Implementation of Building Information Modelling for Road Rehabilitation and Reconstruction Project: Liquefaction Disaster of Palu Area

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ABSTRACT

Purpose: Utilization of Building Information Modeling (BIM) is believed to improve planning accuracy, mitigate construction risks, and better plan the entire life cycle of infrastructure asset projects. The application of BIM technology in post-disaster management can combine GIS technology (Geographic Information System) with BIM technology itself, or commonly referred to as geospatial BIM. The purpose of this paper is to apply BIM technology, explain the stages of road planning and modeling with BIM, and identify the advantages of using BIM compared to conventional methods. The road planning location is the location of the Jono Oge liquefaction disaster, Palu, Indonesia.

Design/methodology/approach: Data collection, data processing with Agisoft Metashape, DEM data input, and orthophoto image data processed by Agisoft Metashape to Autodesk® InfraWorks®, road planning with Autodesk® InfraWorks®, road planning model output and field data presentation. 3D models, IMX format files, FGDB format files, and animation videos.

Findings: The application of BIM technology in planning and modeling road projects at liquefaction locations can be made using Agisoft Metashape software to process aerial photo data taken using drones and using Autodesk® InfraWorks® software for planning and modeling of the road.

Research limitations/implications: Modeling Road design in the application of BIM and the use of Autodesk® InfraWorks® applications on the project. We are not modeling the pavement, just visualizing the geometry of the road.

Practical implications: BIM implementation can drive time, effort, and realistic 3D visualization.

Originality/value: Original paper

Paper type: A case study

Keywords: *Building Information Modelling, Geospatial, Rehabilitation, Reconstruction*

I. INTRODUCTION

On September 28, 2018, an earthquake measuring 7.4 struck the island of Sulawesi, with its epicenter located about 80 km from Palu City, the Capital of Indonesia's Central Sulawesi Province. Nearly 30 minutes after the earthquake, a tsunami hit the coast of Palu City, Donggala Regency, and surrounding areas along the coast, followed by landslides and Liquefaction in mountainous and urban areas. These events caused significant damage to infrastructures such as roads, bridges, airport buildings, water supplies, and other public facilities, including hospitals and schools (Irfan Rifai, 2022). The catastrophic events that co-occurred became a natural

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laboratory on a full scale. These lessons should provide benefits in the form of lessons on the characteristics of earthquakes in disaster mitigation efforts in the future (Rifai et al., 2020). Civil engineering experts have strong beliefs about the interrelationships of the causes of earthquake disasters in most earthquake-prone areas of Indonesia.

Liquefaction events in several locations in the city of Palu caused damage to transportation infrastructure. Due to the movement of the soil at the liquefaction location is a geometric shift in roads and bridges. These changes cause difficulties for planners in carrying out the preparation of re-design, rehabilitation, and reconstruction. In addition, the loss of reference points for road alignment can lead to community conflicts among landowners around roads and bridges. So we need a reliable approach to solve some of these problems. Using the latest technology by utilizing computer-based and satellite-based applications is thought to facilitate work planners and implementers (Haria et al., 2019).

The opportunity to use BIM technology in road construction projects is to obtain various beneficial factors, including efficiency, productivity, constructability, and road safety. The process and workflow of BIM integration in road construction will not be much different from the BIM concept in general. However, a BIM platform may be needed specifically for non-building civil infrastructure. (Xing et al., 2020). Many case studies have proven the application of BIM technology in transportation infrastructure projects, such as in the construction of roads, railways, airports, ports, bridges, and tunnels (Abbondati et al., 2020).

The application of BIM technology has proven to assist road and bridge infrastructure providers in improving planning accuracy, mitigating construction risks, and planning the entire project life cycle of infrastructure assets better. However, on the other hand, there is an effort to need additional resources for BIM integration, for example, the provision of BIM specialist personnel, procurement of computer systems and BIM supporting software, more detailed data, and information collection processes, and time allocation for the preparation of the BEP (BIM Execution Plan), and make it happen (Pruskova & Kaiser, 2019).

The above conditions can certainly be a motivation to realize BIM technology in the rehabilitation and reconstruction of roads and bridges. However, the availability of BIM regulations and infrastructure in implementation, which is still limited in Indonesia, should not be an obstacle to technological development. Therefore, while waiting for the implementation system of BIM technology in this government project to become more evident on standards and mechanisms, all stakeholders involved in the operation of roads and bridges should be prepared by equipping themselves with knowledge about BIM. Therefore, the use of BIM in rehabilitation and reconstruction is expected to be a good start in implementing better geospatial BIM.

