Digital Twin Model from Freehanded Sketch to Facade Design, 2D-3D Conversion for Volume Design

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***Abstract*—The article proposes a method for creating digital twins from freehand sketches for facade design, converting 2D designs to 3D volumes, and integrating these designs into real-world GIS systems. It outlines a process that involves generating 2D exterior images from sketches using generative AI (Gemini 1.5 Pro), converting these 2D images into 3D models with TriPo, and creating design drawings with SketchUp. Additionally, it describes a method for creating 3D exterior images using GauGAN, all for the purpose of construction exterior evaluation. The paper also discusses generating BIM data using generative AI, converting BIM data (in IFC file format) to GeoTiff, and displaying this information in GIS using QGIS software. Moreover, it suggests a method for generating digital twins with SketchUp to facilitate digital design information sharing and simulation within a virtual space. Lastly, it advocates for a cost-effective AI system designed for small and medium-sized construction companies, which often struggle to adopt BIM, to harness the advantages of digital twins.**

***Keywords*—BIM; AI; GIS; digital twins; metaverse; generative AI; GauGAN; TriPo; SketchUp; IFC format; GeoTiff**

I. Introduction

The Japanese construction industry urgently needs to improve work efficiency and productivity. This urgency arises from slow productivity growth, frequent industrial accidents, a declining and aging workforce, and a government policy reducing overtime work starting in 2024. While 31.1% of employees in all industries are aged 55 or older, the percentage for construction is over 36.0%. On the other hand, the percentage of employees aged 29 or younger is over 16.6% in all industries but less than 11.8% in construction.

To address these challenges, the Ministry of Land, Infrastructure, Transport and Tourism will implement the "Building Information Management (BIM)[1] Drawing Review" in the spring of 2026. This initiative will allow confirmation applications using PDF documents and BIM models, promoting efficiency in construction projects through AI, Geographic Information Systems (GIS), and BIM.

This paper focuses on improving construction efficiency using BIM, particularly the 6D BIM model. While many BIM tools are commercially available, they are often expensive. The proposed methods rely on open-source tools to create BIM models, generate 2D and 3D exterior images, and convert BIM data into GIS-compatible formats like GeoTiff[2].

The paper highlights the advantages of BIM in terms of front-loading (shifting efforts earlier in the project lifecycle) and concurrent engineering (parallelizing workflows). It also explores methods for generating BIM data. Beyond the 3D BIM model, the benefits of 6D BIM—which incorporates time, cost, and sustainability—are discussed, especially when combined with a digital twin.

Additionally, the paper proposes methods to enhance efficiency and visualization in construction. AI is utilized to generate 3D models from 2D sketches, which can then be used to check building exteriors and appearances. The generated 3D models are converted into BIM data and subsequently into GeoTiff format for display in GIS tools like QGIS[3]. Open-source tools like SketchUp are also proposed for BIM data generation and 3D model visualization, along with AI-based construction management enhancements. A GauGAN[4]-based method for generating 3D exterior images is suggested to improve design review processes.

The integration of AI and digital twins is shown to simplify construction management tasks, improve efficiency and productivity, and enhance safety. By converting BIM models into GeoTiff format, the models can be optimized for specific geographical conditions at construction sites. There is no such this proposed models and methods which features generative AI, TriPo for creation of BIM models, and generate GIS model which is linked to the created BIM model.

The paper reviews related research and discusses the effectiveness of using BIM and AI for model creation. It introduces methods for creating BIM models from 2D data using generative AI, as well as SketchUp-based techniques. A TriPo[5] method is proposed for converting 2D models to 3D models. Finally, the paper explores integrating BIM models into Metaverse and discusses a conversion tool for translating BIM data into GeoTiff format. The conclusion summarizes these contributions with remarks and further discussion.

II. Related Research Works

Related Research on Generative AI in Construction:

[1] https://ja.wikipedia.org/wiki/BIM
[2] https://ja.wikipedia.org/wiki/GeoTIFF
[3] https://qgis.org/
[4] https://blogs.nvidia.co.jp/blog/what-is-gaugan-ai-art-demo/
[5] https://www.tripo3d.ai/

A framework integrating BIM-data mining with digital twin technology for advanced project management in smart construction has been proposed [1].

Generative Adversarial Networks (GAN[6]s) for construction project management have also been explored, showcasing how GANs can improve project management processes [2].

