UNIVERSITY OF VAASA

SCHOOL OF TECHNOLOGY AND INNOVATIONS

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Ibukun Odubogun

OPTIMIZATION OF wasteWOIMA's MODULAR POWER PLANT INSTALLATION USING 3D SIMULATION AND VIRTUAL REALITY

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ABBREVIATIONS

MSW	Municipal Solid Waste
ISW	Industrial Solid Waste
WTE	Waste to Energy
VR	Virtual Reality
2D	Two Dimensional
3D	Three Dimensional
BOM	Bill of Materials
CAD	Computer Aided Design
LOM	Laminated Object Manufacturing
UAM	Untrasonic Additive Manufacturing
CEMS	Continuous Emissions Monitoring System
MCC	Mobile Control Centre
FGT	Flue Gas Treatment
LFO	Light Fuel Oil
HMD	Head Mounted Display

UNIVERSITY OF VAASA
School of Technology and Innovations
Author: Ibukun Odubogun

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ABSTRACT:

The primary objective of this research is to optimize module installation procedure for Woima's modular WTE power plant by making a Three-Dimensional (3D) simulation of the power plant and inspecting the model using Virtual Reality (VR). This thesis addresses the research question on how to use 3D simulation to reduce time and cost during the construction. Therefore, this thesis suggests an installation procedure where each module fits into the other as it were a lego puzzle. This proposed building procedure is previewed as 3D simulation that could then be used to optimize the construction of wasteWOIMA's modular power plant.

This research work employs the use of primary data, CAD blueprints, sourced from the case company, while secondary data was sourced from books, online repository, academic and scientific journals. To uphold the credibility of this research, it utilized both experimental and case study research strategies to conceptualize the simulation of the power plant which can be previewed on Virtual Reality (VR) glasses. VR model inspection provides an immersive and real-life scale experience. The entire 3D simulation was done using SketchUp software, a 3D modelling and simulation tool. A VR session was also carried out during the research to help identify areas of possible improvement with safety, cost and quality, using HTC Vive VR glasses and Symmetry Alpha software.

The outcome of this research shows that 3D simulation, especially when combined with VR models inspection, can help to optimize models to prevent errors during actual construction work, hence, saving cost and reducing lead time.

KEY WORDS: Waste to Energy, Modular Power Plant, Optimization, wasteWOIMA, 3D Simulation, Virtual Reality

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1. INTRODUCTION

Pollution and Waste are global problems that need to be addressed through the combined effort of policymakers, industry and individuals. Environmental and atmospheric pollution caused by poor waste management practices, have been observed to contribute significantly to global warming. However, recycling and reuse of items is seen as a better alternative than burning or dumping of waste in a designated area. When waste is recycled, it not only reduces the quantity of pollutants in the environment but also reduces dependence on raw materials which are often sourced through energy intensive processes which also releases carbon-monoxide compounds into the atmosphere. Therefore, waste to energy conversion is still a relevant technology as it has been for decades.

Waste is often divided into two categories, Municipal Solid Waste (hereinafter, MSW) and industrial solid waste (hereinafter, ISW). MSW, which is waste discarded in urban areas, is composed predominantly of household waste with a minor amount of commercial waste. ISW is waste produced by industrial activities (Chen 2018: 262.)

The power plant discussed in this research focuses on Municipal Solid Waste which is generated in massive quantities across cities globally. MSW is considered a source of renewable energy and has been used as a source of electricity generation with results that helps to deal with the two key municipal challenges of waste management and electricity generation (Song et al. 2013: 953.)

The MSW generated in cities globally is on a rapid increase owing largely to an increasing human population and rapid urban development. According to World Bank estimates, the total waste generated in urban areas will increase from 3.5 million tons per day to 6.1 tones million in the year 2025 (Makarichi, Jutidamrongphan & Techato 2018: 812.)

Conversion of MSW to energy is not an entirely new technology and has continuously evolved over time. However, the use of decentralized modular units in the form of flat-track containers is a novel concept. This concept was developed by Woima Corporation in Vaasa, Finland with the aim of reducing installation time, site and infrastructure cost reduction and increase the possibility for power plant mobility. Considering these factors, there exist a huge adoption potential in emerging economies, mainly in Africa and Asia but not without peculiar challenges such as the optimization of the WTE power plant layout which prompts the need for further research (Woima Corporation 2018.) The process involved in energy generation requires detailed planning and iteration which would be better optimized with the use of 3D simulation and VR model inspection.

1.1. Research Justification and Contribution

This process derives its uniqueness from the modularity of the power plant's design. The plant design consists of traditional components and stages such as waste delivery, combustion with boiler, flue gas treatment chamber, energy recovery and residual ash collection and treatment.

Woima corporation already has a 3D model of the power plant. However, because no plant has yet been completed, there exists a need to study the best methods or procedures to use during the power plant installation relative to regulations, environmental and socio-economic factors in the society.

The researcher to utilized Three-Dimensional Simulation (hereinafter, 3D simulation) software for the purpose of visualizing the installation procedure. The preferred choice of software is SketchUp Pro 2017 which was initially developed by an American company called Last Software in the year 2000 but is now owned by Trimble Inc. The final simulation was previewed using Virtual Reality (hereinafter, VR) glass to create a more immersive experience. According to Posada, et al. (2015: 26), visual computing involves the acquisition, analysis, and synthesis of visual data using computers that provide tools which are relevant to the field.

1.2. Research Objectives and Questions

The primary objective of this research is to plan an optimized installation procedure for Woima's modular WTE power plant and design a 3D simulation of the power plant's installation. Additionally, the simulation is viewable on VR glasses. The installation procedure is designed considering parameters such as cost, safety analysis and lead time of components. Based on the research objectives, the following research questions have been formulated.

i. *How can the construction process of wasteWOIMA's modular power plant be optimized using 3D simulation and visualization?*

ii. *Which procedure is optimal for constructing wasteWOIMA's modular power plant?*

1.3. Research design

The research design is an essential part of any research process, because it includes the aspect of research which helps to answer the research questions and attain the set research objectives (Saunders, Lewis & Thornhill 2016: 163).

In this section, the overall research processes are discussed. Furthermore, it entails the research strategy in terms of research approach, research purpose and philosophy which were used arrive at useful conclusions. It also contains the research onion as designed by Saunders et al. (2016:174) which has been adapted to suit the objective of this research.

The research purpose places emphasis on the way research questions are presented based on either exploratory, descriptive or explanatory accounts and hence answered in a given study (Saunders et al. 2016: 174). The main method of this work is the exploratory research method. Exploratory research is preferred because it serves the purpose of obtaining better understanding of concepts and solidifies the definition of that problem. It allows the interviewer to ask open questions which helps to better understand the concept of interest and it encourages flexibility and adaptability in the research. Additionally, because as this research progressed, a narrower path was defined by both the researcher and the stakeholders involved, this research method was preferred (Saunders et al., 2016: 174-175.) Exploratory method is also used to identify key variables to be studied (McDaniel Jr. & Gates 2010: 43).

1.3.1. Research philosophy

Research Philosophy deals with the system of beliefs and assumptions as it pertains to the development of knowledge. This research applies some elements of positivism in its research philosophy (Saunders et al. 2016: 124 & 137). Five main research philosophies were discussed by Saunders et al. (2016: 135) and they are positivism, critical realism, interpretivism, postmodernism and pragmatism. This research prefers the philosophy of positivism because it uses existing theories to help develop hypotheses. Additionally, the researcher prefers positivism because the research is value driven and has a practical impact on business metrics, industrial planning and improvement.

1.3.2. Research gap

With the advances in software tools providing possibility to visualize 3D design in Virtual reality, further investigation is needed about and practicalities of such design approach. VR solutions allow for faster preview and immersive first-person experience during the initial stage of Industrial facilities planning. This phenomenon has only started to be analyzed by academic researchers, thus, this work addresses the existing research gap.

1.3.3. Research approach

Research approach is an important research process because the choice of research approach will help determine one’s research design and will also determine the categorization of the research results. Saunders et al. (2016: 145) categorized research approach into three generic groups namely deductive, inductive and abductive. In this study, the inductive approach is considered appropriate because the collected data were precisely for a modular WTE power plant and were subsequently combined to generate specific information about the processes. Furthermore, the collected data was used to explore a phenomenon and develop a theory in the form of a conceptual framework.

Another key component of research methodology is the Research Strategy which defines the plan of action that a researcher will use to attain the goals necessary to answer the research questions (Saunders et al. 2016: 145). Various research practices have evolved over the years largely due to different research traditions among researchers. Hence, most researchers use either qualitative, quantitative or mixed research methodology. The research strategies are experimental, case study, archival and documentary research, ethnography, narrative inquiry, action research, ground theory and survey. The research strategies used in this research are experimental and case study because a pilot power plant of this type is not yet built. The researcher's focus was mainly with waste-WOIMA's modular WTE power plant and not generally all WTE power plants. Therefore, an experimental case study is inferred and the preferred methodology for this research is the qualitative means of data analysis.

The nature of a research can either be cross-sectional or longitudinal. The primary contrast between both time horizons is that while cross-sectional could be described as the "snapshot" time horizon, the longitudinal is the "diary" perspective. In cross-sectional research, the study often focuses on a particular phenomenon and at a given time. It is not necessary to study the development or changes with the phenomenon which is being studied. Therefore, this research utilized cross-sectional time horizon (Saunders et al. 2016: 200.)

In Figure 1 we find the snapshot overview (green outline) of the research processes used in this research and adapted from (Saunders et al. 2016: 124.)