II. LITERATURE REVIEW

A. Building Information Modelling

The basic understanding of BIM is a digital representation of the physical and functional characteristics of a building or object, which contains data and information as a basis for decision-making during the life cycle of the building. Therefore, without realizing it, road and bridge construction implementers in various project scales have implemented the BIM concept only with a minimum level of maturity and dimensions. With pre-construction technical drawings made in the form of 2D CAD drawings, this process already reflects Level 0 of the BIM implementation in 2D dimensions (Babič & Rebolj, 2016). However, in its current development, it is, of course, expected to exceed the more advanced levels above it. Figure 1 shows the development of BIM levels from the beginning to the present.

The implication of BIM's low maturity level and dimensions is the limited benefits that can be obtained. A simple example, if the working drawing is made only in 2D, then the representation of the road or bridge design will be shown from parts of the image that are separated from each other (views/cuts/details), making it difficult to synchronize to minimize errors. The conditions will be different if the working drawings are then developed into a higher-level BIM, with 3D visualization, for example. Any errors or conflicts from 2D images will be immediately detected. This is one of the benefits of BIM called clash detection (Akponeware & Adamu, 2017). In addition, with the availability of 3D models, illustrations of the actual shape of the building and its volumetric dimensions can be known quickly and easily. This data is undoubtedly beneficial for the calculation of the Bill of Quantity and a more accurate estimation of development costs. In essence, the more we can increase the level and dimensions of BIM, the more advanced project management can be, for example, in terms of work schemes and scheduling, estimation of development costs, the operation-maintenance process, and life cycle cost management. (Othman et al., 2021)
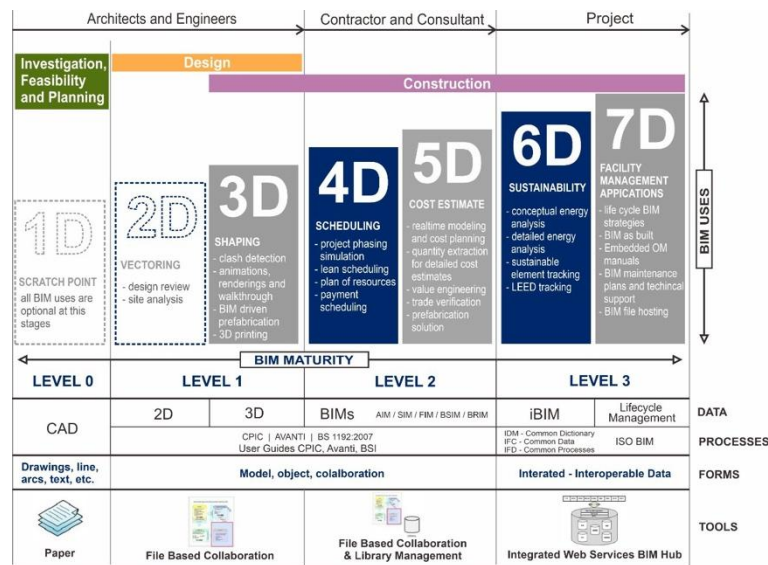
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Figure 1. BIM Maturity (DGH, 2020)

Implementing BIM integration with a high maturity level requires a more significant investment cost at the initial cost stage (Rad et al., 2021). However, some of them can continue to be used for the continuation of the next project. For example, it was procuring BIM supporting tools and purchasing BIM software licenses. Therefore, in every process of building roads and bridges at various project scales, it is necessary to consider starting to utilize this BIM technology. In its implementation, of course, it is adjusted to the level of maturity according to the needs and abilities. Alternatively, at least, we can try and prove the benefits of BIM technology, especially in terms of time efficiency and construction costs (Martins et al., 2020)

If simplified, several things need to be considered regarding the BIM implementation process for road and bridge projects. First, BIM technology is expected to be "mandatory" in every government infrastructure project and a platform to facilitate asset management (Lu et al., 2020). However, in Indonesia, there is no policy and legal basis for implementing BIM for all infrastructure sectors/fields carried out by the government. Furthermore, standards and standard protocols are needed that regulate the BIM implementation mechanism. These standards are needed starting from requiring them in planning documents, coordination procedures, and BIM output models that must be presented at every project scale (Kula & Ergen, 2021).

