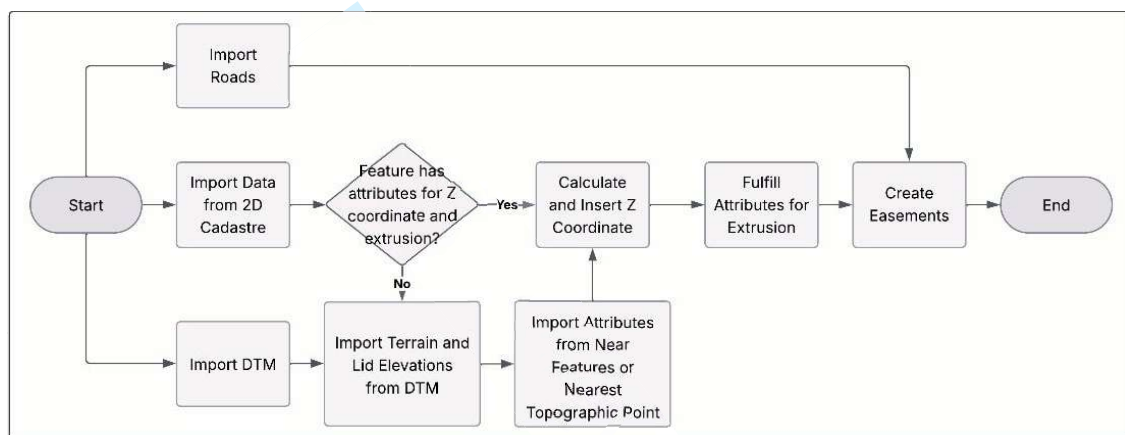
Depth (m)	Diameter (mm)	Offset ** (m)	Covering* (m)
Until 3.50	Until 100	0.70	Networks on public roads: 0.90
	Above 100 until 150	1.50	
	Above 150 until 350	2.50	
	Above 350 until 600	5.00	
	Above 600 until 1500	6.00	
Above 3.50 until 5.00	until 350	3.00	Networks on sidewalks or green areas: 0.60
	Above 350 until 1500	6.00	
Above 5.00	until 1500	7.50	

Source: CAESB

*From upper generatrix

**For both sides from the network axis

Figure 6 illustrates the workflow of the algorithms designed to automate the conversion of the 2D cadastre into a 3D model, enabling 3D visualization.

**Figure 6.** Algorithms Workflow

The feature classes of the 3D dataset were published as an internet service in feature access format. A 3D scene was constructed by incorporating 3D symbology. Pipes are represented as cylinders, while junctions are depicted as spheres with double the pipe diameter to ensure visibility. Hydrants assume their own graphical representation, selected from the ArcGIS Platform symbol library. Polygons representing devices take the shape of cylinders for sewer networks and cuboids for water networks. The cylinders have a 1-meter base diameter, while the cuboids occupy a 1-square-meter footprint, with extrusion applied between the lid and bottom elevations. Easements are visualized as rectangular blocks surrounding the networks, with width and extrusion of the polygons defined in accordance with CAESB standards.

This simplified symbology, with a low level of detail, is well suited for cadastral applications (Santos et al., 2013; Deng et al., 2016) and ensures optimal performance (Guerrero et al., 2013; Liu & Issa, 2012). The final 3D online map integrates CAESB's networks into the ESRI 3D Topographic basemap and was shared via a virtual reality web application featuring navigation tools and user location capabilities. The symbology used and the application are illustrated in Figure 7.

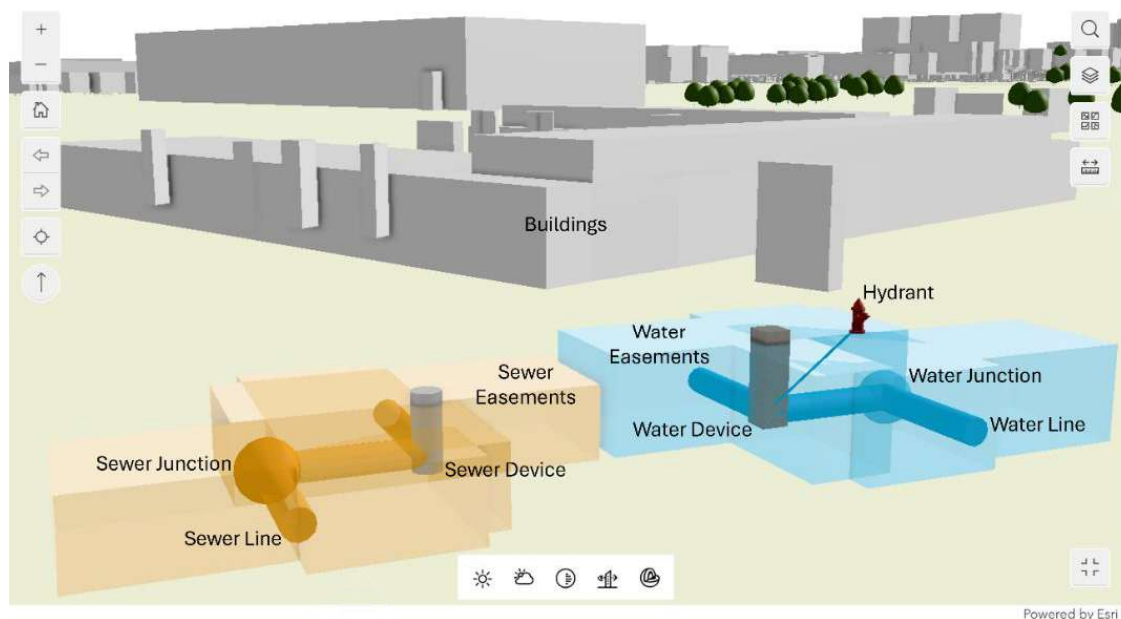


Figure 7. Symbology used in 3D online map

The adopted strategy categorizes data into two distinct groups: those whose vertical positioning is determined by spatial attributes imported from the cadastre and those whose vertical positioning is inferred. Differentiating between these categories is essential for identifying areas where new field measurements are required to progressively enhance data accuracy. This distinction is established through the Z_VALIDATED field, which indicates whether a feature's altimetry has been validated in the field. In the 3D online map, pipes, junctions, and devices with non-validated Z coordinates appear translucent.

RESULTS AND DISCUSSION

The developed methodology enabled the automation of 3D visualization of the water and sewer networks in the Federal District, marking significant advancements in spatial analyses and technical cadastre management. This approach allows for the inclusion of easements in analytical processes, improving the assessment of interference between sanitation networks, urban infrastructures, and trees. Incorporating the third dimension facilitates the integration of the technical cadastre with emerging technologies, supporting engineering efforts in system expansion and network maintenance.

Three-dimensional modelling introduces analytical possibilities previously unattainable in a 2D environment, such as 3D visualization of water and sewage network easements, which has the potential to enhance underground space security. In several locations within the Federal District, buildings have encroached upon easements, as exemplified in Figure 8, revealing inadequacies in space use concessions. In such cases, either network positioning adjustments or building removal may be necessary. With the

inclusion of easement analysis, these issues should be mitigated in future land use concessions.

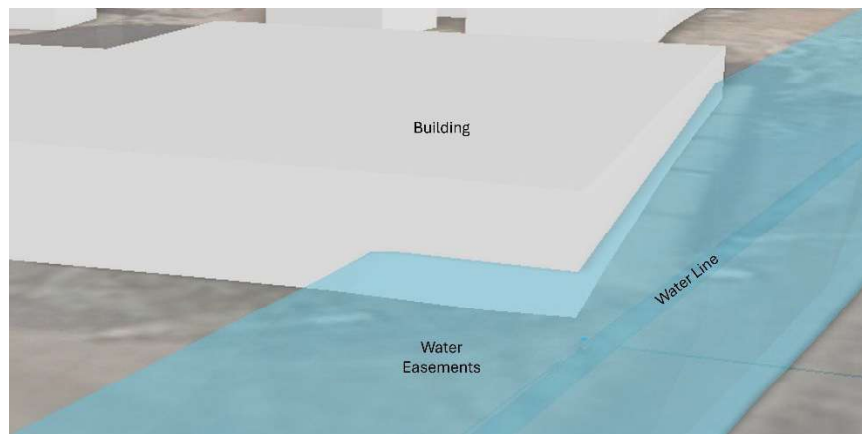


Figure 8. Building advancing on easements

In some locations, easements are exposed on the surface, as illustrated in Figure 9, indicating that the covering is insufficient. To ensure network protection, it is recommended that the covering material in these areas possess greater mechanical resistance or that adaptations be made to the network design. Possible solutions include deepening the network, where feasible, or utilizing pipes made of stronger materials.