TriPo (Triplet Network) in AI Applications:

FaceNet[7]: A Unified Embedding for Face Recognition and Clustering introduces a Triplet Network for facial recognition and clustering [3].

Triangulated Irregular Network[8] (TIN) in GIS: A Review highlights the use and benefits of TINs in GIS applications [4].

GIS and QGIS in Construction Management:

Foundational texts, including Geographic Information Systems and Science [5] and Open-Source GIS: A GRASS GIS[9] Approach [6], provide comprehensive insights into GIS applications.

A study on using QGIS for geospatial analysis in construction projects demonstrates its practical applications [7].

Digital Twin Technology in Construction:

Digital Twin: Enabling Technologies, Challenges, and Open Research outlines the key technologies and challenges in this area [8].

Digital Twin in Construction: A Systematic Review provides a detailed overview of the benefits and applications of digital twins in construction [9].

SketchUp in Architectural Design:

While The Unified Modeling Language User Guide provides general modeling insights, Using SketchUp for Architectural Design and Construction Documentation focuses on SketchUp's role in creating designs and documentation [10][11].

GauGAN and AI in Creative Design:

GauGAN: Semantic Image Synthesis with Spatially Adaptive Normalization and GauGAN: Semantic Image Synthesis with Spatially Conditioned Generative Adversarial Networks explain the principles and applications of GauGAN in creative design [12][13].

BIM in Construction:

BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors provides a comprehensive overview of BIM's benefits and challenges [14][15].

BIM in Construction Projects: Benefits and Challenges discusses how BIM improves construction processes and highlights associated obstacles [15].

III. Proposed Methods and Systems

A. Overall

Improving productivity and streamlining workflows in the construction industry can be achieved not only through BIM-based design but also by leveraging ICT tools like IoT-enabled surveying and construction machinery. By incorporating AI into pre-construction tasks, such as building BIM models, parallel and collaborative work becomes possible, reducing construction time.

Additionally, using tools like RAG[10] (Retrieval-Augmented Generation) to share knowledge and experience can enhance work efficiency during construction. This facilitates the transfer of skills from experienced workers to beginners, improving overall quality. It supports front-loading, a method that allocates resources and focuses efforts early in a project. This approach enables early detection and resolution of problems, such as structural interferences or design flaws, by creating 3D models during the initial stages.

Front-loading minimizes rework caused by design errors or clashes, improving quality and reducing costs. Early detailed considerations and validations improve design accuracy, and simulations using 3D models allow for better decision-making. Reduced rework lowers overall costs, shortens construction times, and accelerates decision-making by enhancing stakeholder communication through 3D models. Furthermore, construction plans become more optimized, as procedures and temporary methods can be rationalized at the design stage. Distributing workloads more evenly across project phases also improves overall efficiency.

The proposed workflow is illustrated in Fig. 1:

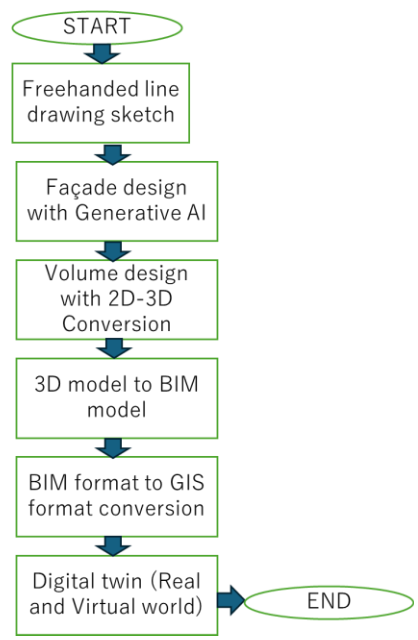

Fig. 1. Process flow of the proposed method for digital twin model creation.

[6] https://www.skillupai.com/blog/tech/mldl-tips-1/
[7] https://github.com/davidsandberg/facenet
[8] https://ja.wikipedia.org/wiki/TIN
[9] https://grass.osgeo.org/
[10] https://aws.amazon.com/jp/what-is/retrieval-augmented-generation/

1) Start with a freehand sketch.

2) Use software like SketchUp[11] to refine the design.

3) Create a 2D façade design using generative AI tools, such as Gemini AI Pro[12].

4) Convert the 2D design into a 3D volume model using 2D-to-3D tools like TriPo.

5) The 3D model can be used as a BIM model in a virtual space.