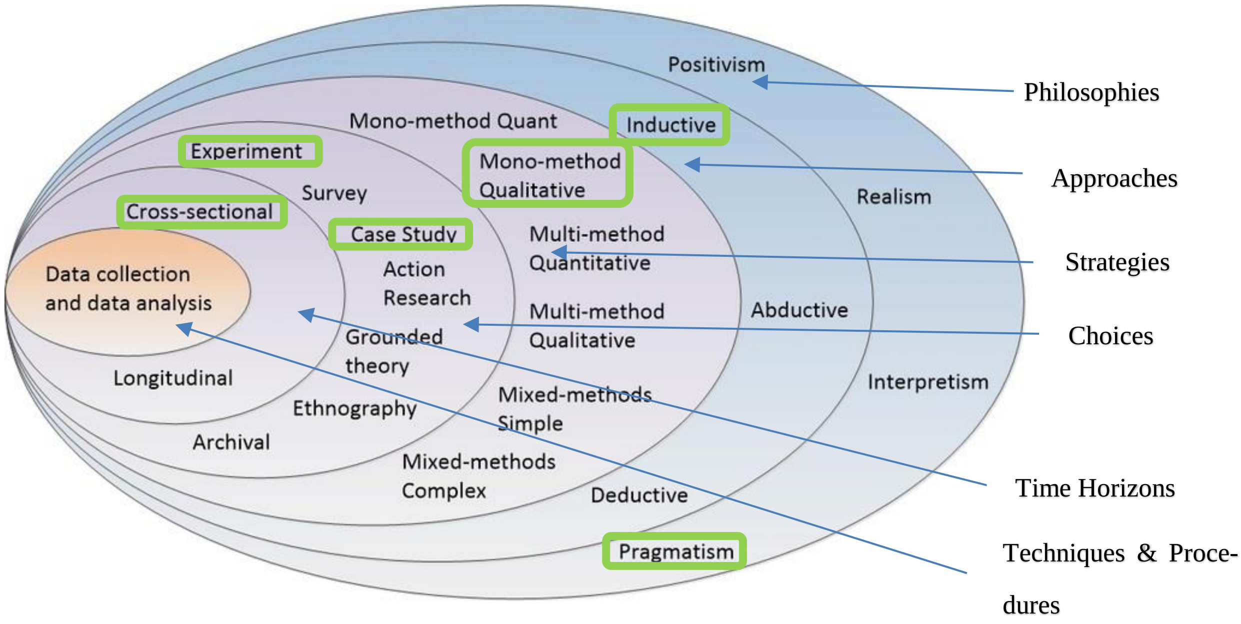

Figure 1. Research Onion (Saunders et al. 2016: 124.)

1.4. Research Limitations

The scope of this research is limited to optimizing the installation procedure of waste-WOIMA's modular WTE power plant using 3D simulation as a tool. External factors that limits the scope of this research include finding literatures that exclusively discuss modular power plants within the context of WTE. This is because Woima corporation's application of modularity to WTE is a novel idea. Notwithstanding, the void has been filled with the use of some relevant literature from the broader concepts of both modular power plants and waste to energy. The scope of the research relative to the key terms are written below.

Waste to Energy – Deals with the conversion of waste into energy. This research focuses only on municipal solid waste but not other forms of waste.

Modular Power Plant – Is a power plant made up of smaller modules which fits together to form a whole unit. This research focuses only on Woima Corporation's modular waste to energy power plant.

Optimization – Involves making the best use of a resource or a situation. This research focuses only on optimizing the construction or installation of Woima corporation's WTE power plant.

wasteWOIMA – Is the name given to the modular WTE power plant which is designed by Woima Corporation.

3D Simulation – Presents computer design in 3D view. This research focuses only on 3D simulation of wasteWOIMA's modular power plant.

Virtual Reality – Is a near realistic rendering of data in 3D format. This research focuses uses VR for preview and inspection of the models.

Additionally, there was a limitation with computing power because although only two of the four possible power lines were simulated, the file was already about 450mb which caused the CAD software to occasionally freeze and took a relatively long time to save changes made to the model. However, the two lines used in the simulation were sufficient to present the simulation.

1.5. Thesis Structure

Based on the structure of this research, **Chapter 2** contains the literature review. This section investigates key definitions, related concepts, relevant studies and theories. **Chapter 3** discusses the research methodology used in this research. This chapter will discuss the motive behind the choice of research methods. **Chapter 4** discusses the 3D simulation tool of choice, including its relevance and hardware requirements. It also details the main results of the research which are analyzed in detail. **Chapter 5** is the conclusive chapter and one that draws useful conclusions about the study area's possibility for future studies.

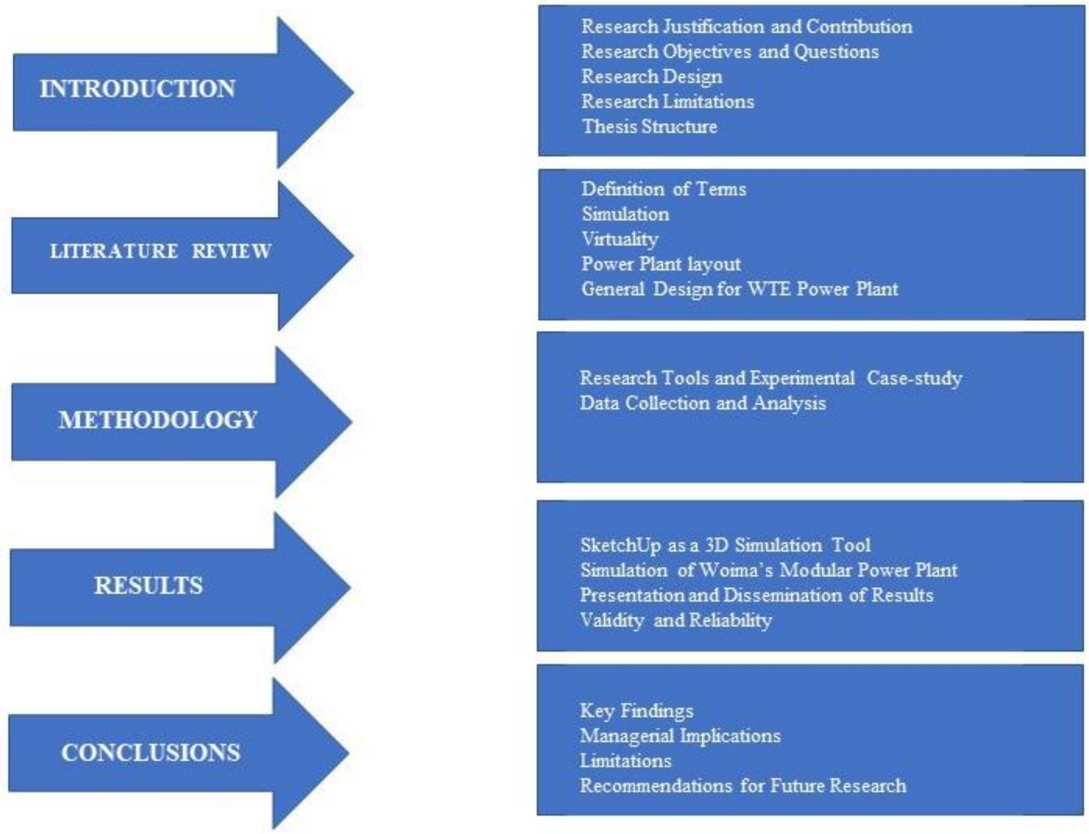

Figure 2. Thesis Structure.

2. LITERATURE REVIEW

This chapter discusses the theoretical background of this research. Important keywords related to the research are presented followed by literature review on 3D simulation with virtual reality and modular WTE power plant layout. The final section of this chapter presents the modular WTE manufacturing processes relative to some similar previous academic research done on the subject.

2.1.Definition of Terms

This section explains basic terminologies associated with simulation and virtual reality.

2.1.1. Waste to Energy

Waste to Energy is a term used to describe the recovery of energy, primarily in the form of electricity or heat from waste. In times past, incineration of waste was used as a means to reduce the quantity of waste and prevent threats to humans through the destruction of harmful substances that poses threats to human health. In more recent times however, incineration is increasingly done with the goal of energy recovery. Therefore, the importance of energy recovery from waste has increased significantly over time (Bosman et al. 2012: 11.) Table 1 below shows the different types of waste and the various fuels that are derived from them.

Table 1. Different Types of Waste and Waste Derived Fuels (Bosman et al. 2012: 11).

Fuel type	Definition
Fuel	Energy carrier intended for energy conversion
Municipal Solid Waste (MSW)	Waste generated by households (may also include similar wastes generated by small businesses and public institutions), e.g. paper, cardboard, metals, textiles, organics (food and garden waste), and wood
Commercial & Industrial Waste (C&IW)	Waste derived from commerce and industry, e.g. packaging, paper, metals, tyres, textiles, and biomass
Refuse Derived Fuel (RDF)	Fuel produced from MSW and/or C&IW that has undergone processing (i.e. separation of recyclables and noncombustible materials, shredding, size reduction, and/or pelletizing), has an input-driven specification
Solid Recovered Fuel (SRF)	Comparable to RDF but considered more homogeneous and less contaminated, is market-driven due to tighter quality specifications
Automotive Shredder Residue (ASR)	Complex mixture of plastics (rigid and foam), rubber, glass, wood, paper, leather, textile, sand plus other dirt, and a significant fraction of metals

Waste to energy power plants are designed to burn municipal solid waste that is not recyclable including other acceptable commercial or industrial waste while at the same time recover energy and purify the gases that are generated during the burning process. There are cycles or stages involved in the energy recovery process. Figure 2 below shows the various stages in the hierarchy of energy recovery processes using WTE. The energy recovered from the process could then be used for household and industrial heating or for electricity generation. Additionally, about half of the energy generated is renewable since it is derived from a process that involves the so-called “carbon-neutral biogenic fraction of waste” (ESWET 2012: 6 & 7.)