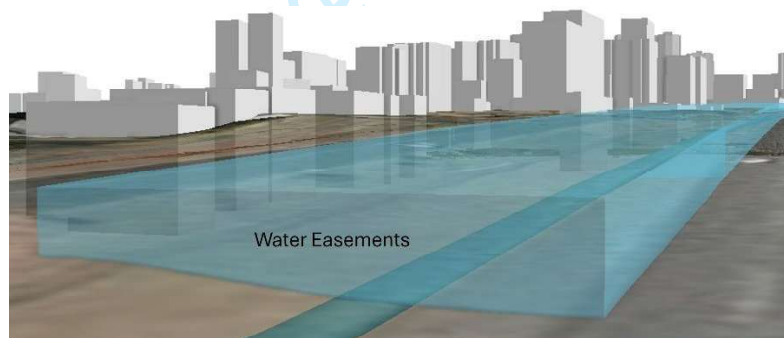


Figure 9. Easements exposed on surface

The water and sewer networks of the Federal District are the first underground infrastructures to achieve comprehensive 3D visualization at the cadastral level. However, accurately representing spatial relationships with other infrastructures remains challenging. Figure 10 illustrates a water network crossing over the metropolitan train channel, an interaction that was impossible to discern in the 2D cadastre, where it was unclear whether one infrastructure passed above or below another. Although 3D modelling provides greater clarity, certain elements, such as the bridge co-located with the water network over the same channel, are still not adequately represented. This advancement promotes more integrated and efficient underground space management, facilitating analyses of infrastructure overlap, minimizing operational risks, and optimizing subsoil utilization.

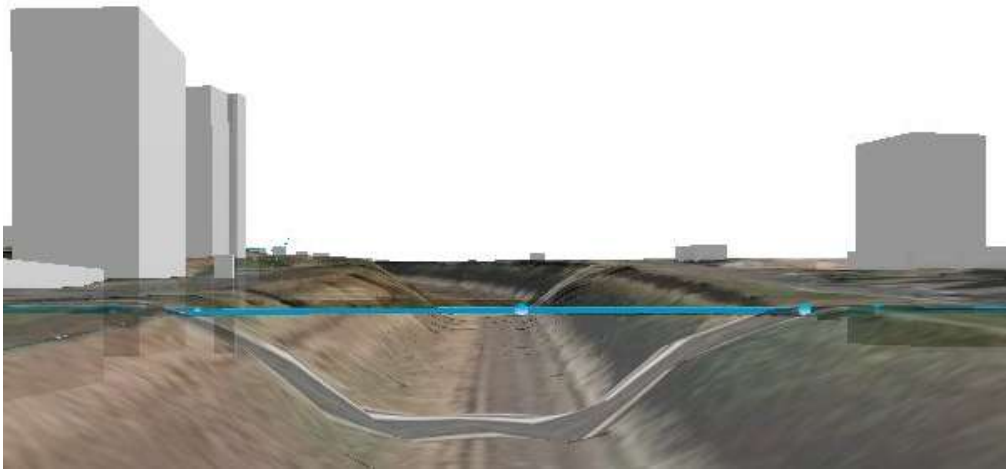


Figure 10. Water network crossing over the metropolitan train channel (blue color)

Another newly enabled analysis involves assessing the presence of trees in unsuitable locations that may compromise the integrity of underground networks. 3D spatial analysis facilitates the identification of critical areas where vegetation could pose risks to pipes, junctions, and devices, allowing for preventive measures to protect the infrastructure. This is exemplified in the ArcGIS Pro surface slice analysis shown in Figure 11. Additionally, the 3D model serves as a decision-support tool for determining optimal tree-planting locations, ensuring vegetation is integrated into the urban landscape without endangering the safety and functionality of sanitation networks. This approach balances the need for green spaces with the preservation of underground infrastructure.

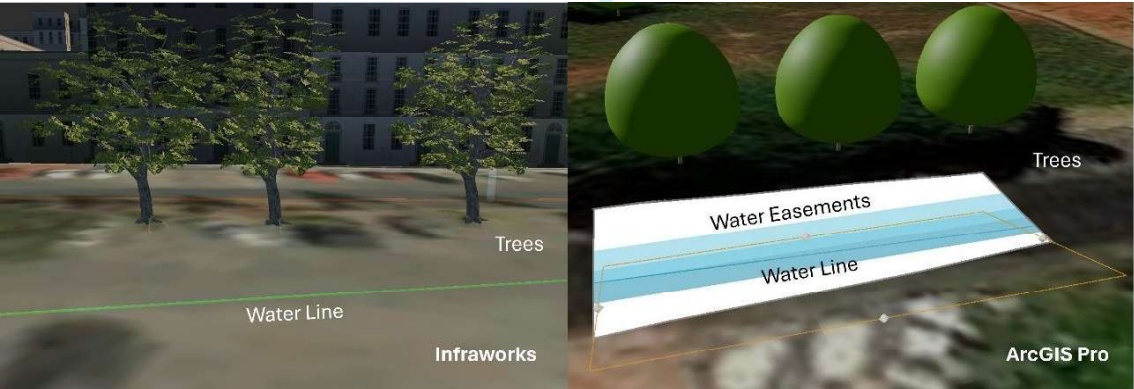


Figure 11. Analysis of trees and networks position

The figure also demonstrates that the same dataset can be accessed through multiple tools, including Building Information Modelling (BIM) software, in this case, the InfraWorks. The data was published in a format that supports the integration of the technical cadastre in GIS with other modern technologies, such as BIM, Virtual Reality (VR), and Augmented Reality (AR). Figure 12 illustrates the use of this data in a VR application developed to enhance network cadastre visualization for field workers.

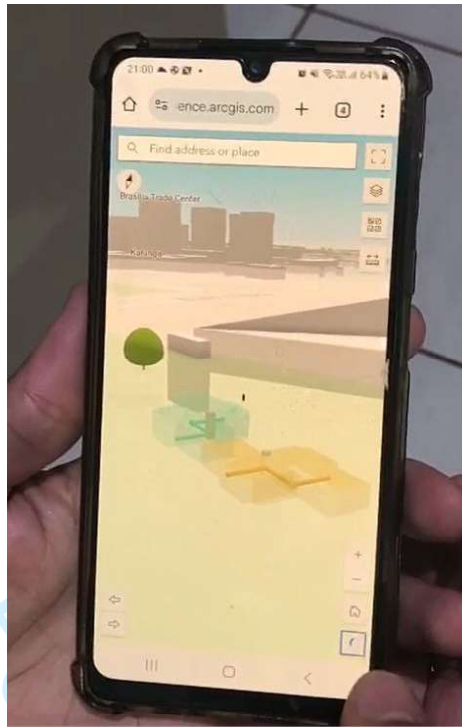


Figure 12. Use of VR application developed for field workers

The 3D model enables more precise quantification of network length, a key indicator of the scope and quality of services provided by sanitation companies. In a 2D model, capturing vertical variations within the network is challenging, whereas these variations become clear in the 3D visualization. Figure 13 depicts a segment of the water supply network designed to serve a hydrant, whose elevation is not accounted for in the 2D model. Specific code instructions were incorporated into the script responsible for generating the 3D model to ensure an accurate representation of the hydrant's branch connections.