It can be realized that knowledge and mastery of the BIM methodology in the field of roads and bridges are still minimal. This is driven by the relatively high price of licensed BIM software and the preparation of a supporting computer system. In addition, the BIM platform that is currently developing is more dominated by modeling buildings and vertical infrastructure (Gamil & Rahman, 2019). Although there have been many best practices for implementing BIM for road and bridge infrastructure projects abroad, the reviews and studies on their implementation have not been widely published. Meanwhile, for small-scale and low-cost road and bridge construction projects, there is a possibility that the use of BIM will be ineffective (Cao, 2022).

B. Geographical Information System

GIS is a computer-based information system designed to work with data that has spatial information. This system captures, checks, integrates, manipulates, analyzes, and displays data that spatially refers to the earth's condition. GIS technology integrates joint database operations, such as querying and statistical analysis, with mapping's unique visualization and analysis capabilities. (Zhu & Wu, 2022). It is this capability that distinguishes GIS from other information system applications that makes it useful for explaining events, planning strategies, and predicting field conditions that occur. In addition, GIS is a technology used to retrieve, store, analyze and display spatial and non-spatial data. GIS provides the ability to combine tabular data and graphic information into a spatial map. With this capability, users can understand and absorb information from maps more quickly and effectively than reading a list of data in tabular format (Usmani, 2020).

In the early 1990s, with the development of computer and GIS technology, the integration of GIS in the needs analysis system of mechanical earthmoving management systems has been widely developed. However, a mechanical earthmoving management system with tiered levels from segments to networks requires tools to perform integrated system analysis. One of the tools that can integrate it is GIS with a combination of BIM (M. Wang et al., 2019). In previous studies, GIS was mainly used to display results and generate reports. However,

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GIS functions are not yet fully integrated into the road-network level. Therefore, further analysis is needed to get more potential from GIS (Francini et al., 2018).

Several road and bridge planning system analysis systems have developed GIS capabilities. However, the GIS functions taken are not yet integrated using the full potential of GIS. For example, the developed system does not provide dynamic integration between GIS visualization and needs analysis of road and bridge planning modelling (H. Wang et al., 2019). Implementing the GIS approach with the BIM approach is very dependent on the proper hardware to support the installation and software that can be utilized to the limit of its data manipulation and analysis capabilities. With the rapid development of GIS, various kinds of commercial software have emerged, although with the same purpose and function (Karimi & Iordanova, 2021).

C. Information Communication Technology

The increase in infrastructure and improvements made by the government are expected to spur economic growth. The repair and development of infrastructure show that Indonesia is on the right path regarding infrastructure development. However, in the report results, there was a decrease in the index. After being traced, it turns out that the decline in the index value is most likely due to the weak competitiveness of several factors. One of the most influential factors is Information Communication Technology (ICT) technology (Javed et al., 2020). Using ICT for rehabilitation and reconstruction planning should be more effective and efficient than traffic jams that are starting to get crowded. By optimizing various variables, the integrated use of BIM is an increasingly sophisticated optimization of ICT usage (Tang et al., 2020).

Information and communication technology (ICT) is a device that can assist humans in creating, converting, storing, and communicating information. One application or system that was born from the sophistication of ICT in the infrastructure sector is BIM. BIM has many benefits in supporting construction development. The advantages of using BIM compared to paper-based information systems can be viewed in terms of effectiveness and productivity in developing infrastructure. BIM can help designers, drafters, contractors, and management teams collaborate, visualize, and manage construction work from the planning or design phase to the facility management phase (Altohami et al., 2021). BIM is an information system that processes input into information in the form of building modeling as a tool in the decision-making process in every stage of a construction project. Unfortunately, BIM in construction projects faces various obstacles, a result of which the benefits of its application are not optimal.

The application of BIM, a set of advanced technologies, makes the entire process run in an integrated manner in a digital model, which is then translated as a three- to a five-dimensional image. The sophistication of BIM makes it not just an application but a tool that can support the achievement of development targets. On this basis, many contractors or infrastructure development implementers want to learn more about BIM. However, when the technology is too sophisticated and not balanced with the user's ability to operate it, it is a loss for the user. Thus, to optimize the technology, the capabilities and competencies of human resources must first be met (Mesároš et al., 2022).

II. METHODOLOGY

The method of writing this paper is in the form of implementing rehabilitation and reconstruction aimed at changing for the better. Therefore, information technology advances have become an essential aspect of its implementation. The use of 3-dimensional maps is one of the essential tools for planning for post-disaster rehabilitation and reconstruction of roads or bridges in liquefaction areas. The use of this 3-dimensional map is because the planning map has quite a lot of information. In this paper, we will discuss creating road and bridge components in Autodesk® InfraWorks®. This application is one of the supporting applications in planning using BIM technology.