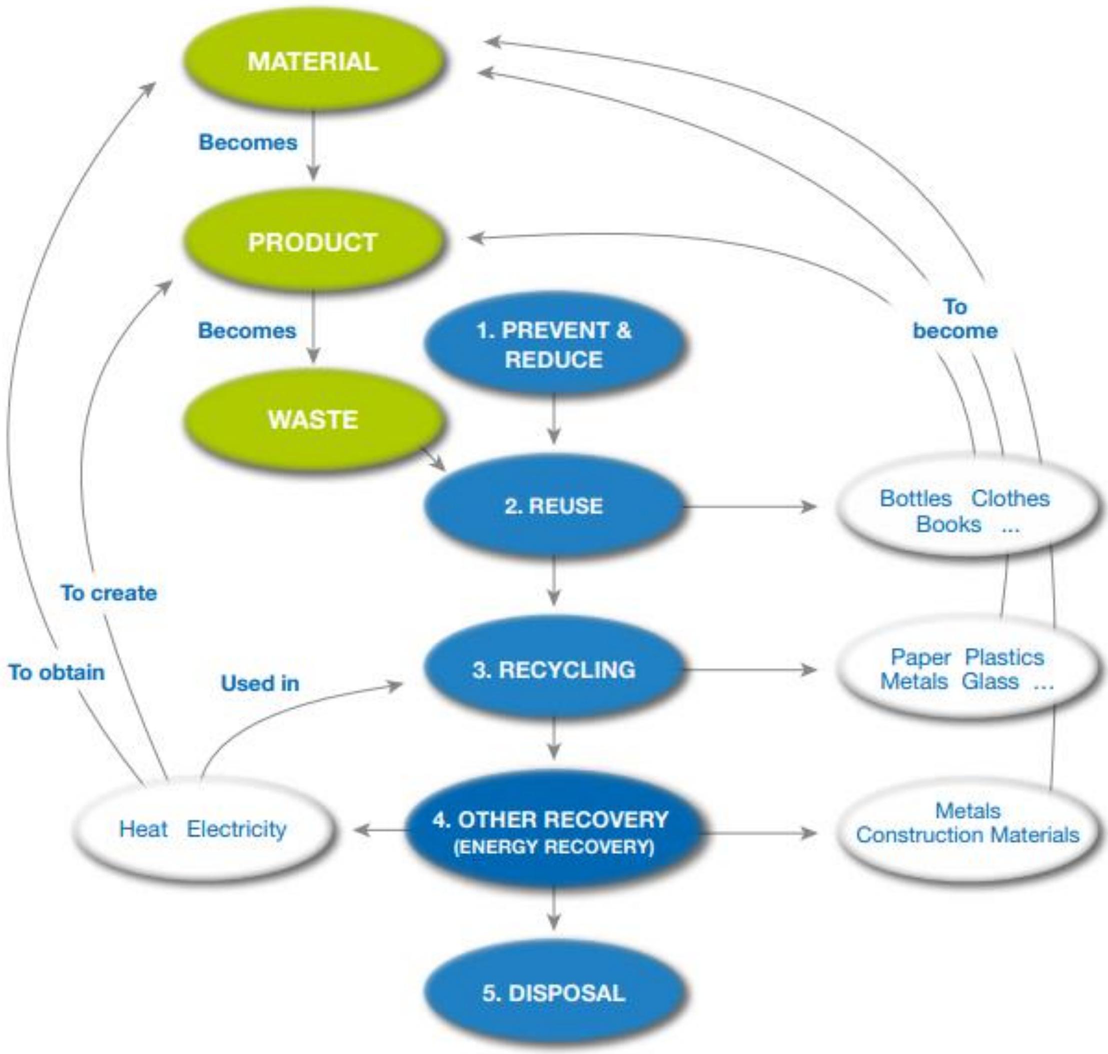

Figure 3. The Waste Hierarchy, from the Waste Framework Directive 2008 (ESWET 2012: 4).

2.1.2. Modularity

Modular design is a concept that deals with product architecture and how products can be designed in a more compact and sustainable way (Sonego, Echeveste & Debarba 2017: 197). According to Mutingi, Dube & Mbohwa (2017: 478-479), modular design approach separates a system into relatively smaller modules which are built independently to enable the assembly of different systems from the modules. As a result, development of modular products increases variety of products and enhances competition in the international market. Additionally, modularity makes it easier to upgrade, adapt, modify, assemble and disassemble products (Sonego, Echeveste & Debarba 2017: 197).

Modular power units

There exists some modular power solutions mainly modular diesel generator units and the increasingly popular modular nuclear power units. Some of the main components used in modular diesel generators are container sized and share similarities with the flat rack containers used by WasteWOIMA. Therefore, modular diesel generators are discussed below to give a better perspective of modular power units using an already established example.

A typical example of a major global manufacturer and supplier of modular diesel generators is Caterpillar Intercontinental. They provide solutions for industrial and mining industries through the manufacture and supply of diesel and natural gas engines, diesel-electric locomotives and industrial scale gas turbines (Caterpillar 2019). In Figure 4 below, we find an example of Caterpillar's industrial energy solution using standard shipping containers and sharing similarities to the flat rack containers used by WasteWOIMA.

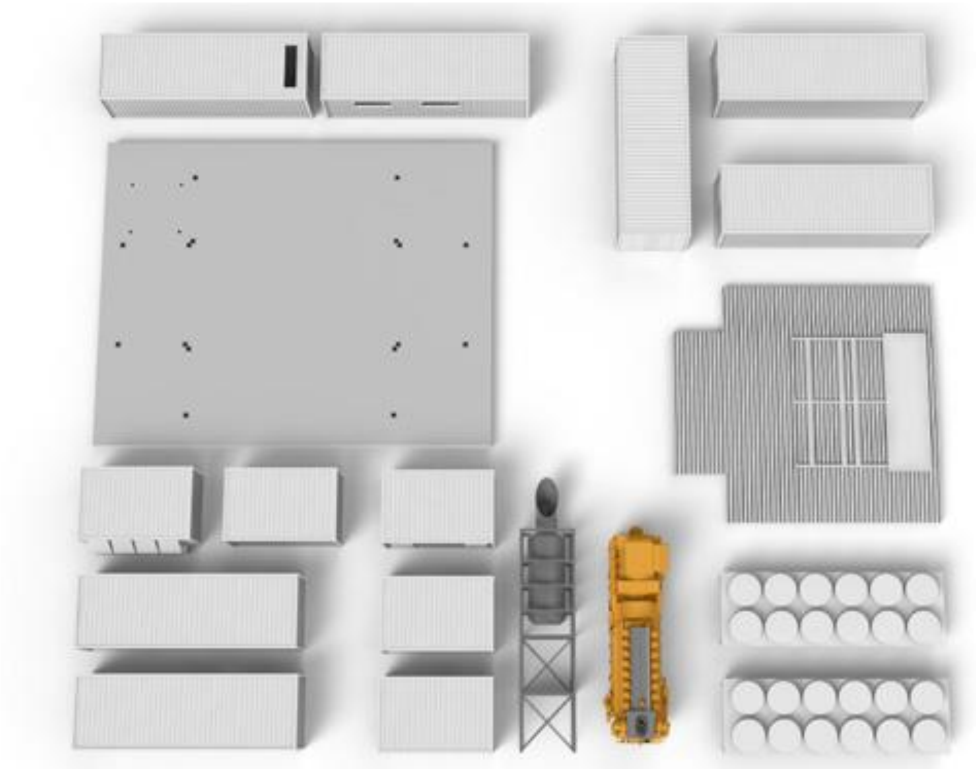

Figure 4. New: Cat Modular Power Plant. Just 12 Days. Caterpillar 2014: 3.

According to the company, they are able to install a complete industrial sized power unit in only 12 days. The primary reason is that these diesel generator units come in modular container sized units which are easier and faster to transport. Additionally, the modular approach makes it faster to assemble. The Figure 5 below shows a mobile crane as it assembles some container sized diesel generators on the left frame while the right frame shows a close-up view of how some of the containers and stacked together using nuts and bolts to form a lock and key system.

Figure 5. New: Cat Modular Power Plant. Just 12 Days (Caterpillar 2014: 2)

2.1.3. Crane Requirements

In major construction projects, cranes are often the single biggest equipment in terms of both size and investment on the construction site and make up the main source of occupational hazards. According to statistics from the Singaporean workplace safety and health institute, incidents related to crane accounted for about twenty percent of all fatalities in the construction sector between the years 2011 and 2014 (Yeoh, Wong & Peng 2016:1.)

The use of mobile cranes is not too different either as they also occupy a relatively significant workspace. Not taking into account the workspace of a crane prior to its use increases the potential for conflict between the crane and other components in proximity of the construction project. Such spatial conflicts could result in work interruptions, hazardous working environment, reduction in productivity and damage to available structures (Tantisevi & Burcu 2007:262.)

The above-mentioned factors suggest the need to develop workspace models before the construction projects commence because to assess the available space and special conflicts on a construction site, one needs to make a 3D representation of not only the workspace but also the other components in it at a given time. However, a major challenge with 3D modelling or simulation of crane requirements in the workspace is that although the crane is mostly located in a fixed location, some parts such as the booms and hooks typically move during operation. Therefore, to identify crane related requirements and potential conflicts, one needs to account for the unique characteristics of cranes, their moving parts and the ever-changing workspace requirements over a period of time (Tantisevi & Burcu 2007:262.)

In this research, the use of mobile cranes is preferred for the 3D simulation because of the relative flexibility and availability in developing economies compared to fixed cranes. Below is a Figure showing an example of the mobile crane required on the construction side of a wasteWOIMA's modular WTE power plant. In the dual figure on one side shows the mobile crane in idle position while the other side shows the crane in a hoisted position.

Figure 6. LTM 11200-9.1 Mobile Crane (Liebherr 2019)

Technical Data

The technical data of the crane model is adapted into a table below.;

Table 2. Technical Data for LTM 11200-9.1 Mobile Crane (Liebherr 2019).

Technical Data	Minimum	Maximum
Load Capacity		1,200 Tonnes
Radius	2.50 Metres	136 Metres
Hoist Height		188 Metres
Telescopic Boom	18.30 Metres	100Metres
Lattice jib	6.50 Metres	126 Metres
Drive engine		8-Cylinder Engine
Drive engine/power		500kW
Number of Axles		9
Drive/Steering Standard		18 x 8 x18
Driving Speed		75 km/h
Total Ballast		202 Tonnes

2.1.4. 3D World, Components and Layout

In a typical 3D simulation environment, there exists a virtual environment called a 3D world. Using visual components software (a widely used 3D simulation and visualization tool) as example, this virtual space is where the creation, manipulation and interaction with objects in the form of 3D modeling and simulation occurs. The user's point of view in the 3D world is controlled using a camera embedded in the software. The user is able to navigate using a regular mouse or 3D mouse with a combination of buttons as commands (Visual Components 2018.)

Components are the objects which are manipulated in the 3D world. They can be exported in image format or other geometry file types. Additionally, components can be created either statically or dynamically in the 3D world using simulation (Visual Components 2018.)

The layout comprises of the various components in the 3D world, which is combined to create scenes, then saved using the software. Therefore, components are the building blocks of any layout. Furthermore, it is possible to export a layout in a 3D pdf format, image/video format or in the form of an animation viewable in a VR glass (Visual Components 2018.)

2.2.Simulation

Simulation is often used in research for complex systems and it is an accepted method of planning in manufacturing industries. Simulation derives its usefulness from the ability to imitate a system and its features over time to further improve an already existing or futuristic process. The ability of simulation to emulate real life environments help Engineers to better understand the system which is being studied then transfer the knowledge attained in the virtual simulation environment to the real-life system (Banks, Carson, Nelson & Nicol 2010.)

The simulation approach could be further divided into four categories as determined by the various level of abstraction of similar models. The four categories are Discrete Event (DE), Dynamic Systems (DS), Agent Based (AB) and System Dynamics (SD) (Borshchev & Filippov 2004.) The are briefly explained below.

Discrete Event (DE)

At this category, the natural state of the model is discrete and only passive entities with the ability to trigger variable changes are used by the simulation. DE is seen as relevant at the tactical level and has median degree of abstraction (Borshchev & Filippov 2004.)