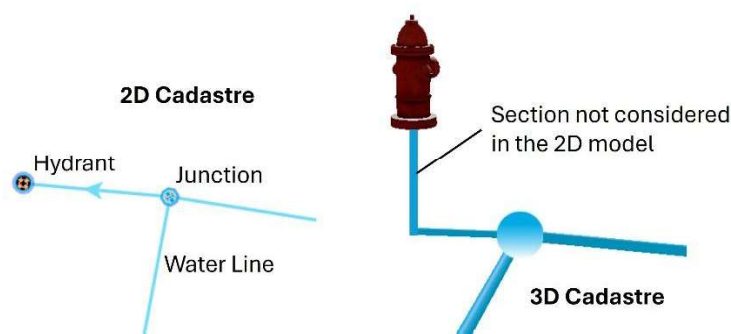


Figure 13. Vertical section not considered in 2D model

Despite the progress achieved, certain limitations were identified. The accuracy of the 3D visualization in the urban areas of the Federal District is higher than in rural regions and neighbouring cities, due to the greater availability of detailed spatial data. Since the DTM was used to compensate for the lack of altimetric information, the quality of the 3D representation varied according to the resolution of the available data. This

discrepancy underscores the need for continuous improvement of the technical cadastre, incorporating more precise measurements to enhance the reliability of 3D modelling.

In instances where the technical cadastre contains erroneous or incomplete information, the proposed methodology has proven effective in detecting inconsistencies and data gaps. This enables the identification of specific locations where record accuracy may be enhanced, as exemplified in Figure 14, which depicts the water supply network erroneously positioned above existing buildings. The local network cadastre was derived from printed plans that lacked altimetric information. Consequently, in the 3D modelling process, the entire region's network was assigned elevation values from a single topographic reference point. Due to variations in terrain, this approach caused the network to be improperly displayed. Such occurrences underscore the importance of future field data collection efforts aimed at refining and correcting the existing cadastre.

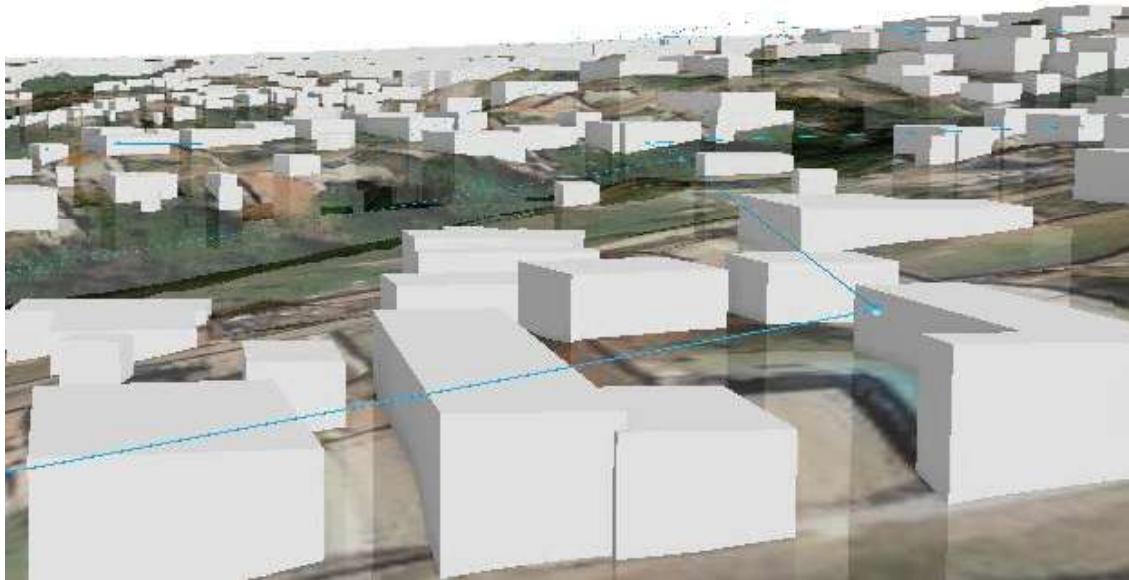


Figure 14. Local for cadastre correction

Thus, beyond supporting advanced spatial analyses, the 3D model contributes to the ongoing refinement of the cadastre, making it progressively completer and more accurate over time. It serves as an additional tool for assessing data quality, ensuring timely corrections only where necessary, thereby minimizing resource waste. This is particularly crucial in developing countries, where field data collection is often constrained by limited resources.

3D web maps, also referred to as online scenes, are three-dimensional virtual environments commonly used in design, architecture, engineering, simulations, and gaming. These representations may cover specific facilities, buildings, urban sectors, entire cities, or broader regions, with scale and level of detail tailored to the intended application.

The automation of the 3D modelling process significantly reduced the time and effort required to generate spatial representations. Compared to manual modelling, which is labour-intensive and prone to inconsistencies, the automated workflow ensured uniform application of rules and rapid processing of thousands of features. This enabled the timely generation of 3D scenes, even in areas with complex network layouts.

Moreover, the automated approach facilitated the identification of data gaps and inconsistencies, such as missing elevation values or misaligned features, which would be difficult to detect in a manual workflow. These findings underscore the importance of automation not only for visualization but also for data quality assurance.

CONCLUSIONS

The 3D visualization achieved through the proposed methodology represents a significant advancement for sanitation service providers accustomed to conventional 2D representations. However, there is substantial potential for further expanding this approach. The automatic generation of 3D visualization has proven essential for the project's sustainability, ensuring that models are updated efficiently and without the need for manual intervention. Additionally, this research has demonstrated that the exchange of spatial data among institutions is crucial for enabling comprehensive 3D modelling, reinforcing the importance of inter-institutional collaboration in managing underground infrastructure.

The methodology was implemented using commercially available software; however, it can be replicated using free alternatives. The 3D model demonstrated strong performance without incurring additional costs, as no new software or hardware was required. During the development process, the existing tools used by CAESB for technical cadastre management were leveraged to ensure compatibility and efficiency. Furthermore, minimal adjustments to work processes were necessary, as the core data required for 3D visualization, such as dimensions, generatrix, and pipe diameters, had already been collected and recorded in the database, though previously overlooked. These attributes are now fully utilized, contributing to a functional 3D model that benefits multiple workers.

The objectives were successfully achieved using existing tools and infrastructure, avoiding the need for additional software or hardware acquisitions and thereby minimizing costs. Nonetheless, the data produced is structured to support future technological enhancements. With further investments, advanced applications such as virtual and augmented reality could be integrated, significantly improving the

418 visualization and analysis of spatial networks. Furthermore, the synergy between 3D
419 visualization in GIS and BIM can be explored, enabling scalable implementations tailored
420 to specific needs. These developments will facilitate more efficient and interactive
421 underground infrastructure management.

422 Automating 3D visualization has proven to be a fundamental strategy in
423 simplifying the creation of three-dimensional models. Manual construction, such as
424 drawing or vectorizing 3D shapes, is notoriously complex and may discourage even
425 experienced designers. Conversely, leveraging spatial data attributes has been
426 demonstrated as a practical and efficient approach to generating 3D objects automatically.
427 This methodology not only streamlines the process but also ensures greater consistency
428 and speed in visualization.

429 Despite the advancements achieved, it is important to acknowledge that no 3D
430 model will be entirely accurate, particularly when converting pre-existing data. The
431 accuracy of models directly depends on the quality of available datasets, and older
432 systems may exhibit limitations regarding information precision. Additionally,
433 underground network coverage and spacing standards are intricate, complicating their
434 application and monitoring. To enhance implementation feasibility, it is advisable to
435 adopt generalized conditions that accommodate most cases while preserving network
436 safety and functionality. In this study, a temporary solution was used to address the
437 absence of terrain and lid elevations; moving forward, newly incorporated data should
438 contain elevations measured in the field.

439 Beyond water and sewer networks, ongoing research advancements will pave
440 the way for improved management of other buried assets, allowing for analyses of
441 interferences and topological relationships among various networks in three dimensions.
442 Experience has shown that 3D modelling of water and sewer networks would be
443 impractical without access to spatial data provided by multiple entities. This underscores
444 the need to strengthen stakeholder roles and foster more effective collaboration,
445 promoting structured and cooperative data exchange through spatial data infrastructures.
446 Such an approach supports integrated and innovative underground infrastructure
447 management, which is essential for urban planning and sustainability. As 3D models
448 become more widespread and visualization methods diversify, concerns regarding data
449 models and sharing standards will likely increase to ensure compatibility among different
450 3D representations, regardless of their origins. For example, an energy company might
451 develop a 3D online map depicting its underground electricity networks and seek to
452 integrate sanitation company data representing buried networks within the same

environment. In this study, local copies of external institutional data were utilized; as a future enhancement, direct consumption from online services could be implemented, ensuring real-time updates.