Autodesk® InfraWorks® is a paid application, but if we need learning can use it for free. The free application can be downloaded on the official Autodesk® website (https://www.autodesk.com/education/free-software/infraworks). Following are the steps for making road and bridge components in Autodesk® InfraWorks®. The data used in the planning in this paper uses field data from the survey results of the Directorate General of Highway conducted by P2JN Palu, Indonesia. The use of GIS and drones for aerial photography is the primary data that will be run in Autodesk® InfraWorks®. The first step in using Autodesk® InfraWorks® is to create a model from a location map. The model is a map that will become a workboard in the form of a 3-dimensional map that will contain map attributes such as elevation, roads, and bridges. Furthermore, in this paper, the model builder menu is used.

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III. RESULTS AND DISCUSSION

A. Geometric Planning of Roads in Liquefaction Area

An earthquake is a natural phenomenon in the form of ground shaking that can cause damage to nature and infrastructure and endanger human life. Some phenomena that earthquakes can cause are structural failure, Liquefaction, landslides, and tsunami waves. One of the phenomena that can cause severe damage is Liquefaction. Liquefaction is a change in soil properties to become like a liquid due to an increase in pore water pressure which causes the soil to lose its shear resistance. Qualitative analysis is used to classify whether the soil in a location is vulnerable or not to Liquefaction. If the soil is classified as soil that is not susceptible to Liquefaction, there is no need for further analysis.

On the other hand, it is necessary to carry out further quantitative analysis to determine the level of vulnerability of the soil to Liquefaction and estimate the mitigation steps that need to be taken. In this engineering practice, liquefaction analysis will be carried out in the villages of Jono Oge and Sibalaya, Central Sulawesi. The area has undergone Liquefaction. Therefore, liquefaction analysis was carried out to determine the potential for Liquefaction in the future.

Qualitative analysis of liquefaction potential includes analysis using historical, geological, and soil characteristics. Analysis of historical criteria using post-earthquake research found that Liquefaction often occurs at the exact location if soil conditions do not change. This historical case study can be used to determine liquefaction susceptibility. Based on several explanations and the results of in-depth interviews with several parties, the actual liquefaction incident in the Palu area has been going on for a long time. It has become a discussion among the elders of the Kaili tribe (local tribe). The elders referred to this Liquefaction as 'Nalodo.' The term is, of course, already known and has become a passed down story, which should serve as a warning for us to prepare better mitigation management than what currently exists.

Liquefaction that occurred shortly after the most significant earthquake rocked Palu City still leaves many interesting questions, starting from the affected area and the form of Liquefaction and what happens is also quite varied. There are four areas with the most significant liquefaction influence, namely Petobo, Balaroa, Jono Oge, and Sibalaya. The standard theory states that Liquefaction can occur if the sandy soil (sand, silty sand, clayey sand) which contains little clay and tends to be uniformly graded. The most significant impact on road geometry is the result of lateral spread.

Lateral spread is the movement in the lateral direction of the soil blocks as a result of Liquefaction and loss of shear strength in the subsoil. Land displacement occurs as a combination of gravity and inertial forces caused by earthquakes on relatively gentle slopes (can reach as low as 30o). The degree of damage that occurs depends on how far the displacement of the ground produces the displacement. The displacement that occurs can be several centimeters up to several meters, as was the case in the past. Although due to the condition of the moving soil on top of the liquefied soil layer, it can still be solid, maximum passive forces may occur. Pipes, bridges, roads, buildings, and other civil engineering structures can experience fatal damage due to Liquefaction. Structures located near or at the boundary are significantly displaced and offset by several or even tens of meters. While at the foot of the slope will be compressed or flexed.

Repairing the geometric road at this liquefaction location requires high accuracy. This condition is caused by changes and shifts in the land surface, which is the basis for land selection. This new road is designed for a design speed of 40 km/h and follows the existing route. At the location of Biromaru Palolo, which has shifted, the road segment is returned to its original pre-earthquake alignment according to land ownership. Figure 2 shows the impact of Liquefaction on the geometric road in the Jono Oge area.

Figure 2. Road geometric condition on October 04, 2018

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(Mediaindonesia.com, 2018)

After three years since the liquefaction disaster, the condition of changing land coordinates becomes an exciting thing in this plan because the change in land ownership coordinates becomes permanent. These conditions can be seen in figure 3. Reference points and other reference points must be defined in more detail. Taking reference points using other main buildings such as airports is an alternative that can be used. However, the data verification and validation process must still be carried out by conducting local surveys such as the use of drones.