Dynamic Systems (DS)

Simulation utilizes mathematical models of dynamic systems comprised of variables and algebraic equations. It is most suited for continuous physical systems. For example, the Finite Element Method (FEM) or Computational Fluid Dynamics (CFD) procedures. At an operational micro level, this category is regarded as relevant and has a low degree of abstraction (Borshchev & Filippov 2004.)

Agent Based (AB)

In this category, simulation may utilize behavior of active agents in a specific environment for the purpose of modeling. Behavior of individual agents is based on some predefined logic, but they can also interact dynamically with other agents such that there is no central control within the system thereby making the system behavior decentralized (Borshchev & Filippov 2004.)

System Dynamics (SD)

System dynamics is generally regarded as a high level of abstraction because here, the model’s description of a related system is based on a set of differential equations which symbolizes the interacting feedback loops and flows which affect stock variables (Borshchev & Filippov 2004).

Figure 7 below shows the simulation approach based to their levels of abstraction including either as discrete or continuous behavior.

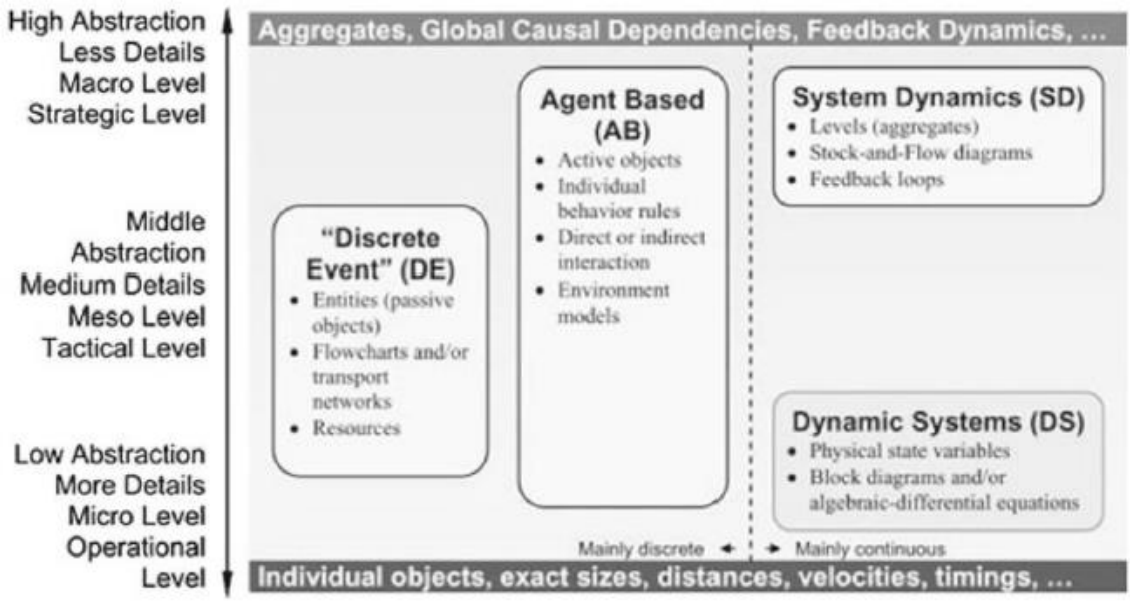

Figure 7. Simulation approaches on abstraction level scale (Borshchev & Filippov 2004).

In the simulation approaches mentioned above in section 2.2, the use of any category may vary depending on the approach. For example, in manufacturing procedures such as inventory scheduling and management, assembly line balancing, capacity planning and resource allocation, DE and AB simulation are favoured. While SD is preferred in industrial activities that involves supply chain management, organizational design, and project management to enhance strategic decision making (Jahangirian et al. 2010.)

In industrial research, several simulation approaches such as Monte Carlo are repeatedly executed, and they involve using models with random variables. As a result, 3D simulation tools and software such as SketchUp Pro 2017 which is the preferred software for this research are used. Other similar software includes AutoCAD and SolidWorks.

Hence, according to Naik & Kallurkar (2005: 44), simulation is a highly recommended technique for the analysis of facility planning.

Figure 8 below shows the importance of simulation and in what ways it helps an organization.

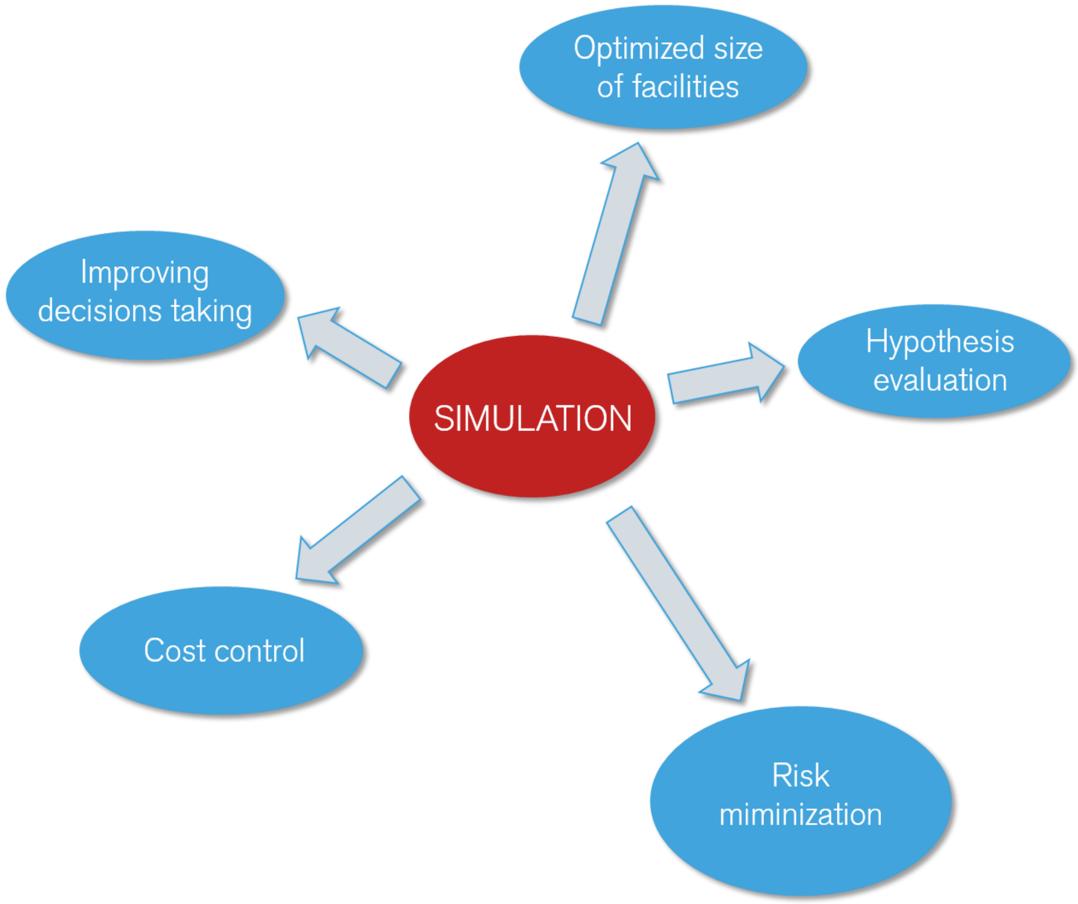

Figure 8. Advantages of Simulation (4D Labs 2017).

The Figure above shows the value of simulation and in what ways it can be utilized in any given organization. With modular WTE power plants issues associated with cost control, minimization of risk, facility size optimization and improved decision are of particularly high importance (4D Labs 2017.)

Brief History of 3D Simulation

During the first thirty years of simulation, output was mainly in the form of textual reports, but it was in the 1980's that animation was integrated into commercial simulation. Initial debates focused on the merits of animation and whether it was merely a tool for thrill-seekers alone with little to no impact on the success of simulation related projects. However, in more recent years animation is seen as a critical success factor of simulation projects. One of the earlier animated simulation software was called "See Why", it was developed in the late 1980's and it used "rudimentary character-based animation". The creators of See Why later developed another system called the Witness simulation software. In the same period, the a 2D vector-based animation system called Cinema was developed and it worked as a real-time animation system. Subsequently, Jimes Henriksen who worked at Wolverine software developed a 2D animation system called Proof in 1989 (Roberts and Pegden 2017: 320.)

3D animation capabilities began to surface in the 1990's with some systems such as AutoMod software which was focused on material handling. There was also Taylor Ed which preceded FlexSim and Simple++ which preceded PlantSim. The argument about animation also extends to the need for higher quality 3D simulation as against 2D animation because experts argue that 2D animation is sufficient to derive the benefits of simulation and using 3D animation does not necessarily bring any better results. However, it is also obvious that the extra details from 3D animations helps to better transmit information from the models (Roberts and Pegden 2017: 320.)

When the object-oriented framework which is an immersive 3D modelling structure and modern 3D sketching features are combined, it proves to be a powerful recipe to bring 3D animation into mainstream 3D simulation. As a result, most simulation platforms now utilize 3D as a standard parameter. The next generation of animation in simulation has seen the use of VR platforms to display simulation animations, allowing users to have an immersive experience in the VR environment that imitates the real-life objects and provides the possibility to interact with objects in the VR environment (Roberts and Pegden 2017: 320-321.)

2.3.Virtual Reality

The term 3D Visualization is increasingly associated with virtual reality because 3D visualization helps to provide a more detailed presentation of the simulation layout. The level of detail required at industrial settings is so high that 2D simulation is not anymore adequate to meet demands (Masik, et al. 2016: 50). Hence, the need for 3D visualization. A typical 3D visualization that is increasingly used across industries and for entertainment purposes is Virtual Reality glass. As it pertains to this research, VR is used to preview simulation models in the VR environment.

Virtual reality has a somewhat natural definition considering the definition of the two words "virtual" and "Reality". In simple terms VR means "near-reality". However, a more technical and detailed definition describes VR as a "three-dimensional, computer generated environment" which presents an interactive interface with persons and can be explored (Virtual Reality Society 2018.)

Virtual Reality is also described as a tool that enables the "representation and simultaneous perception of interactive virtual environments". The simulated environment is created in real time by computers and allow for the display of physical properties. VR is used in various industries including, "flight simulation", urban design and architectural planning. When 3D visualization is functional and interactive enough, it speeds up the industrial planning process significantly (Masik, et al. 2016: 50-51.) VR is therefore, relevant to this research because after the 3D simulation of the installation procedure is made, VR is used to view the process at a detailed level.