Another identified challenge is the lack of integration among institutions responsible for underground infrastructure management. While water and sewer network easements are considered in project planning, a holistic perspective regarding their interactions with other underground systems is often lacking. Most existing standards and regulations remain centred on two-dimensional modelling, further reinforcing the need to modernize technical frameworks to incorporate 3D modelling.

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Critérios SciELO Brasil

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versão 29 de junho de 2020

Por meio deste formulário os autores informam o periódico sobre a conformidade do manuscrito com as práticas de comunicação da Ciência Aberta. Os autores são solicitados a informar: (a) se o manuscrito é um preprint e, em caso positivo, sua localização; (b) se dados, códigos de programas e outros materiais subjacentes ao texto do manuscrito estão devidamente citados e referenciados; e, (c) se aceitam opções de abertura no processo de avaliação por pares.

Preprints

Depósito do manuscrito em um servidor de preprints reconhecido pelo periódico.

O manuscrito é um preprint?	
☐	Sim - Nome do servidor de Preprints: DOI do Preprint:
☒	Não

Disponibilidade de Dados de Pesquisa e outros Materiais

Autores são encorajados a disponibilizar todos os conteúdos (dados, códigos de programa e outros materiais) subjacentes ao texto do manuscrito anteriormente ou no momento da publicação. Exceções são permitidas em casos de questões legais e éticas. O objetivo é facilitar a avaliação do manuscrito e, se aprovado, contribuir para a preservação e reuso dos conteúdos e a reprodutibilidade das pesquisas.

Os conteúdos subjacentes ao texto do manuscrito já estão disponíveis em sua totalidade e sem restrições ou assim estarão no momento da publicação?	
☐	Sim: ☐ os conteúdos subjacentes ao texto da pesquisa estão contidos no manuscrito ☐ os conteúdos já estão disponíveis ☐ os conteúdos estarão disponíveis no momento da publicação do artigo Segue títulos e respectivas URLs, números de acesso ou DOIs dos arquivos dos conteúdos subjacentes ao texto do artigo (use uma linha para cada dado):
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Os autores poderão optar por um ou mais meios de abertura do processo de *peer review* oferecidos pelo periódico.

Quando oferecida a opção, os autores concordam com a publicação dos pareceres da avaliação de aprovação do manuscrito?	
☒	Sim
☐	Não
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☐	Não

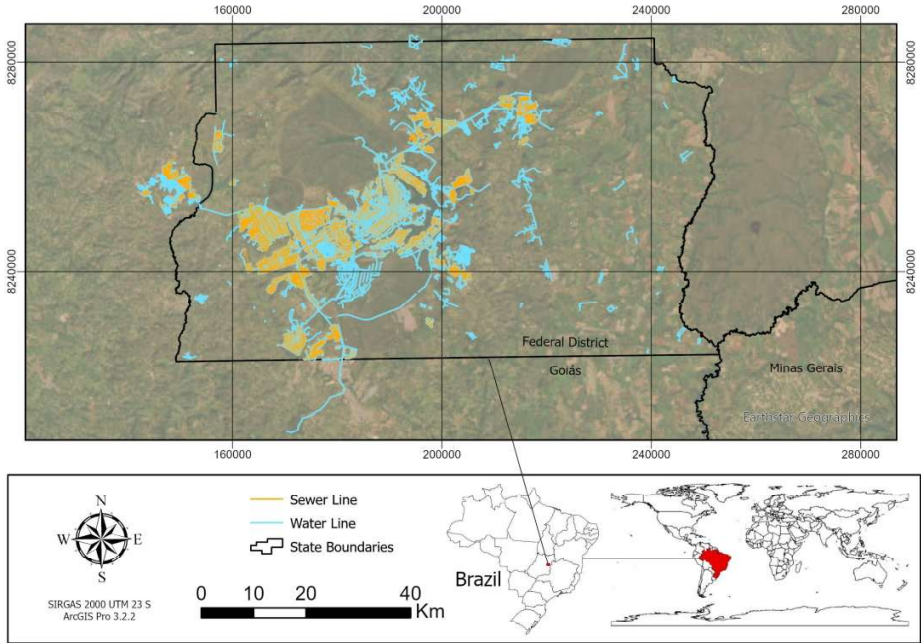


Figure 1. Coverage of the used spatial data.

209x147mm (300 x 300 DPI)

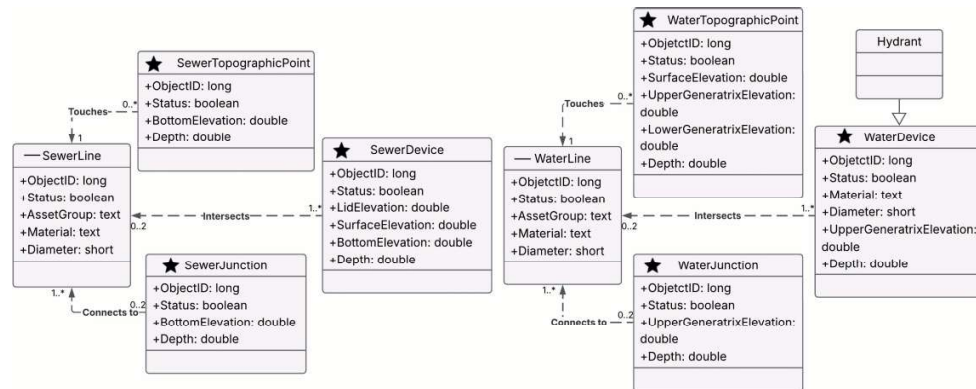


Figure 2. Technical cadastre classes used in the research.

289x114mm (300 x 300 DPI)

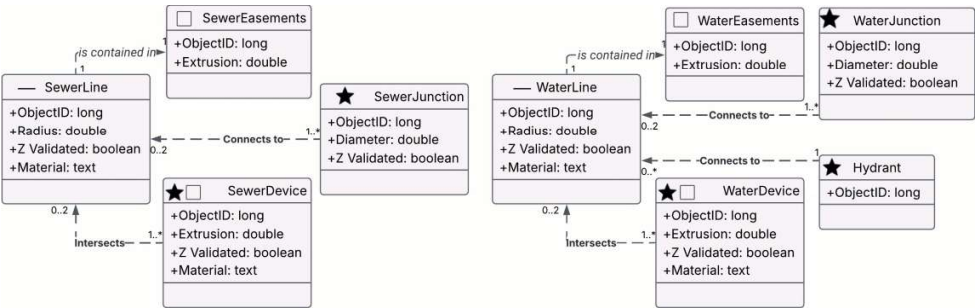


Figure 3. Classes used in the 3D visualization.

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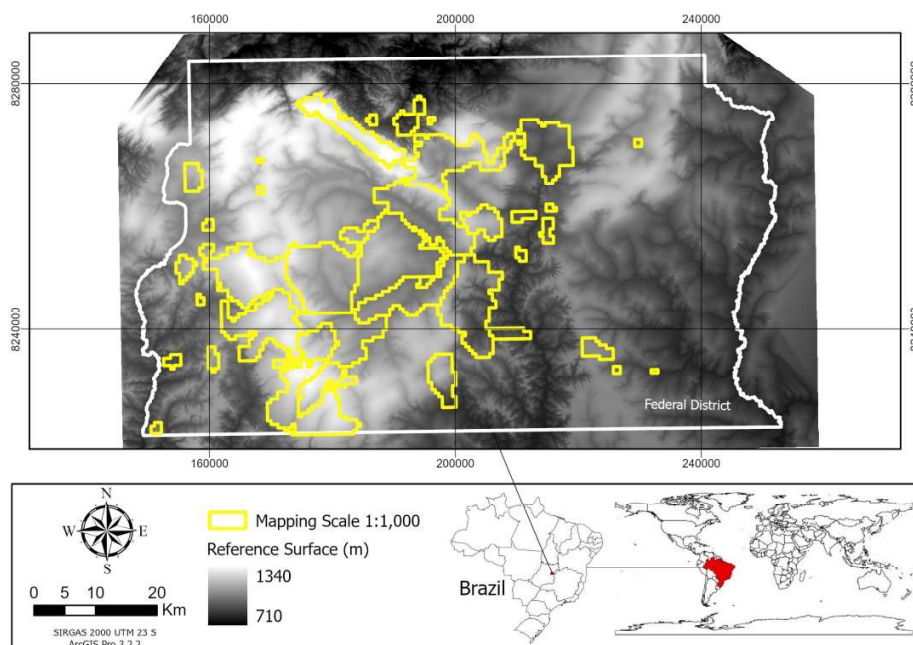


Figure 4. DTM reference surface.