To create BIM models in real-world applications, BIM data (e.g., IFC files) is converted to GeoTiff format, enabling GIS visualization with tools like QGIS. These steps outline a proposed digital twin creation method for construction design.

In the virtual space, users can perform various simulations, and the results of these studies can be implemented in real-world applications through GIS-based visualization.

B. SketchUp[13]

Revit[14], ArchiCAD[15], and Gloobe[16] are popular tools for generating BIM data but come with high costs: 427,900 yen, 418,000 yen, and 165,000 yen per month, respectively. A more affordable alternative is SketchUp, which is free but offers fewer features. Here's how SketchUp can be used for BIM data generation:

1) Basic Use of SketchUp

Modeling: Create 3D models using SketchUp's intuitive interface.

Use basic tools like lines, planes, and arcs to model buildings and structures.

2) BIM Data Requirements

BIM Data: Includes building structure, materials, dimensions, and related metadata.

In SketchUp, you'll need to create a detailed model with this information.

3) Using Plugins

IFC Exporter[17]: Export SketchUp models as IFC (Industry Foundation Classes) files, the standard format for BIM data.

Plugin Installation: Search for "IFC Exporter" in SketchUp's Extension Warehouse and install it to improve compatibility with BIM software.

4) Adding Attributes and Metadata

Dynamic Components: Add attributes and parameters to objects, such as size, material, or manufacturer details for doors and windows.

5) Using Layers and Groups

Layers and Groups: Categorize elements into layers and groups for better organization, making it easier to identify and work with specific elements.

6) Exporting and Importing

Export IFC Files: Use the IFC Exporter plugin to export SketchUp models as IFC files.

Import into BIM Software: Import these IFC files into BIM tools like Revit or ArchiCAD for further analysis and design.

7) Integration with Other Tools

SketchUp Pro and Layout: Use Layout, a feature in SketchUp Pro, to create 2D documents for construction drawings and specifications as part of the BIM workflow.

8) Best Practices

Standardize Model Structure: Use consistent layer structures and naming conventions to improve collaboration and make models easier to understand.

While SketchUp is not a dedicated BIM tool and primarily serves as 3D modeling software, it can still be used to create detailed models and ensure compatibility with other BIM software through the steps above. However, its BIM functionalities are limited compared to specialized tools.

Fig. 2 shows an example of an initial building design created with SketchUp.

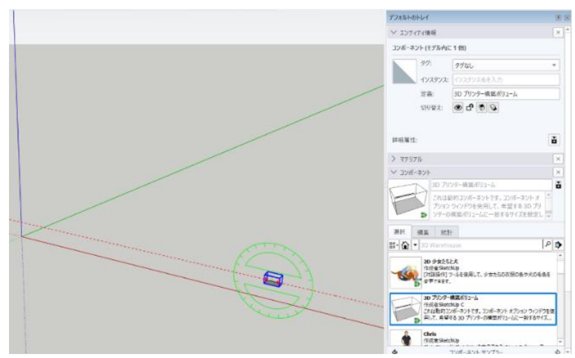

Fig. 2. Just the beginning of design of building for construction.

C. Generative AI and TriPo

For exterior design checks, images generated by Generative AI can be highly useful. Fig. 3 illustrates a 2D exterior design image created using Claude 3.5 Sonnet[18], a Generative AI tool. This 2D image can then be converted into a 3D model using tools like TriPo.

While there are numerous software options available for 2D-to-3D image conversion, TriPo demonstrated the best quality among the 10 tools tested as is shown in Fig. 4. 3D images converted from 2D image generated by Generative AI based on TriPo can be rotated and can be displayed from the arbitrary view of line of sight.

[11] https://www.sketchup.com/en
[12] https://deepmind.google/technologies/gemini/pro/
[13] https://help.sketchup.com/ja/downloading-sketchup
[14] https://recademy.jp/knowhow/4373
[15] https://graphisoft.com/jp/solutions/products/archicad
[16] https://archi.fukuicompu.co.jp/products/gloobe/
[17] https://github.com/Autodesk/revit-ifc/releases
[18] https://www.anthropic.com/news/claude-3-5-sonnet

Fig. 3. 2D exterior designed image creation with generative AI of Claude 3.5 sonnet.

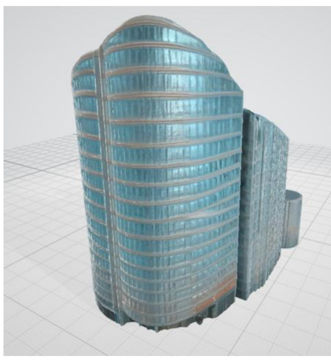

Fig. 4. 3D image converted from 2D image generated by Generative AI based on TriPo.