Application of Virtual Reality

Virtual reality systems are used in many fields including gaming, architectural design, flight simulation, urban planning and manufacturing. A Head Mounted Display (HMD) alongside hand-held controllers which are used for navigation and base stations which produce a virtual environment of simulation models. Examples of VR systems are HTC

Vive, Samsung Gear VR, Oculus Go, Oculus Rift and Sony Play Station VR (PCmag 2019). Figure 8 shows HTC Vive virtual reality system.

Figure 9. VR system - HTC Vive showing headset, controllers and base stations (HTC Vive Europe 2019).

Virtual Reality in Production

Production systems have developed over the years as production systems, manufacturing planning and operations have been discovered and adapted to achieve a more reliable, error free and faster production system. The most significant discovery has occurred in the field of information technology which in turn led to the emergence different manufacturing technologies globally. Computer integrated manufacturing and simulation using CAD modelling software, VR and finite element analysis has proven relevant to achieving a faster and more efficient manufacturing decisions (Nee & Ong 2013.)

VR has been used previously in the manufacturing industry for product design planning, in VR based manufacturing robots and factory layout planning. With product design, Nee et al. are of the opinion that VR helps product designers and process engineers for intuitive interaction in terms of visualization of both the upstream and downstream interaction of machines. Furthermore, with 3D simulation designers, VR provides an intuitive interaction with the 3D simulation because the real dimensions can be experience and that experience provides clearer engineering data. The areas which require adjustment may be noted during the VR viewing session and can be simultaneously improved using the CAD software during the design phase which helps to reduce overall design time (Neugebauer, Weidlich, Zickner & Polzin 2007.) The use of VR creates the possibility to achieve a properly designed and optimized plant layout and help organizations save up to 50% in operating cost of a production environment (Xie & Sahinidis 2008).

2.4.Power Plant Layout

Visualization of the power plant layout using the VR environment provides the possibility to realize a detailed view of the final power plant layout before any actual construction or investment begins. Slight alterations to the location of equipment and machinery can significantly alter the easy movement of material and output. Additionally, it could affect other outcomes such as cost and the efficiency of the whole production process. The efficiency of production in any given plant depends on how the machines, flowpaths, personnel amenities, and storage units are well located within the facility (Okpala & Chukwumuanaya 2016: 201.) Power plants often need changes in their layout to increase efficiency and output due to bottlenecks that occur over time. Other reasons include the need to adapt to internal and external changes such as a change in technology, process and production volume. Therefore, layout design is a continuously repetitive process based on the “changing constraint of dynamic environment”. Evolving industries require continuous optimization of the layout (Naik & Kallurkar 2005: 43-44.) Concerning this research, the continuous requirement for layout design changes is a justification for the use of modular power plants with emphasis on waste to energy as a source of power generation.

Certain factors often determine power plant layout and with modular WTE power plants these parameters are more easily applied in the plant. The factors range from technical issues to cost and personnel safety (Okpala & Chukwumuanaya 2016: 201.) They include;

a. Flexibility – A well designed power plants is easily modified to meet the ever-evolving demands of customers and the industry.
b. Throughput – The design of the power plant should be such that it is able to attain production output in the fastest possible time to ensure customer satisfaction and loyalty.
c. Efficient Space Utilization – This involves the proper management and allocation of space within the plant unit to ensure that spaces are enough for daily operations.
d. Communication Flow – Power plants need to be designed such that there is ease of flow in communication between department and between the plant and customers.
e. Safety – This is one factor that can never be compromised. Therefore, the plant's design should help to limit accidents to the barest minimum without compromising on efficiency.
f. Accessibility of Components – Units that require repairs and maintenance should be readily accessible. This implies that machinery and equipment should be located in spacious sections for ease of servicing and maintenance.

2.5.General Designs for WTE Power Plants

While there are various designs for different WTE power plant projects, they would typically contain most or all the following processes and chambers (Branchini 2012:21);

- waste reception;
- waste and raw materials storage;
- pre-treatment of waste (if required, on-site or off-site);
- waste loading into the process;
- treatment of the waste using thermal energy;
- energy recovery for example with boiler and conversion;
- cleaning flue-gas;

- flue-gas cleaning/residue management (from the flue-gas treatment);
- discharge of flue-gas;
- emissions monitoring and control;
- wastewater control and treatment (e.g. from site drainage, flue-gas treatment, storage);
- ash/bottom ash management and treatment (accumulated from the combustion stage);
- solid residue discharge or disposal.

Table 3 below shows the schematics of the main components in a traditional WTE power plant and their purposes.

Table 3. Purpose of the main components of a waste incineration plant (Branchini 2012:21).

OBJECTIVE	RESPONSIBILITY OF
– Destruction of organic substances – Evaporation of water – Evaporation of volatile heavy metals and inorganic salts – Production of potentially exploitable slag – Volume reduction of residues	Furnace
– Recovery of useful energy	Energy recovery system
– Removal and concentration of volatile heavy metals and inorganic matter into solid residues – Minimizing emission to all media	Flue gas cleaning

The table above shows us the objectives of the different chambers in the WTE power plant. The table provides a miniature yet detailed summary of how the three main chambers including the furnace, energy recovery system and flue gas cleaning work and what exactly happens in each compartment.

Comparison Between Traditional and Modular WTE Plants

Although waste to energy technology dates to the end of the 19^{th} century, the technology was mainly popularized in the 20^{th} century (Bergmeier 2003: 1359). Therefore, in a city like Vaasa in Western Finland which is often considered as the energy cluster of the Nordics, there exist a fully operational waste to energy power plant called Westenergy. Officially known as Westenergy Oy Ab, the company owns and operates a modern WTE power plant in Mustasaari, a municipality near to the city of Vaasa. Westenergy is a non-profit which was founded by energy companies from five municipalities for the purpose of efficient energy management.

Therefore, Westenergy's WTE power plant makes for a good comparison with Waste-WOIMA's modular WTE Power plant considering that both companies are part of the energy cluster in Western region of Finland and they both provide waste to energy solutions. In Figure 10 and 11 below, there is a cross-sectional representation of both a modern though fixed WTE power plant and a modular WTE power plant respectively. Comparison between these two types of design are also discussed including their main components which are labelled.

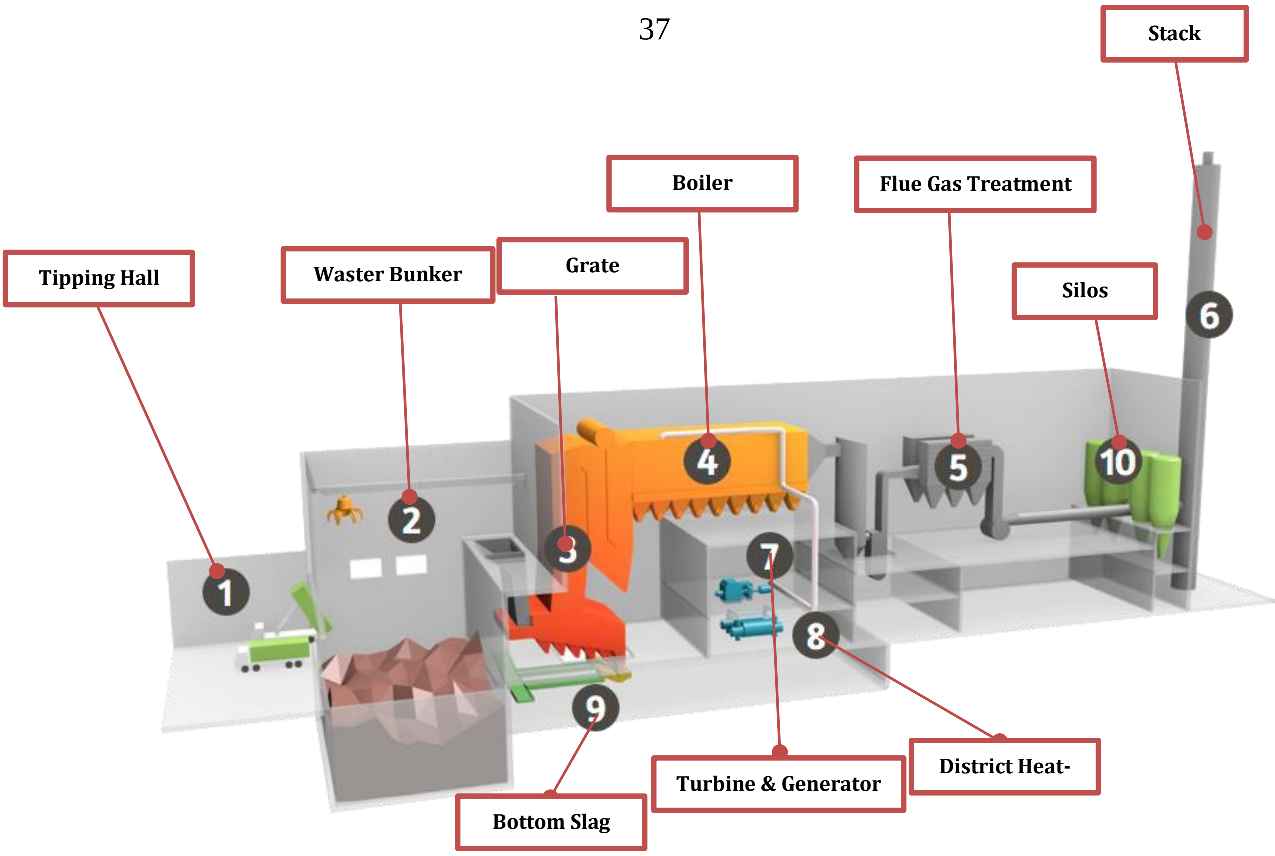

Figure 10. Cross-Section of Westenergy's WTE Power Plant in Vaasa (Westenergy 2019b)