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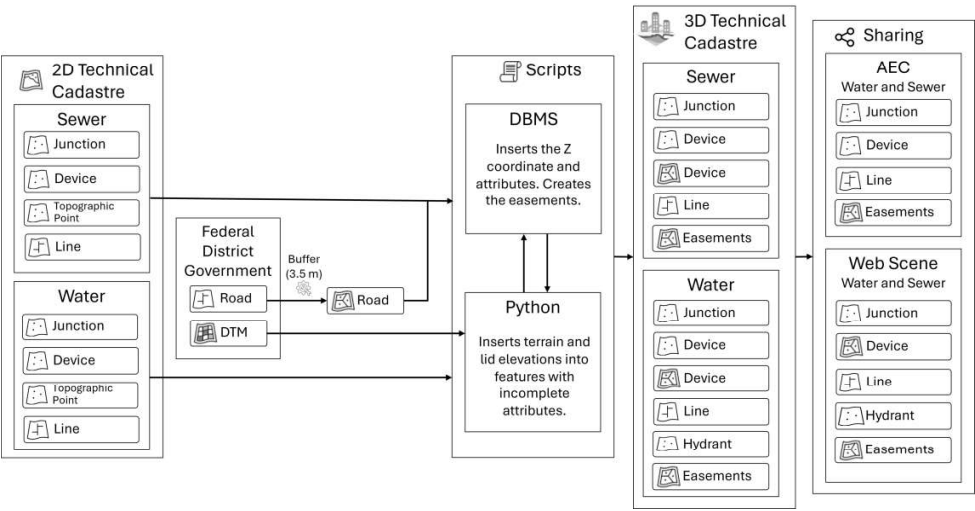


Figure 5. Data import and processing workflow.

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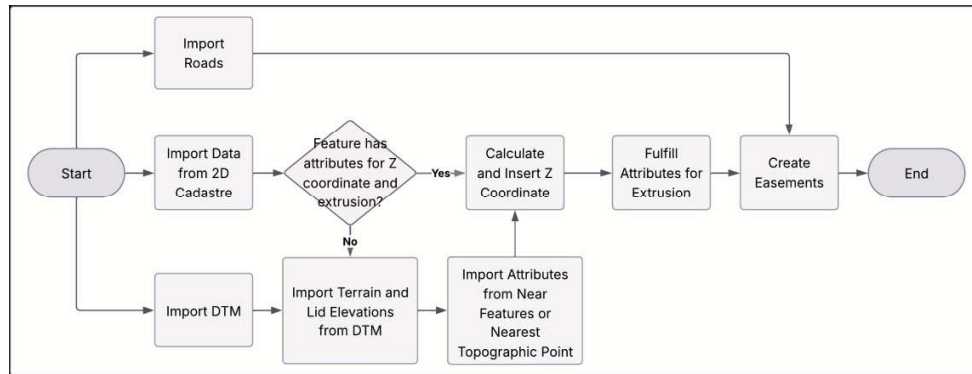


Figure 6. Algorithms Workflow.

2022x770mm (38 x 38 DPI)

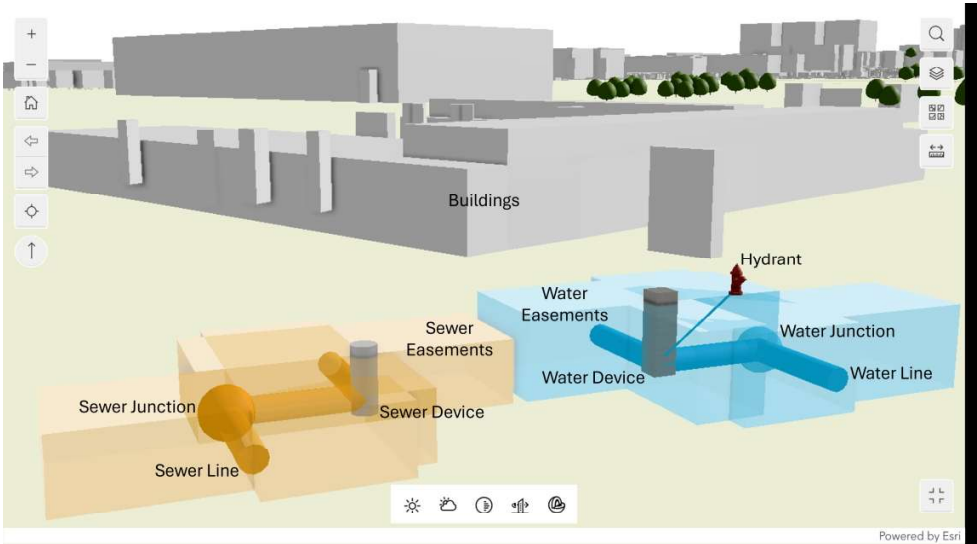


Figure 7. Symbology used in 3D online map.

870x483mm (130 x 130 DPI)

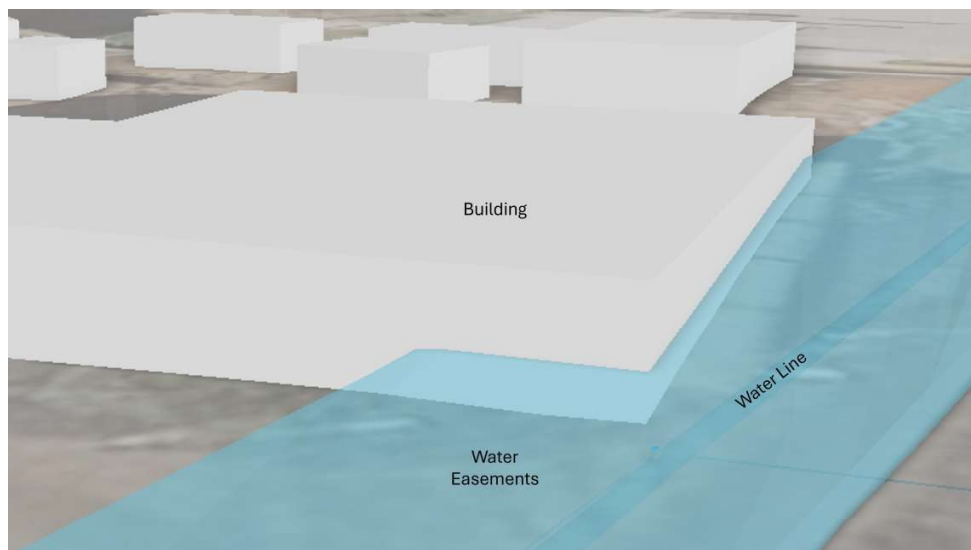


Figure 8. Building advancing on easements.

338x190mm (300 x 300 DPI)

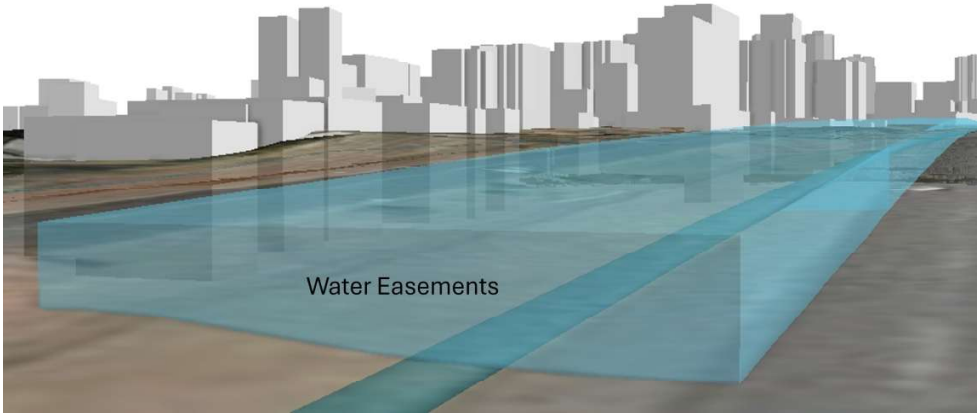


Figure 9. Easements exposed on surface.