Figure 3. Road geometric condition in January 2022

The survey results using GIS support equipment equipped with drone photos were then poured into 3-dimensional and 2-dimensional maps. The results of simplifying the mapping results and the data contained therein can then be printed out into a 2-dimensional map that can be used to confirm field conditions. An example of the use of a two-dimensional map can be seen in figure 4. The use of a two-dimensional geometric road is still needed in the field to be used for surveyors, implementers, and operators who are still in the stage of adjusting their knowledge.
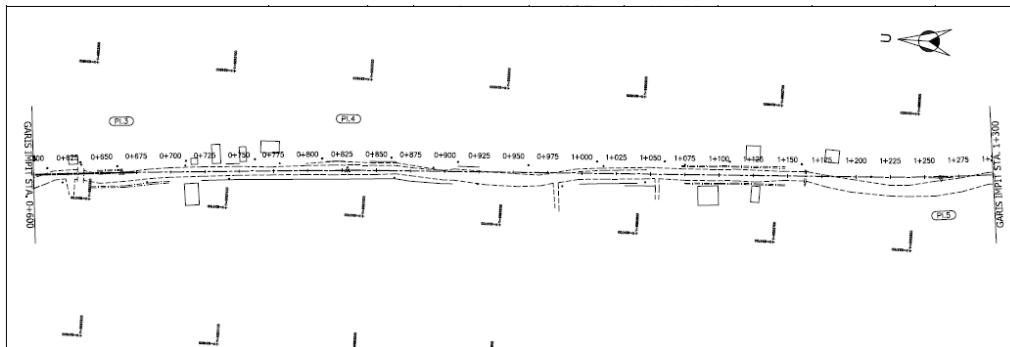

Figure 4. Two-dimension road geometric

B. Autodesk® InfraWorks® Implemented

Geometric modeling of roads using Autodesk® InfraWorks® application by adjusting the horizontal and vertical alignment data according to the DED design of P2JN with liquefaction condition, ignoring the existing contours and using the contours of the Infraworks. The stages in planning with Autodesk® InfraWorks® are as follows:

1. First, please open the Autodesk® InfraWorks® apps.
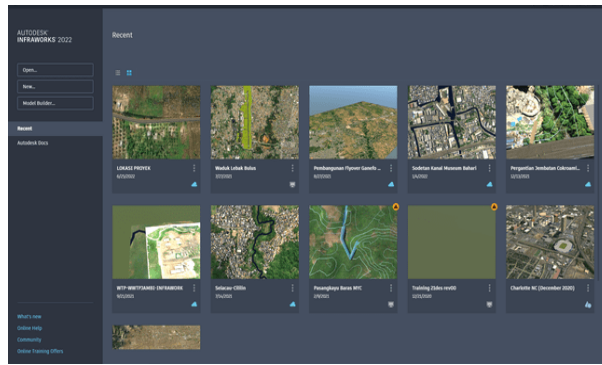
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Figure 5. Autodesk® InfraWorks® home tabular

2. Click the Model Builder tab, and Fill in the coordinates to be set with the decimal Degrees (Latitude, Longitude) coordinate system. To know the Latitude and Longitude of an area, you can use the Google Earth application by opening google earth, searching location to be addressed, placing a mark on the location, and go to tools – option – decimal degrees.
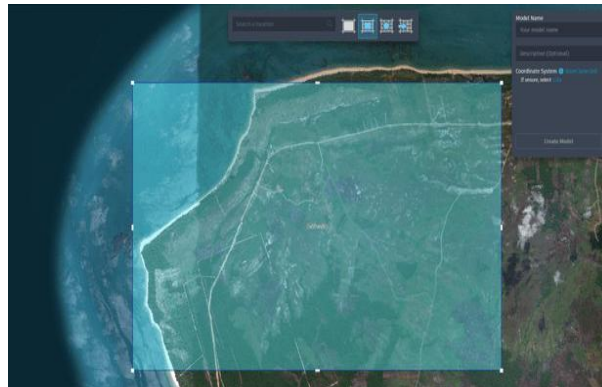3. Give a boundary on which area we will make as a reference (maximum 200 km2).