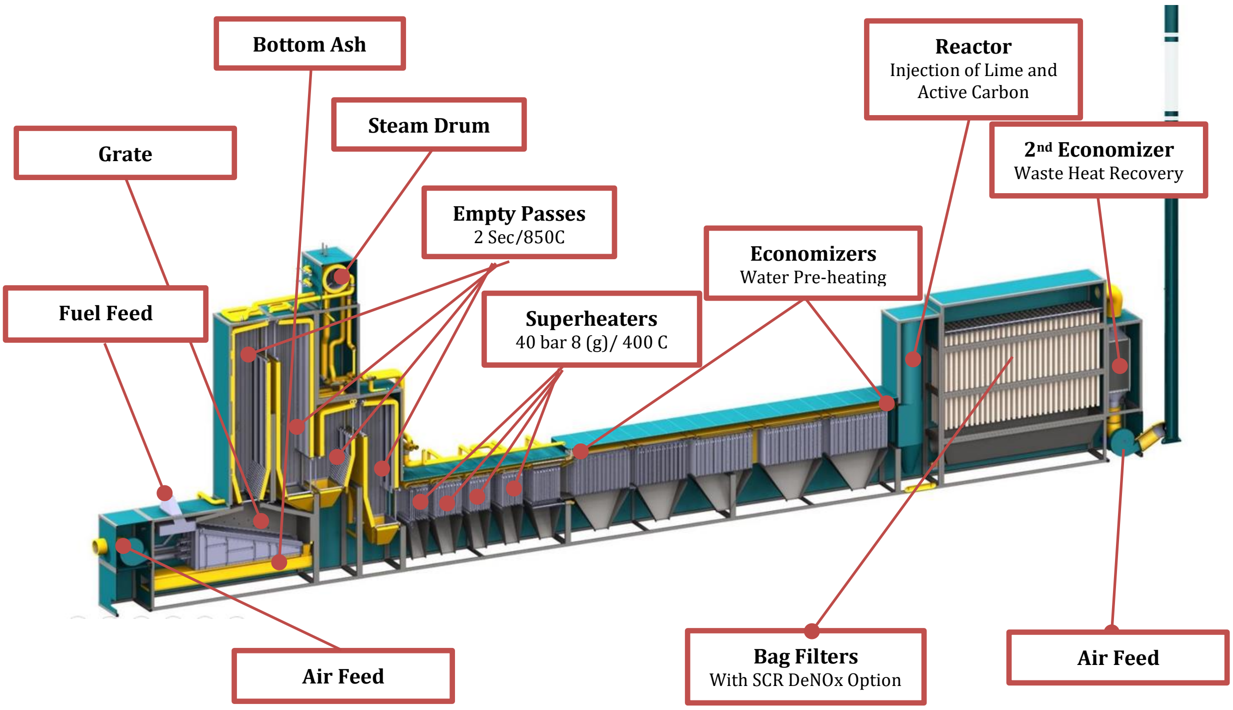

Figure 11. Cross-Section of Westenergy's WTE Power Plant in Vaasa (wasteWoima Presentation 2018)

From the Figures above we can conclude that the two WTE power plants share core similarities in their mode of operation and the different stages of waste conversion to energy. However, the key difference is in the design of wasteWOIMA's modular approach.

2.5.1. Waste Storage and Delivery

In the waste delivery area, the trains, containers or delivery trucks arrive to dump the waste into the bunker often after visual control and weighing of the waste. It is important to use an enclosed delivery system to avoid industrial hazards such as noise, emission and foul odour that comes from the waste. Figure 12 below shows a regular municipal solid waste bunker device where the bunker is often waterproof, and the bed is made of concrete. The waste is gathered and mixed with the help of cranes which have grapples and the waste mixing helps to attain a balance in factors such as the heat value, size, composition and structure of the waste in the incinerator (Branchini 2012:23.)

Figure 12. A picture of a typical municipal solid waste bunker device (Branchini 2012:23.)

Typically, the main incineration air for the furnace is extracted through the bunker compartment to avoid excess gas formation – for example methane gas, or dust accumulation. Additionally, the bunker could have a storage capacity of between three to five days and the depth could reach tens of metres. However, dimensions are dependent on the nature of the power plant and other local factors (Branchini 2012:23.)

There is another stage called “Feeding” and this refer to adding the appropriate quantity of fuel to the grate for continuous combustion and generation of energy. Steady feeding is also friendly on the environment because it ensures that the combustion process is controlled and consistent (Branchini 2012:23.)

2.5.2. Combustion Process

Waste incineration is basically the oxidization of combustible items from waste. Generally, waste could be highly heterogenous and often consists of organic and inorganic substances such as metals, water and minerals. The incineration process produces flue-gases which contain most of the available fuel energy in the form of heat. Organic fuel substances will burn once they reach the required ignition temperature and come in contact with oxygen. The combustion process happens in the gas phase, occurs in milliseconds and at the same time releases energy where the provided calorific value of oxygen and waste is enough. At this stage, the process may lead to a thermal chain reaction where the combustion process is self-supporting and there will be no need to add fuel (Branchini 2012:23.)

Below are some of the stages involved in the incineration process:

a. Drying and Degassing – In this stage, the volatile contents are vapourized typically at temperatures of between 100°C and 300°C, the processes of drying and degassing only require that heat be supplied and do not generally need an oxidizing agent.
b. Pyrolysis and Gasification – Pyrolysis involves the extended decomposition of organic materials using an oxidizing agent at roughly between 250°C and 700°C temperature while gasification involves reaction of carbonaceous residues with water vapour and Carbon Dioxide at temperatures of usually between 500°C to 100°C. Therefore, solid organic substances are transferred to gaseous state.
c. Oxidation – Here, the combustible gases generated from the earlier stage are oxidized but it does depend on the selected incineration procedure. This stage occurs at flue-gas temperatures typically between 800°C to 1450°C (Branchini 2012:24-25.)

Figure 13 below is a schematic representation of five main stages on the grate of a combustion chamber for burning waste in the WTE power plant.

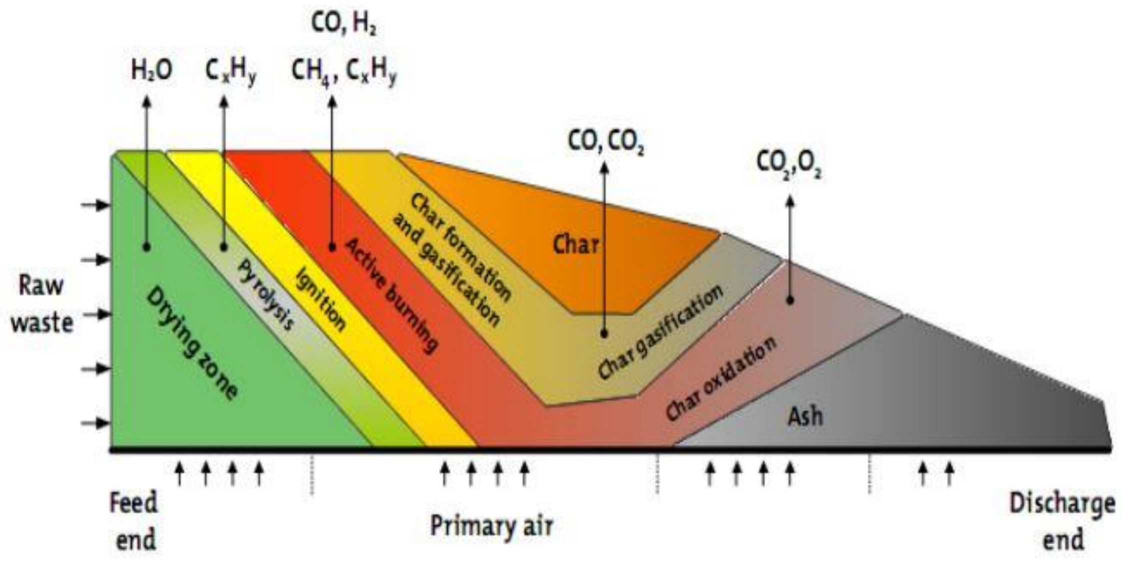

Figure 13. Schematic of process on the grate of a combustion chamber burning waste (Branchini 2012:23.)

The entire power plant design, schematics and processes are displayed in Figure 14 below. Additionally, this image contains a legend of what each section or component does in the energy production process using waste to energy.

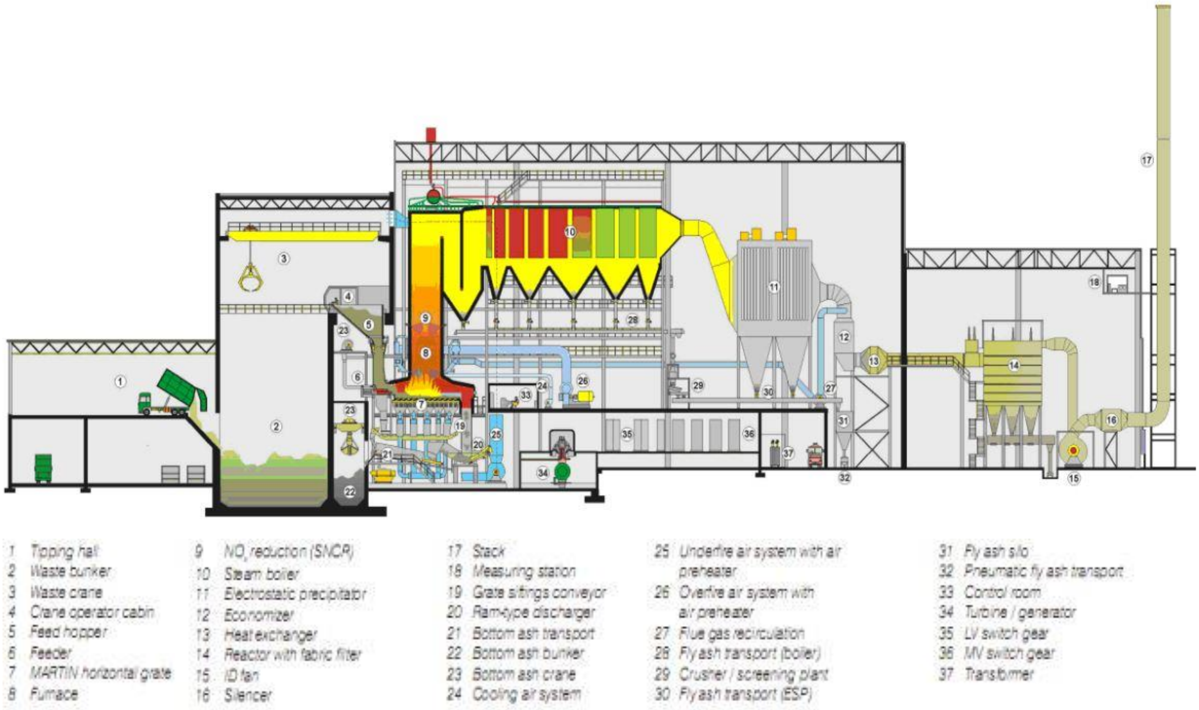

Figure 14.Typical new generation WTE power plant (Branchini 2012:22.)

From Figure 13 we can observe that there are many components and stages between the waste bunker transformer at the end stage for this WTE power plant. Altogether, there are thirty-seven stages involved and each one is labelled in numbers on the image while each number is described in the legend at the bottom of the image.