243x103mm (300 x 300 DPI)



Figure 10. Water network crossing over the metropolitan train channel (blue color).

401x187mm (38 x 38 DPI)

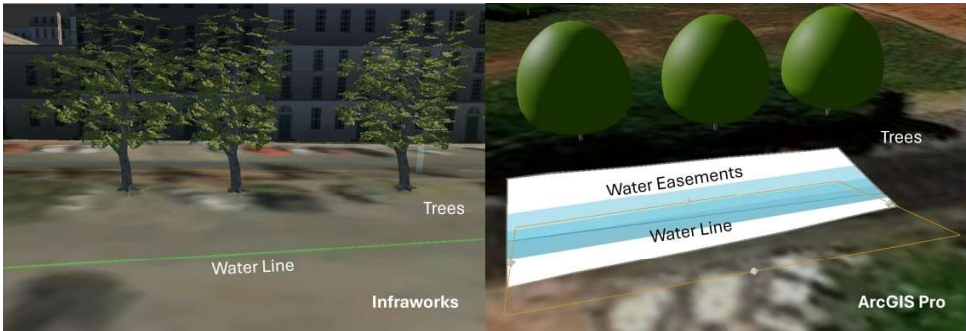


Figure 11. Analysis of trees and networks position.

342x115mm (300 x 300 DPI)

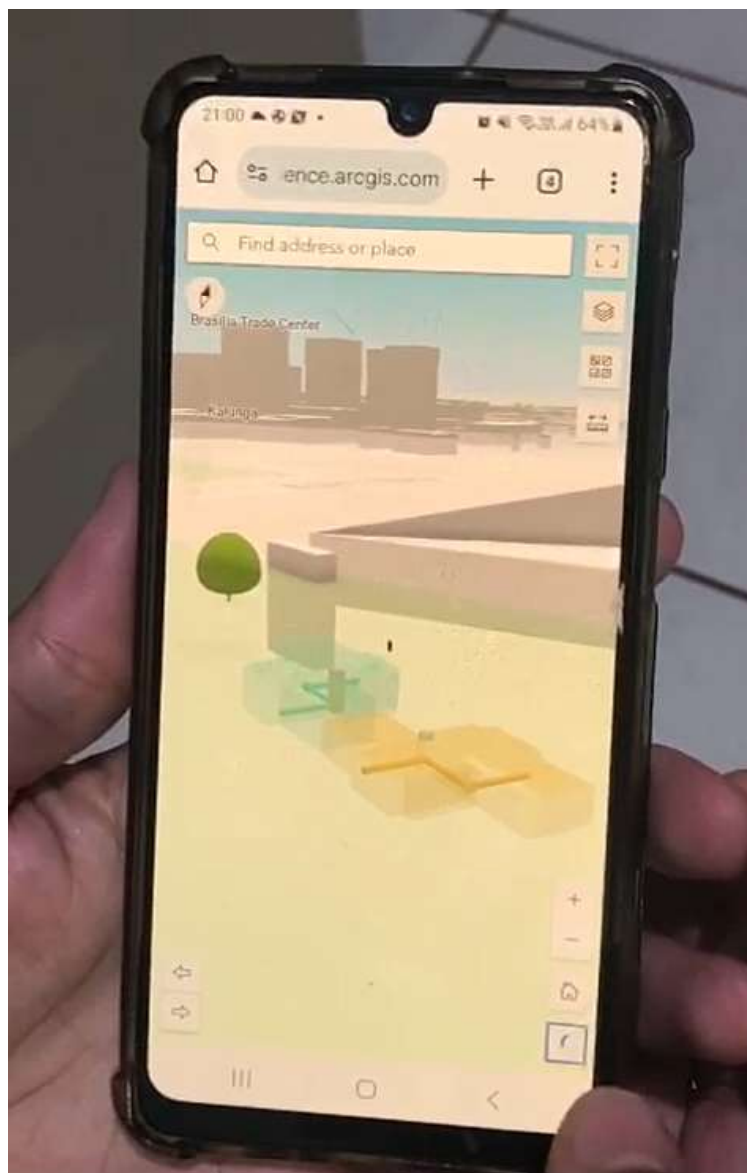


Figure 12. Use of VR application developed for field workers.

317x493mm (38 x 38 DPI)

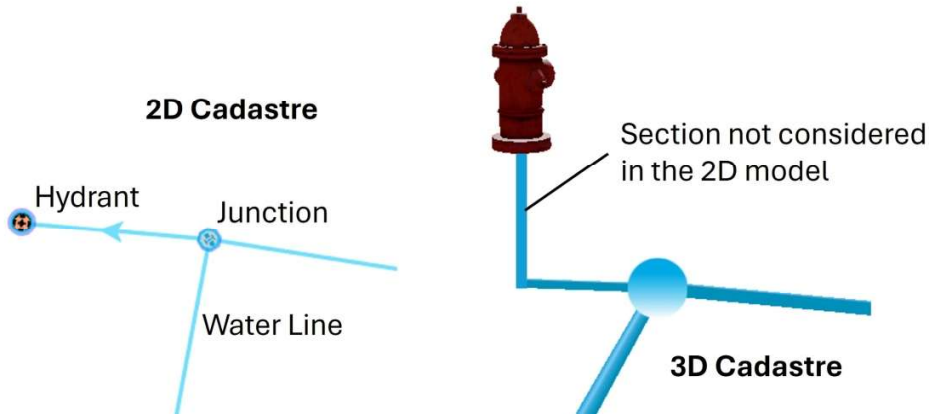


Figure 13. Vertical section not considered in 2D model.

200x90mm (300 x 300 DPI)

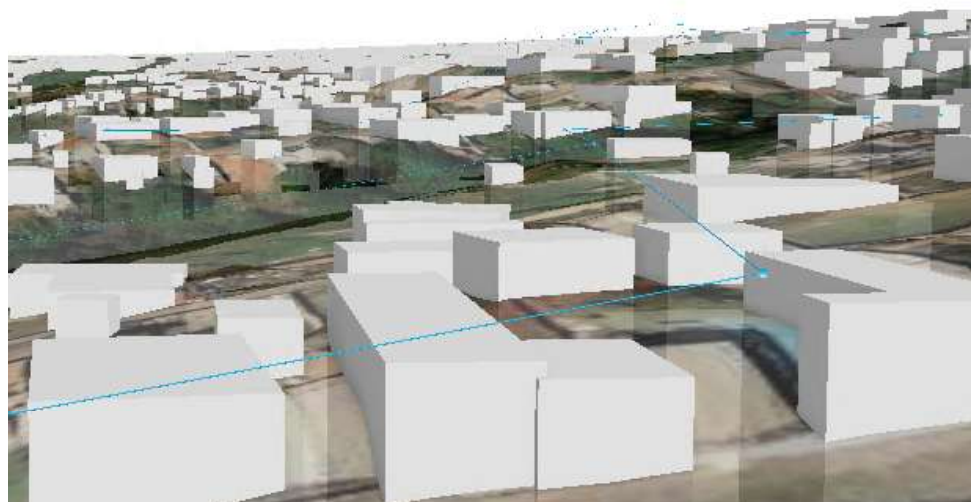


Figure 14. Local for cadastre correction.