D. GauGAN

GauGAN is a powerful tool for visualizing architectural concepts and designs. Here are its key applications:

1) Concept visualization: Architects and designers can use GauGAN to quickly bring initial ideas to life. From simple sketches or written descriptions, it generates realistic architectural images that can be shared with clients and team members.

2) Environmental simulations: GauGAN can simulate buildings in various environments and seasons, helping visualize how a project will look under different conditions. For example, it can easily create scenes like “a modern house in snowy mountains” or “a skyscraper in a bustling city center.”

3) Landscape design: Designers can use GauGAN to experiment with surroundings, such as planting options or terrain layouts. It enables easy addition or modification of elements like green spaces, water features, or rock gardens, ensuring harmony between the building and its environment. GIS tools can further assist in evaluating this harmony.

4) Presentation materials: Realistic images generated by GauGAN are ideal for client presentations or proposal materials. These visuals help communicate the project vision effectively and leave a strong impression.

5) Rapid design iteration: GauGAN allows designers to make quick adjustments to their designs and view results in real time. This speeds up the design process and encourages the exploration of multiple ideas in a shorter timeframe.

6) Urban planning: Urban planners can use GauGAN to visualize new developments or redevelopment projects. By combining elements like streets, parks, and buildings, it can depict a detailed vision of a city’s future.

7) Interior design: GauGAN is also helpful for designing interior spaces. It can simulate natural light effects, window views, and overall spatial aesthetics, supporting better decision-making in interior design.

These capabilities make GauGAN a valuable tool for generating ideas in the early stages of architectural design, enhancing client communication, and enabling faster design iterations. By improving both efficiency and creativity, GauGAN significantly supports architectural and urban design projects.

E. BIM Model Creation by Claud 3.5 Sonnet

Create a structured BIM dataset based on what can be observed from the images, paying attention to:

1) Overall properties and characteristics of the building
2) Details of the structural system
3) Spatial configuration and estimated dimensions, especially of the characteristic curved curtain walls
4) Envisaged technical systems
5) Sustainability features
6) Contextual information

The Python code for this is as follows:

```
{
 "buildingProperties": {
  "type": "Mixed-Use High-Rise",
  "architecturalStyle": "Contemporary",
  "mainFeatures": ["Curved Glass Facade", "Corner Location"],
  "estimatedHeight": "65-75 meters",
  "estimatedFloors": {
   "aboveGround": 18,
   "retail": 1
  }
 },
"structuralSystem": {
  "primaryStructure": "Steel and Concrete",
  "facade": {
   "type": "Curtain Wall",
   "materials": ["Glass", "Aluminum"],
   "features": ["Curved Glass Panels", "Horizontal Banding"]
  }
 },
 "spatialOrganization": {
  "footprint": {
   "shape": "Curved Rectangle",
```

"estimatedArea": "800-1000 square meters"
},
"floorLayout": {
"groundFloor": {
"use": "Retail/Lobby",
"features": ["Double Height Entrance", "Commercial Space"]
},
"typicalFloor": {
"use": "Commercial/Residential",
"estimatedArea": "700-900 square meters"
}
}
},
"technicalSystems": {
"presumedMEP": {
"hvac": "Central System",
"elevators": {
"estimated": "3-4 units",
"type": "High-Speed"
},
"lighting": {
"natural": "Floor-to-ceiling windows",
"artificial": "LED Systems"
}
}
},
"sustainability": {
"features": [
"High-Performance Glazing",
"Natural Daylighting",
"Possible Green Building Certification"
]
},
"context": {
"setting": "Urban",
"surroundings": {
"adjacent": ["Street", "Parking Area"],
"neighborhood": "Commercial District"
}
},
"metadata": {
"note": "This BIM data is approximate and based on visual assessment only. Actual building specifications may vary."
}
}

F. Other Useful Software Tools

The Architecture Design Bot[19] is an AI-powered tool that streamlines the architectural design process. It can generate architectural images from text prompts, create variations of existing design proposals, automatically produce 3D models, and provide optimization suggestions for compliance with regulations and cost-efficiency. Additionally, it aids in idea generation during the early design stages, quickly generates client-ready proposal variations, reduces the time needed for rendering and 3D modeling, and automates compliance checks with building codes.