2.5.3. CEMS – Continuous Emission Monitoring System

The Continuous Emission Monitoring System (hereinafter, CEMS) provides accurate and continuous data on the flue gas composition including reports which ensures that the emission regulation standards are met. The system is regularly calibrated to ensure the accuracy of data. Additionally, the CEMS data is used for the control of the so called “flue gas treatment additive dosing rate” (wasteWOIMA 2018: 8.)

CEMS is made up of the following components; Extractive Analyzer, Sampling Probe, Dust Monitor and Flow Monitor (wasteWOIMA 2018b: 8). These components are shown in the Figure below which represents a CEMS.

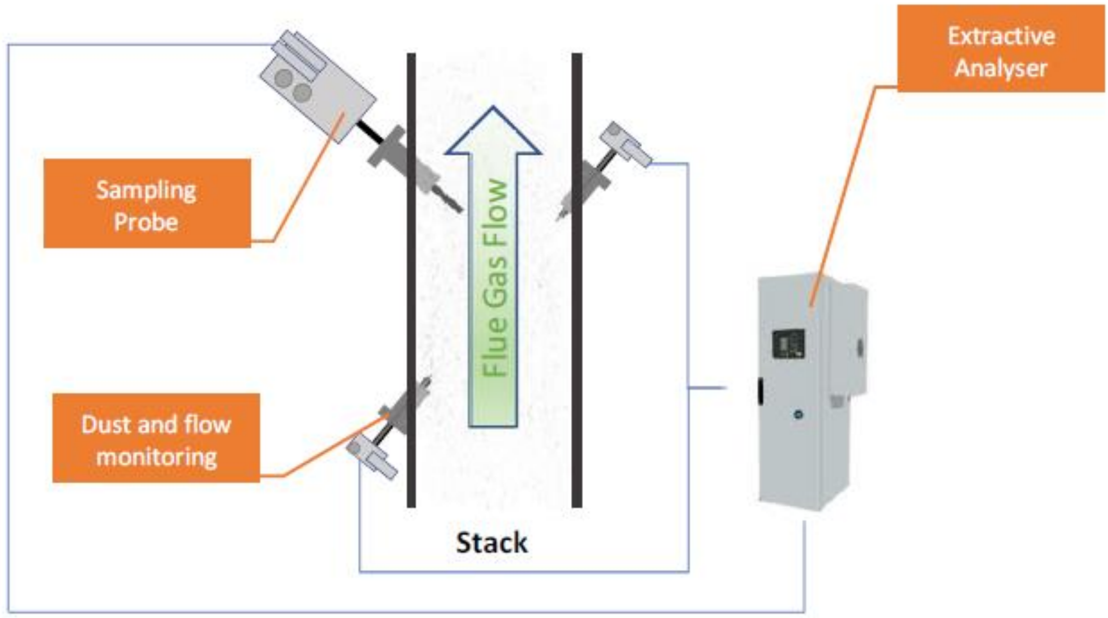

Figure 15. A Typical CEMS (wasteWOIMA 2018)

As a European based company, wasteWOIMA's power plant and its flue gas treatment has been developed to exceed the requirements of both the world bank and European Union (hereinafter, EU) emission limit. Below is a Table showing both the EU and World Bank's directives on industry specific emission standards.

Table 4. Current EU and World Bank Emission limits (wasteWOIMA 2018).

		World bank			EU	
	Raw Gas	Basic*	Medium*	Advanced*	Daily**	Units
Total dust	2000	30	30	10	10	mg/m3
Total organic carbon (TOC)		-	-	10	10	mg/m3
Hydrogen chloride (HCl)	600	-	50	10	10	mg/m3
Hydrogen fluoride (HF)	5	-	2	1	1	mg/m3
Sulphur dioxide (SO2)	250	-	300	50	50	mg/m3
Nitrous oxide (NOx)	350	-	-	200	200	mg/m3
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	60	-	-	0.5	0.5	mg/m3
Hg + Cd	1.8	-	0.2	-		mg/m3
Ni + As	1.3	-	1	-		mg/m3
Pb + Cr + Cu + Mn	50	-	5	-		mg/m3
Hg	0.3	-	-	0.05	0.05	mg/m3
CD and Tl	1.6	-	-	0.05	0.05	mg/m3
Dioxins and Furans	3	-		0.1	0.1	ng/m3

2.5.4. Energy Recovery

Using West Energy’s power plant as an example, the energy recovery process is described below in two main stages.

Boiler

Typically, heat exchange from the flue gases to the boiler water occur primarily in the boiler. At the initial stage, water is preheated, and the walls of the boiler consist of pipes coated with Inconel. The water inside the pipes is heated till it turns to steam then it is further super-heated to about 400 degrees Celsius and 40 bars pressure in the super-heater compartment of the horizontal pass then the hot and high-pressure steam finally flows to the turbine (West Energy 2019.)

Turbine and Generator

At this stage, steam is passed to the turbine at 40 bars of pressure, and roughly 70 tons of steam is injected to the turbine every hour. The turbine rotates at a speed of 9000 rpm, then kinetic energy is transferred to the generator through the gear box. The speed of rotation in the generator is 1500 rpm and maximum output of the 10,5 kV and 50 Hz generator is 15 MW while the turbine and generator set of the plant is based on a turbo diesel engine (West Energy 2019.) Typically, the diesel generators are needed to initial-ize the energy conversion process.

3. METHODOLOGY

Research methodology is the structure and guideline for the whole research process. In this chapter, the research tools, method of data collection, how the data is analyzed, and its validity are discussed.

3.1.Data Collection and Analysis

For many researchers, the source of data is often either primary or secondary (Saunders et al. 2016: 316). For the 3D simulation part of the research, primary data were given from the case company. In the literature review, secondary data was mainly used, and the researcher ensured that the means of data collection, review, analysis and interpretations aligned with answering the research question and meeting the research objectives (Burns & Bush 2008: 32.) Scientific journals and articles were the main source of secondary data used for this research, while books were also sourced from the Tritonia library at the University of Vaasa campus. Additionally, previous research work in similar field was considered and studied.

Primary data – CAD models used for the plant visualization was prepared by professional CAD designers for Woima corporation and was provided to the researcher for the purpose of this study. Additional technical specifications for the process of building the power plant was provided by the company's Chief Technical Officer. Discussions with the management team delivered further information on the sequence of construction.

After receiving the CAD models, the researcher converted it from stp file format to skp (SketchUp) format using Fusion 360 free version for students, an Autodesk CAD software. The model properties, including colour and texture were preserved during the conversion.

Secondary data – CAD models of additional equipment like the mobile crane was derived by online search from a digital repository. Prices and cost estimations were received through online searches. The mobile crane's CAD model was sourced from Grabcad, a digital repository of CAD models and components. The crane was painted yellow using the paint tool, and the components were sorted into groups before the simulation process started.

Timeline

This research utilized cross-sectional time horizon because it focuses on the construction of a modular WTE power plant at a given time. The timeline of the simulation is not real time but based on assumptions of a timeline suitable for presentation. The construction time in real life will vary significantly. Therefore, the timeline used in the simulation should not be interpreted literally.

In this study, inductive research approach is considered appropriate because from the collected data, which is specific for Woima corporation, a more general conclusions for the modular power plant installation processes was drawn. Additionally, it helped to determine the research design and categorization of the research results.

Key Assumptions

The following assumptions were used to describe the event scheduling and process interaction between components as they are installed in the power plant. The process involves modeling of time and sequence simultaneously. While the company is yet to have a complete power plant, they have plans to complete one in the near future in a developing country where their product is best suited

The visualization uses components that have generic abstraction level and scale and do not represent the final manufacturing blueprints. The next paragraph shows the process sequence between components with a constant simulation time interval of one and four seconds for scene delay and scene transition respectively.

The first item to appear is the mobile crane, followed by the foundation, the stack, FGT Reactor, Bottom Ash Container, Convection, Grate, Steam Drum, DeNOx Control System, Water Treatment, Howden Twin 10mw, MCC Centre, Staff Facilities, DG_LO Container and the Steam Centre.

Lead Time Analysis

Lead time Analysis was made on the components in order to determine their estimated times of arrival. When the time of arrival is determined, the order of construction is easier to plan. The installation of components with shorter lead times commenced before the arrival of those with longer lead times. Therefore, the ones with longer lead times were planned to arrive from the manufacturer when the construction already started but before it ended. Lead time analysis is typically done along with cost analysis.

Cost Analysis

Cost Analysis of components was made to determine individual and total cost of buying the component or in the case of the mobile crane, component rental. Other associated costs were also considered along with components cost in order to understand the most cost-effective approach during construction.

System Dynamics (SD) – Due to the high-level abstraction of System dynamics, it is applied to the general timeline of the entire simulation because SD is focused on identifying components, their present state and the rate at which they transform. The processes during the construction of the power plant are dynamic. Therefore, rate of transformation was particularly relevant during the simulation owing to the lead time of certain components such as steam turbine and crane.

3.2. Research Tools and Experimental Case-study

In this research, SketchUp Pro software was used to animate the models and present them as a simulation while HTC Vive VR glass was used for VR preview. The research strategies used in this research are experimental and case study because a pilot power plant of this type is not yet built. The researcher's focus was mainly with wasteWOI-MA's modular WTE power plant and not generally all WTE power plants. Therefore, an experimental case study is inferred and the preferred methodology for this research is the qualitative means of data analysis.

Case study strategy is a useful tool for the preliminary and exploratory stages of a research or as the basis for establishing tools that are more structured for uses in experiments (Rowley 2002: 16). The experimental aspect focuses on the adjustment of different variables with the installation procedure to attain a higher level of construction optimization (Woima Corporation 2018).

4. RESULTS

This chapter presents the results of this research and is sectioned into two main parts. In the first section, SketchUp Pro 2017 software is presented, explained justified while in the second section, the entire simulation process of WasteWOIMA’s Modular WTE Power Plant for Layout Optimization is shown followed by the VR sessions carried out during the research to help identify areas for possible improvement. Presentation of research results using VR headset and video production for WasteWOIMA’s Modular WTE Power Plant is the final section presented in this section.

The research tools, data collection method and mode of data analysis used in this chapter were done with consideration to the nature of the research and the technologies which were applied. These analyses were done using 3D visualization which include both 3D simulation and VR model inspection. Aside SketchUp Pro 2017 software, other tools used include, HTC Vive and Symmetry Alpha.

The model used for this simulation was made by professional CAD designers for Woima corporation. The researcher first converted the model from stp file format to skp (SketchUp) format using Fusion 360 free version for students, an Autodesk CAD software. The model properties, including colour and texture were preserved during the conversion. After the conversion, the researcher modified the model and added the mobile crane, which was sourced from Grabcad, a digital repository of CAD models and components. The crane was painted yellow using the paint tool, and the components were sorted into groups before the simulation process started. Simulation was done using a combination of section cuts and section plane tools which are available from the SketchUp menu.