414x225mm (38 x 38 DPI)

Table 1. Easements for water networks

Diameter (mm)	Material	Covering* (m)	Offset ** (m)
Until 150	PEAD/PVC, PB JE	0.80	1.50
	FF, FOFO	0.60	
Above 150 until 200	PEAD/PVC, PB JE	0.80	2.00
	FF, FOFO	0.60	
Above 200 until 250	PEAD/PVC, PB JE	0.80	
	FF, FOFO	0.85	
Above 250 until 300	All	1.10	
Above 300 until 350		1.25	5.00
Above 350 until 400		1.50	
Above 400 until 1500		2.00	6.00

Source: CAESB *From upper generatrix **For both sides from the network axis

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Table 2. Easements range for sewer networks

Depth (m)	Diameter (mm)	Offset ** (m)	Covering* (m)
Until 3.50	Until 100	0.70	Networks on public roads: 0.90
	Above 100 until 150	1.50	
	Above 150 until 350	2.50	
	Above 350 until 600	5.00	Networks on sidewalks or green areas: 0.60
	Above 600 until 1500	6.00	
Above 3.50 until 5.00	until 350	3.00	
	Above 350 until 1500	6.00	
Above 5.00	until 1500	7.50	

Source: CAESB

*From upper generatrix

**For both sides from the network axis

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CONCLUSÕES DA TESE

É inegável que a modelagem tridimensional oferece inúmeras vantagens em relação à modelagem bidimensional, permitindo uma representação mais precisa e detalhada das redes de infraestrutura. No entanto, aproveitar os dados 2D existentes para construir modelos 3D confiáveis não é uma tarefa trivial, especialmente quando os dados altimétricos e outros dados necessários são limitados ou inconsistentes.

As fornecedoras de software SIG apresentam exemplos de modelagem tridimensional de áreas restritas, que possuem dados completos, sugerindo que existe uma metodologia pronta para ser aplicada diretamente em novos contextos. Inicialmente, acreditava-se que esta pesquisa se concentraria exclusivamente na aplicação de métodos consolidados em um contexto específico, a modelagem 3D das redes de água e esgoto do Distrito Federal. No entanto, ao longo do estudo, ficou evidente que a abordagem idealizada não seria possível, pois o cadastro técnico existente possui limitações nos dados que tornam inviável a construção de modelos 3D com a aplicação direta dos métodos conhecidos.

A pesquisa foi posta diante do desafio de desenvolver uma metodologia que permitisse a modelagem tridimensional de redes de água e esgoto mesmo com dados insuficientes. A alternativa de abandonar os cadastros existentes e realizar um levantamento de campo completo que atendesse às exigências dos métodos de modelagem 3D conhecidos se mostrou economicamente inviável, devido aos custos elevados e à complexidade da coleta de informações em todo o sistema de saneamento, o que exigiria a escavação das redes ou, no mínimo, percorrer a todas com equipamentos de sondagem do subsolo. A inviabilidade de um levantamento de campo de larga escala reforçou a necessidade de um novo método capaz de extrair o máximo potencial das informações disponíveis.

Os resultados mostraram que a modelagem tridimensional não poderia se basear apenas em uma conversão direta dos dados 2D, mas é possível ajustar os atributos disponíveis para compor uma estrutura geométrica coerente com a infraestrutura real. Profundidade, cota do terreno, diâmetro das tubulações e cota das geratrizes foram combinados de forma estratégica para corrigir lacunas e estruturar digitalmente a infraestrutura subterrânea, de modo que, mesmo com uma disponibilidade limitada de dados, é possível construir modelos tridimensionais com alto grau de precisão no posicionamento horizontal e vertical.

É importante destacar que a maioria das inconsistências identificadas nos dados originais ainda não foi corrigida. Os erros permanecem e serão sanados gradualmente, à medida que novos levantamentos forem realizados e os processos de atualização forem incorporados à rotina institucional. A pesquisa não apenas revelou essas limitações, como também propôs caminhos para superá-las, com soluções automatizadas e metodologias adaptadas à realidade dos dados disponíveis.

Além disso, a proposta da tese representa uma mudança conceitual na forma de aquisição e modelagem dos dados. O cadastro técnico, originalmente concebido para uma representação bidimensional, passa a ser entendido como base para uma estrutura tridimensional dinâmica, capaz de integrar atributos geométricos, temporais e funcionais. Essa transformação exige novas práticas de coleta, organização e análise, e inaugura uma nova etapa na gestão de redes de infraestrutura enterradas.

O avanço alcançado nesta pesquisa só foi possível graças à existência de uma infraestrutura consolidada de dados espaciais e a um ecossistema tecnológico robusto, com softwares, servidores e equipes técnicas capazes de suportar a automatização e a visualização tridimensional. Isso demonstra que, com investimentos adequados em parque tecnológico, outras cidades e instituições podem alcançar resultados semelhantes, promovendo a modernização dos cadastros técnicos e a gestão eficiente da infraestrutura urbana.

Por conta da metodologia desenvolvida, Brasília se tornou a primeira cidade na América Latina a ter um modelo 3D de todo o cadastro técnico das redes de água e esgoto. Com a contribuição para o avanço das práticas de modelagem espacial e automatização na estruturação de dados geoespaciais, esta pesquisa resultou na primeira tese do Departamento de Geografia da Universidade de Brasília associada ao registro de um produto tecnológico.

Composta por três artigos submetidos para publicação em periódicos indexados na plataforma *Web of Science* da Clarivate, classificados com conceito A no sistema Qualis da CAPES, esta tese está de acordo com a regulamentação do Departamento de Geografia da Universidade de Brasília.

Preview (ESA-2025-0082)

From: rmoruzzi@rc.unesp.br

To: robertoborges@caesb.df.gov.br, ambiental.roberto@gmail.com

CC:

Subject: Engenharia Sanitária e Ambiental - Decision on Manuscript ID ESA-2025-0041

Body: 29-May-2025

Dear Mr. BORGES:

I am pleased to inform that your manuscript entitled "MODELLING WATER AND SEWAGE NETWORKS IN THREE DIMENSIONS: A REVIEW AND THE BRAZILIAN CASE" was accepted for publication in Engenharia Sanitária e Ambiental in its current form.

Thank you very much for expressing your interest in Engenharia Sanitária e Ambiental, and we look forward to your continued contributions to the Journal.

Sincerely,
Dr. Rodrigo Moruzzi
Associate Editor, Engenharia Sanitária e Ambiental
rmoruzzi@rc.unesp.br, rmoruzzi@rc.unesp.br

Entire Scoresheet:
Reviewer: 1

Recommendation: Accept

Comments:

The infrastructure network in Brazil presents significant challenges from a regulatory, organizational, and modeling perspective, whether in 3D format or in databases. These challenges are largely due to the continental scale of the country, as well as the lack of established cartographic standards. The article makes a valuable contribution by shedding light on this topic, both in the context of the 2030 Agenda and other relevant considerations. The summary table of best practices is clear and well structured. It would be interesting to include similar comparative analyses throughout the text, addressing each stage of the process (such as comparisons between methods, software, etc.), which would further enrich the discussion.

Additional Questions:

Does the manuscript contain new and significant information to justify publication?: Yes

Does the Abstract (Summary) clearly and accurately describe the content of the article?: Yes

Is the problem significant and concisely stated?: Yes

Are the methods described comprehensively?: Not applicable

Are the interpretations and conclusions justified by the results?: Not applicable

Is adequate reference made to other work in the field?: Yes

Length of article is: Adequate

Number of tables is: Too few

Number of figures is: Too few

Please state any conflict(s) of interest that you have in relation to the review of this paper (state "none" if this is not applicable).: None.

Rating:

Interest: 1. Excellent

Quality: 2. Good

Originality: 1. Excellent

Overall: 2. Good

Preview (ESA-2025-0082)

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CC: robertoborges@caesb.df.gov.br, ambiental.roberto@gmail.com, renatofg@unb.br, josef.strobl@plus.ac.at, osmarjr@unb.br, robertogomes@unb.br

Subject: Engenharia Sanitária e Ambiental - Manuscript ID ESA-2025-0082

Body: 02-Jun-2025

Dear Mr. BORGES:

Your manuscript entitled "THREE-DIMENSIONAL MODELLING OF WATER AND SEWER NETWORKS: CASE STUDY IN THE CENTRE OF TAGUATINGA, FEDERAL DISTRICT – BRAZIL" has been successfully submitted online and is presently being given full consideration for publication in the Engenharia Sanitária e Ambiental.

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Enviado em: quarta-feira, 16 de julho de 2025 09:36
Para: Roberto Souza Borges
Cc: Roberto Souza Borges; renatofg@unb.br; Hudson Ferreira Teles; Alexandre Machado Có
Assunto: RBRH, Brazilian Journal of Water Resources - Decision on Manuscript ID RBRH-2025-0109

16-Jul-2025

Dear Mr. BORGES:

Manuscript ID RBRH-2025-0109 entitled "Automated 3D visualization of water and sewer networks in GIS: a methodological approach applied to the technical cadastre of the Federal District, Brazil" which you submitted to the RBRH, Brazilian Journal of Water Resources, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter.