Other Free Tools for Generating BIM Data:

1) FreeCAD

Open-source 3D parametric modeler.

Create 3D drawings from 2D sketches.

Compatible with Windows, Mac, and Linux.

BIMx (Graphisoft)

2) Free applications are available for iOS and Android.

View and explore 3D BIM models.

Provides seamless 2D and 3D project navigation.

BIM Vision

3) IFC model viewer.

Supports models created in various systems like Revit, ArchiCAD, and Tekla.

4) B-processor[20]

Tool specifically developed for BIM.

Intuitive and easy-to-learn 3D modeling.

Includes features for cost calculations and carbon emission data.

5) Edificius (ACCA Software)[21]

Free BIM software with real-time rendering capabilities.

Integrates structural analysis with architectural design.

Enables accurate land mapping using satellite imagery from Google Maps.

Free 30-day trial available.

[19] https://prod.d2eu75mpuy425r.amplifyapp.com/

[20] https://tracxn.com/d/companies/b-processor/__atQDLzH2udrUrz2ES_zzho_gxGXMFnkxeLmKHa-s0Us#competitors-and-alternates

[21] https://www.accasoftware.com/en/trial/edificius

These tools offer a range of capabilities to support BIM workflows, from basic modeling to advanced features like rendering, analysis, and environmental data integration.

G. Digital Twin

The benefits of using BIM and digital twins together include the following:

1) Real-time monitoring and predictive analysis: Digital twins integrate real-time data into 3D models created with BIM/CIM, allowing real-time monitoring of construction project progress. This helps identify and address issues early. Additionally, AI-driven predictive analysis enables proactive identification of potential problems and determination of optimal construction methods.

2) Optimization of construction processes: Data collected via digital twins can be reflected in BIM/CIM models to continuously improve construction workflows. For example, analyzing equipment usage and worker movements can lead to more efficient procedures.

3) Enhanced safety: The combination of digital twins for real-time monitoring and detailed 3D BIM/CIM models allows for the early detection of potential safety hazards, enabling preventive measures to reduce risks.

4) Improved maintenance efficiency: After construction, digital twins can monitor the condition of buildings and infrastructure in real time, reflecting updates in the BIM/CIM model. This enables preventive maintenance and optimized repair planning.

5) Better collaboration: By integrating digital twins with BIM/CIM, all stakeholders can share up-to-date project information, improving communication and collaboration.

6) Advanced simulation capabilities: Incorporating real-time data from digital twins into BIM/CIM models facilitates more precise simulations, allowing for accurate predictions of design changes' impacts and optimization of construction methods.

7) Improved lifecycle management: Continuous data collection and utilization across the design, construction, operation, and maintenance phases enable optimization throughout the entire lifecycle of buildings and infrastructure.

8) Faster and more accurate decision-making: Combining real-time data with detailed 3D models enhances decision-making speed and accuracy.

The integration of digital twins and BIM/CIM significantly improves visualization, efficiency, and quality in construction projects. It also plays a crucial role in advancing digital transformation in the construction industry. To fully leverage these technologies, establishing robust data management systems and enhancing the skills of personnel involved are essential.

H. BIM File (IFC Format) to GIS File (GeoTiff Format)

"BIM file workspace" (Revit or IFC file) to geodatabase dataset base map information DEM 1m mesh[22]. Assign an appropriate geographic coordinate system to the BIM model. In Japan, JGD2011 (plane rectangular coordinate system) is often used. Extract necessary information from the BIM model (e.g. topographical data, building outline, etc.). Convert the extracted data into a raster format (GeoTIFF, etc.).

The method of converting BIM data to GeoTiff that can be displayed in GIS such as QGIS is as follows:

1) AutoCAD Civil 3D: Read BIM data and export to GIS format

2) FME [23] (Feature Manipulation Engine): Tool specialized in conversion between various formats

3) QGIS: Open-source GIS software that allows conversion using plug-ins

4) Resolution setting: Set the appropriate resolution when converting to GeoTIFF

5) Attribute information retention: Reflect important attribute information contained in the BIM model in the GIS data

6) Utilize detailed 3D models created with BIM for geospatial analysis (promoting integration of BIM and GIS, enabling more effective data utilization at each stage of construction project planning, design, construction, and maintenance)

Below is the Python code that makes this possible. First, convert the BIM data to an intermediate format (e.g. GeoJSON[24]) and then convert it from the intermediate format to GeoTIFF. The code works in the following steps:

1) The bim_to_geojson function reads the BIM data and converts it to GeoJSON format

2) Assumes that the input is already in GeoJSON format

If it uses real BIM data (e.g. IFC files), it will need to parse the data using an appropriate library (e.g. IfcOpenShell) and convert it to GeoJSON format.