Figure 6. Autodesk® InfraWorks® boundary menu

4. Give the model a name, Coordinate system settings in Autodesk Infraworks, and Set the coordinate settings first. The coordinate system used is UTM (Universal Transverse Mercator), which is a coordinate system that refers to the flat shape of the Earth through specific projections. Then Click Create Model.
5. Open the model we have created. The contour data used is Infraworks contour data (contour data is less accurate than the original contour). Contours can also be obtained from the results of field contour surveys that have been processed using Civil 3D (.dwg) and contour photogrammetry results through Raster input (format .jpg,.tif,.dem)
6. Click the menu Create-component Road, and specify the trace and planning criteria. Define planning tracks and criteria using the Component tab. Make a road track assuming it is a planned track by ignoring the elevation of the road and its geometry.
7. The next step is to determine the coordinates of the point of intersection of the lines for the planned bend. Set the X and Y coordinates at the starting point, PI (point of intersection), and the endpoint based on the plan drawing by clicking on the point.
8. Define horizontal alignment criteria. The type of bend to be used and the bend selection criteria to be adjusted to the flow chart. Also, which is determined in the form of the type of bend radius plan (Rc), spiral/transition curve (Ls), and superelevation value.
9. Define a vertical alignment criterion. Determine the type of curve, whether concave or convex and for the length of the curve (Lv), elevation PVI, as well as the location (station) PVI adjusted to the image DED by :
10. Type Ctrl+0 to bring up the Profile View view. Profile View is used to determine the PVI (Point of Vertical Intersection)

    As a final stage, the road components, the Design toolbar menu, review, and engineer roads can be finalized. Start through the design menu, review and engineer roads, then click the Design roadways menu (to see the menu name, sort on the menu logo), then click Component Roads. The Road property will appear on the

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right side of the work screen. There is a Road field (name road), Creation Method (straight paths and turns), and type (choose a road type such as two lanes with a shoulder). Then attributes (choose a road function and design speed based on the road function); after you fill in, click on the map from the start to the end of the road component that will be created, and click twice when you reach the endpoint or right-click and select End Draw. The results of the final design draft can be seen in figure 7.

Figure 7. Implemented photogrammetry

After the road is finished, click the component of the road. It will display information from the component of the road. The information contains road names, road function attributes, and geometry (information on road length, elevation range, and percent grade). Also, grading (cut and fill material, limit grade, cut slope, fill slope). Then road quantities (shows road length, area, and volume of asphalt and road shoulders or material quantities).

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Figure 8. Implemented rehabilitation and reconstruction

Based on the map and data provided from BIM, the implementing contractor can immediately carry out rehabilitation and reconstruction work. The work began with land improvement, which is the main thing in the Jono Oge liquefaction area. The properties of coordinates, land elevation and location conditions in this area were chosen because they are directly connected to provincial roads whose handling is carried out by the same contractor. As an initial step to get the soil structure under the plan, it is necessary to return the soil elevation to standard as an illustration of the implementation can be seen in Figure 8.

The work must be done quickly and ensure the psychological community is not disturbed again. This is done to ensure trauma healing and monitor changes in groundwater around the site. For the first stage of backfilling the Jono Oge liquefaction area, the type of tool with the most use at the job site was chosen. Then, to carry out mechanical earthmoving in the form of excavation, transportation, embankment, and compaction, the heavy equipment used is selected based on the needs and location of the project. The accuracy of the work and the accuracy of selecting the required data properties get high accuracy by using Autodesk® InfraWorks®. The positive impact received is that there is no doubt from stakeholders about the misuse of the data, which initially was very doubtful. The thing to evaluate is that the standard used in Autodesk® InfraWorks® is AASTHO 2011, so the parameters are determined. Then the calculation results are calculated automatically on Autodesk Autodesk® InfraWorks® refer to AASTHO 2011, and it is necessary to adjust the standards by Autodesk® InfraWorks® application users so that the planning results are by the standards used in Indonesia.

V. CONCLUSION

The implementation of BIM with Autodesk® InfraWorks® in the implementation of the rehabilitation and reconstruction design for road and bridge construction in the liquefaction area is quite reliable. The accuracy of the data needed to prevent community trauma from previous disaster events can be avoided. The implementation of Autodesk® InfraWorks® in the field can convince all stakeholders that geometric road planning has accommodated all data and conditions under applicable standards. At the implementation stage, implementing contractors and supervisory consultants get convenience because BIM provides quite a lot of property data. Suggestions for further research are to try to continue road planning using Autodesk® Civil 3D® software with adjustments to Indonesian regulations while still paying attention to AASHTO 2011.

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