The reviewer(s) have recommended publication, but also suggest some revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript.

To revise your manuscript, log into <https://mc04.manuscriptcentral.com/rbrh-scielo> and enter your Author Center, where you will find your manuscript title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision.

You may also click the below link to start the revision process (or continue the process if you have already started your revision) for your manuscript. If you use the below link you will not be required to login to ScholarOne Manuscripts.

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You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript using a word processing program and save it on your computer. Please also highlight the changes to your manuscript within the document by using the track changes mode in MS Word or by using bold or colored text.

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When submitting your revised manuscript, you will be able to respond to the comments made by the reviewer(s) in the space provided. You can use this space to document any changes you make to the original manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the reviewer(s).

IMPORTANT: Your original files are available to you when you upload your revised manuscript. Please delete any redundant files before completing the submission.

Because we are trying to facilitate timely publication of manuscripts submitted to the RBRH, Brazilian Journal of Water Resources, your revised manuscript should be submitted by 11-Aug-2025. If it is not possible for you to submit your revision by this date, we may have to consider your paper as a new submission.

Once again, thank you for submitting your manuscript to the RBRH, Brazilian Journal of Water Resources and I look forward to receiving your revision.

Sincerely,
Dr. Adilson Pinheiro
Editor-in-Chief, RBRH, Brazilian Journal of Water Resources
pinheiro@furb.br

Associate Editor
Comments to the Author:
Dear Authors:

Although the reviewer has recommended a minor revision, I believe that the manuscript requires a more substantial revision before it can be reconsidered for publication. In particular, the scientific contribution of the study to the field of water resources is not clearly demonstrated. The introduction lacks a thorough analysis of the state of the art, and it remains unclear how the study advances current knowledge. There are also fundamental issues that need to be properly addressed to meet the standards of RBRH, as pointed out by the reviewer. Therefore, based on my own evaluation and the reviewer's comments, I recommend major revision.

Kind regards,
Iran E. Lima Neto
Associate Editor, RBRH

Entire Scoresheet:
Reviewer: 1

Recommendation: Minor Revision

Comments:

The article is well written and relevant to the RBRH. Below are some observations:

Line 29: When summarising DBMSs, it is important to state directly which database is used and the type (SQL, No-Sql, distributed, etc). The DBMS is a class of programmes that manage information, but the type of DB can vary.

Line 61: DBMS are systems that manage databases. The point here is to define the type of database to be adopted by the authors in the proposal in order to provide readers with greater clarity of approach in the research.

Line 65: In line with the previous comment, DBMS is not responsible for storing, but for managing different versions in banks that support this purpose. Rewrite paragraph.

Line 120: One of the most relevant issues for 3D data is the file formats used. The CityGML standard is used for GIS data, but BIM uses the IFC model. Which model is used here?

Figure 1 and 4: The figure lacks important data source with indication according to LGPD for images and shps files

Line 281: This argument only makes sense when it comes to a bank connected to others that hold information at the same cadastral level.

Line 343: I believe that the most relevant contribution to the authors' context would be the assessment of interruptions and conflicts between networks. In addition, 3D has a cognitive advantage for the user in terms of understanding the arrangement of elements in space. On the other hand, this visualisation cannot be of a very large area without encumbrances. Even so, there is a gain in communicating information. However, there is a need for future work that better elaborates the representation of network elements beyond spheres and tubes without essentially textual descriptions of attributes. This is one of the reasons why AR and VR are still limited to position.

Line 374: This revision paragraph should be moved to the appropriate section or deleted.

Line 416: Even though commercial software was used, it is important to describe in detail how the data was made available. There are a series of steps such as layouts, conversion of formats for visualisation, servers and types of services before the data reaches the browser screen for consultation. So my suggestion is to review this session, which is more appropriate for revision, and detail these steps.

Line 484: remove paragraph

Additional Questions:

Does the manuscript contain new and significant information to justify publication?: Yes

Does the Abstract (Summary) clearly and accurately describe the content of the article?: Yes

Is the problem significant and concisely stated?: Yes

Are the methods described comprehensively?: No

Are the interpretations and conclusions justified by the results?: Yes

Is adequate reference made to other work in the field?: Yes

Length of article is: Adequate

Number of tables is: Adequate

Number of figures is: Adequate

Please state any conflict(s) of interest that you have in relation to the review of this paper (state "none" if this is not applicable).: none

Rating:

Interest: 2. Good

Quality: 2. Good

Originality: 3. Average

Overall: 2. Good

Ficha de Notificação de criação ou invenção

Este Formulário destina-se à Comunidade Acadêmica da UnB para agendamento de atendimento junto ao Núcleo de Inovação Tecnológica (NIT) quanto à nova propriedade intelectual desenvolvida no âmbito da UnB. Ao responder o presente Formulário, será realizado um agendamento para atendimento junto ao Núcleo de Propriedade Intelectual (Nupitec) da Coordenação de Inovação e Transferência de Tecnologia (CITT) do NITCDT/UnB.

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ROBERTO SOUZA BORGES

2. Matrícula * 

200072005

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- ☐ Servidor(a)
- ☐ Outra

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Exemplos: Instituto de Química (IQ), Instituto de Ciências Biológicas (ICB), Faculdade de Tecnologia (FT).

ICH

5. Informe o seu Departamento ou Laboratório, se houver.

Exemplos: Laboratório de Materiais e Combustíveis (LMC), Departamento de Biologia Celular (CEL), Departamento de Engenharia Elétrica (ENE).

Departamento de Geografia

6. Informe um e-mail para contato *

Importante informar o e-mail correto, pois é o meio pelo qual o Nupitec entrará em contato para realização do atendimento.

borges.roberto@aluno.unb.br

7. Informe um telefone para contato, com o DDD (somente números). *

O Nupitec só utilizará essa informação para realização do atendimento.

61996899589

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A tecnologia desenvolvida poderia ser protegida por qual(ais) modalidade de propriedade intelectual abaixo. É possível marcar mais de uma opção.

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- ☒ Programa de computador
- ☐ Desenho industrial
- ☐ Cultivar
- ☐ Topografia de circuito integrado

- ☐ Direito de autor ou conexo
- ☐ Não tenho certeza sobre o que foi desenvolvido
- ☐ Outra

9. Descreva sucintamente o que foi desenvolvido. *

Exemplo: foi desenvolvido nanocompósitos baseados em Carbon-dots, com propriedades luminescentes e de carreamento de nutrientes, que quando aplicado via foliar e/ou radicular na planta potencializam a fotossíntese.

Foram desenvolvidos um conjunto de scripts em linguagem de programação Python e em Structured Query Language (SQL) para converter cadastros técnicos de redes de água e esgoto em duas dimensões (2D) para três dimensões (3D).

A ferramenta em Python dispara em sequência procedimentos em sistema de gerenciamento de banco de dados (SGBD) que calculam a coordenada Z e preenchem os atributos necessários para a visualização 3D das tubulações, das

10. Adicione um arquivo que seja relevante para análise do Nupitec (máximo 10MB) (Pergunta não anônima)

Anexe um arquivo do Word, PDF ou imagem que possa ajudar o Nupitec a entender melhor a sua tecnologia. Exemplo: imagem da marca, artigo, dissertação de mestrado, tese de doutorado, TCC, resumo e interface gráfica do programa de computador.



IlustracaoAlgoritmos_Roberto Souza Borges.pdf

11. Qual a área em que a sua tecnologia se encaixa? *

- ☐ Ciências humanas, sociais e suas tecnologias
- ☐ Linguagens, códigos e suas tecnologias
- ☐ Ciências da natureza e suas tecnologias
- ☐ Ciências da saúde e suas tecnologias
- ☒ Engenharias e suas tecnologias

☐ Matemática e suas tecnologias

☐ Outra

12. Já foi realizada uma reunião anterior com o Nupitec para tratar da presente tecnologia? * 

Informe se já existe uma demanda em andamento no âmbito do Nupitec ou se já ocorreu uma reunião anterior para falar da presente tecnologia.

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A critério do Nupitec.

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A critério do Nupitec.

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A critério do Nupitec.

16. Qual a sua preferência de atendimento? * 

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