Next, the geojson_to_geotiff function converts the GeoJSON data to a GeoTIFF. This function does the following:

1) Calculates the extent of the GeoJSON data

2) Determines the raster size based on the specified resolution

3) Creates an empty raster using NumPy

4) Draws each feature in the GeoJSON to the raster

5) Saves as a GeoTIFF using the rasterio library

To run this code, the following libraries are required:

rasterio

numpy

shapely

[22] https://www.gsi.go.jp/gazochosa/gazochosa61002.html
[23] https://en.wikipedia.org/wiki/FME_(software)
[24] https://ja.wikipedia.org/wiki/GeoJSON

These libraries can be installed with the following command of “pip install rasterio numpy shapely”. The Python code for this is as follows:

```
import json
import rasterio
from rasterio.transform import from_bounds
import numpy as np
from shapely.geometry import shape
from shapely.affinity import scale
# Step 1: Function to load BIM data and convert to GeoJSON
def bim_to_geojson(bim_file):
# Implement the code to load and analyze BIM data here
# In this example, it assumes that the data is already in GeoJSON format
with open(bim_file, 'r') as f:
geojson_data = json.load(f)
return geojson_data
# Step 2: Function to convert GeoJSON to GeoTIFF
def geojson_to_geotiff(geojson_data, output_file, resolution=0.1):
# Get GeoJSON extent
features = geojson_data['features']
gemetries = [shape(feature['geometry']) for feature in features]
all_geoms = shape({'type': 'MultiPolygon', 'coordinates': [geom.coordinates for geom in geometries]})
minx, miny, maxx, maxy = all_geoms.bounds
# Calculate raster size
width = int((maxx - minx) / resolution)
height = int((maxy - miny) / resolution)
# Create raster data
raster = np.zeros((height, width), dtype=np.uint8)
# Draw each feature in GeoJSON to a raster
for feature in features:
geom = shape(feature['geometry'])
geom = scale(geom, xfact=1/resolution, yfact=1/resolution, origin=(minx, miny))
coords = np.array(geom.exterior.coords).astype(int)
rasterio.features.rasterize([coords], out=raster, transform=from_bounds(minx, miny, maxx, maxy, width, height))
# Save as GeoTIFF
with rasterio.open(
output_file,
'w',
driver='GTiff',
height=height,
width=width,
count=1,
dtype=raster.dtype,
crs='+proj=latlong',
transform=from_bounds(minx, miny, maxx, maxy, width, height),
) as dst:
dst.write(raster, 1)
# Main process
bim_file = 'input.json' # BIM data file (assuming GeoJSON format in this example)
output_file = 'output.tif'
geojson_data = bim_to_geojson(bim_file)
geojson_to_geotiff(geojson_data, output_file)
print(f"Conversion completed. Output file: {output_file}")
```

IV. Conclusion

This study proposes a method for generating 2D exterior images from sketches using generative AI (Gemini 1.5 Pro) and a technique for converting 2D images into 3D models using the free tool TriPo. Additionally, it demonstrates how 3D models can be created using the free tool GauGAN, making it easier to visualize and verify building exteriors.

The study also presents a process for creating design drawings with the free tool SketchUp and generating BIM data using generative AI (Claude 3.5 sonnet). While the BIM data generated may not be fully complete, the findings demonstrate the feasibility of using free tools for this purpose.

Furthermore, a method is proposed for converting BIM data (IFC files) into GeoTiff format using Python code, illustrating that GIS visualization can be achieved with free tools like QGIS. Lastly, the study suggests a method for generating digital twins using SketchUp and shows that simulations in virtual environments are possible, enhancing the scope of design and analysis in construction projects. This approach is quite new and has original ideas. The conventional models and methods are traditional expensive BIM model creation and are not linked to the GIS system at all.

A. Future Research Works

Although it is confirmed that the proposed methods and systems can be feasible, detailed design of BIM model requires more detailed information. Also, CG design and environmental parameter settings are required for creation of digital twin, fundamental digital twin can be created by the proposed method though. Therefore, one of the business use cases will be attempted in the near future.

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