4.1. SketchUp as a 3D Simulation Tool

In this section, the simulation tool used for this research is presented. SketchUp Pro 2017 is a 3D modelling and simulation tool used for the modelling and simulation of the

WTE power used in this research. The features of SketchUp are presented followed by a presentation of individual components used in the simulation.

SketchUp Pro 2017 CAD software was preferred for this research because of the relatively short learning curve, availability of needed tools and good memory management considering the total file size of the model was about 450mb. In addition, the researcher had a copy of the software on his personal computer thereby, reducing the need to source for a new tool.

4.1.1. SketchUp Pro Software

SketchUp was designed to be both a powerful 3D modelling and multi-purpose CAD software and one which is easy to use. It was originally created by a company called Last Software in the year 2000. It was designed to serve as a modelling tool for Architects, designers and movie makers. After some collaborative work with Google on adapting google earth plugin to the software, Google acquired the company in 2006. However, in 2012 the software was bought from Google by Trimble Inc. which subsequently released yearly versions starting with SketchUp 2013 and improved support for third-party developers by creating the extension warehouse which allows users of the software to share and download extensions and plugins (Mastersketchup 2011; Scan2cad 2018)

The software family nowadays comprises of three software packages and they include; SketchUp free, SketchUp Pro and SketchUp for schools (Sketchup 2019). The version of choice for the WTE power plant simulation in this research is SketchUp Pro 2017 and it was the latest version available to the researcher as of the time of publishing this research. It is an advanced modelling and simulation tool that has been built on a reliable platform and software architecture. The features of the software are wide ranging and include; layout simulation, modelling, exporting of images, video layouts and animation layouts with the possibility to inspect the model in VR glasses.

4.1.2. The Home Screen

Figures 16 and 17 below shows an overview of the user interface (hereinafter, home screen) of SketchUp software where one is the default home screen without a model and the other one with the model used for this research. The home screen has the typical set of menus, tabs and toolbars such as copy, paste, group, delete, measure, selection tool, move tool, pan tool, a property panel (right) showing specific properties of the components selected in 3D environment. There is also a possibility to add more tools to the home screen including those generated from plugins.

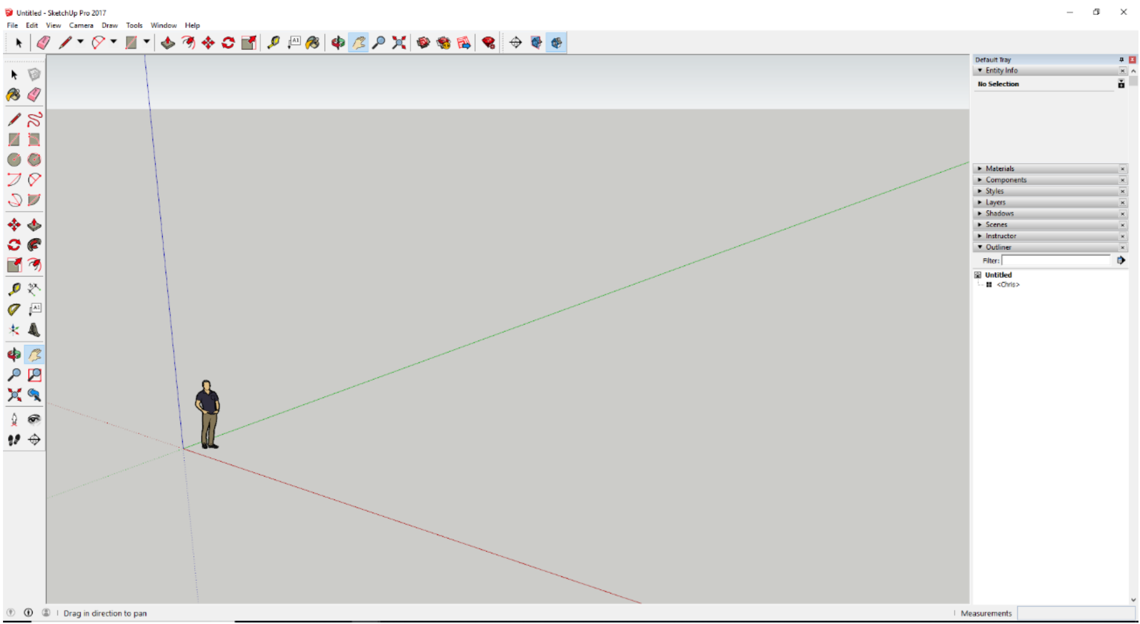

Figure 16. SketchUp Home Screen With Default Humanoid Model (SketchUp Pro 2017)

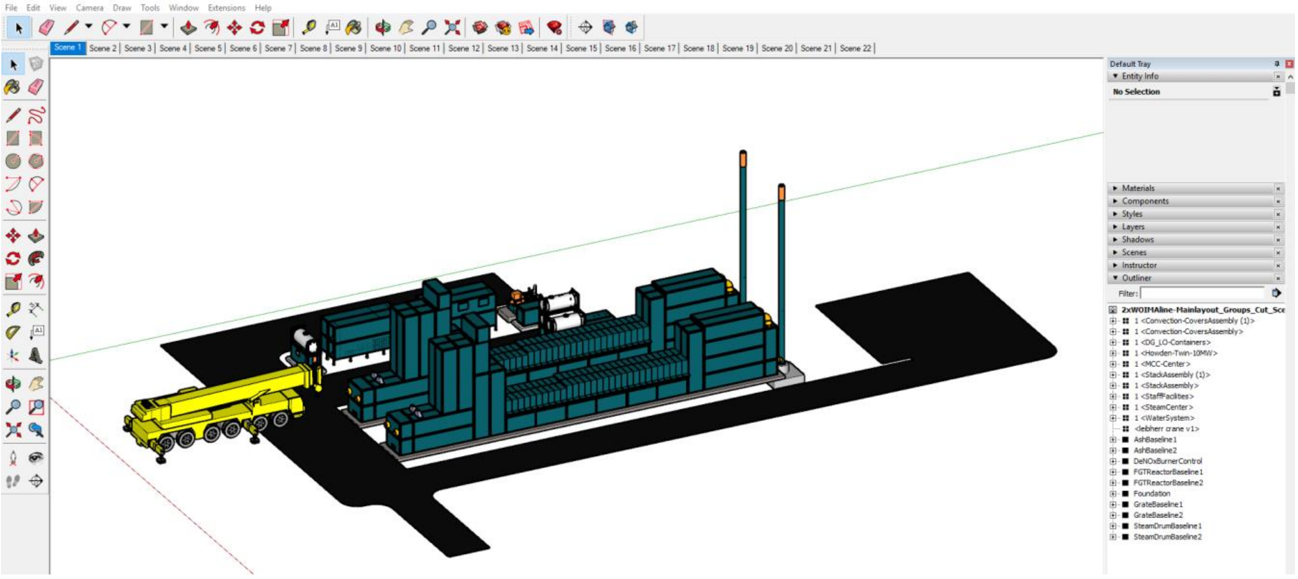

Figure 17. SketchUp Home Screen with Power Plant Model (SketchUp Pro 2017)

3D Shapes

It is possible to start the design of any model from the scratch using available tools in the SketchUp environment. One of such toolsets is available to choose from the View menu under the Toolbars option. This drawing toolbar presents all the basic tools needed to build models or edit imported models. Figure 18 below shows an example of this toolbar.

Figure 18. Basic Drawing Toolbar (SketchUp Pro 2017)

4.1.3. 3D Warehouse

SketchUp has a wide range of component collections on an online database called 3D Warehouse. 3D Warehouse is a resourceful online community for 3D model creators and those looking for models. With 3D Warehouse, one is able to upload models for other users to download. It is also possible for users to provide feedback and comments to the uploaded 3D models. Additionally, it serves as a community where users of the software can connect and ask relevant questions. It is also possible to contact content creators (Scan2cad 2018). Figure 19 below is an example of how the 3D Warehouse frontpage typically looks like.

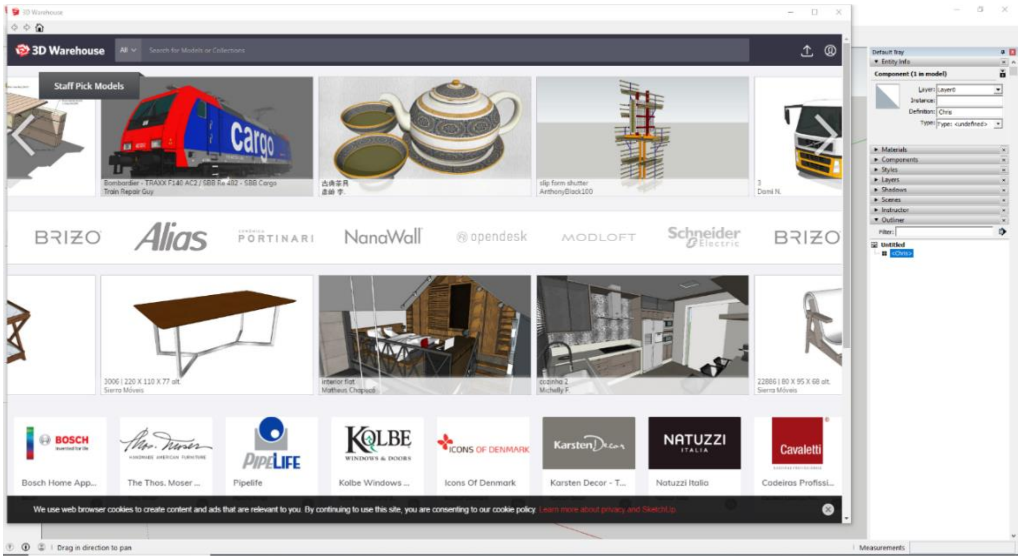

Figure 19. 3D Warehouse (SketchUp Pro 2017)

4.1.4. Extension Warehouse

SketchUp also has a separate platform extension called the Extension Warehouse. This is a platform which provides extensions or plugins developed for SketchUp. With these extensions, users can add certain special features to their SketchUp models. The options on the Extension Warehouse include plugins for drawing, printing or industry specific tools such as plugins for architectural design and construction. It is also possible to search for plugin by name or function such that when one clicks on a plugin of interest, the product description and reviews from previous users are visible from the Extension Manager. Extensions can generally help to save time and repair 3D models among other uses. Figure 20 below shows sample home screen of the extension manager.

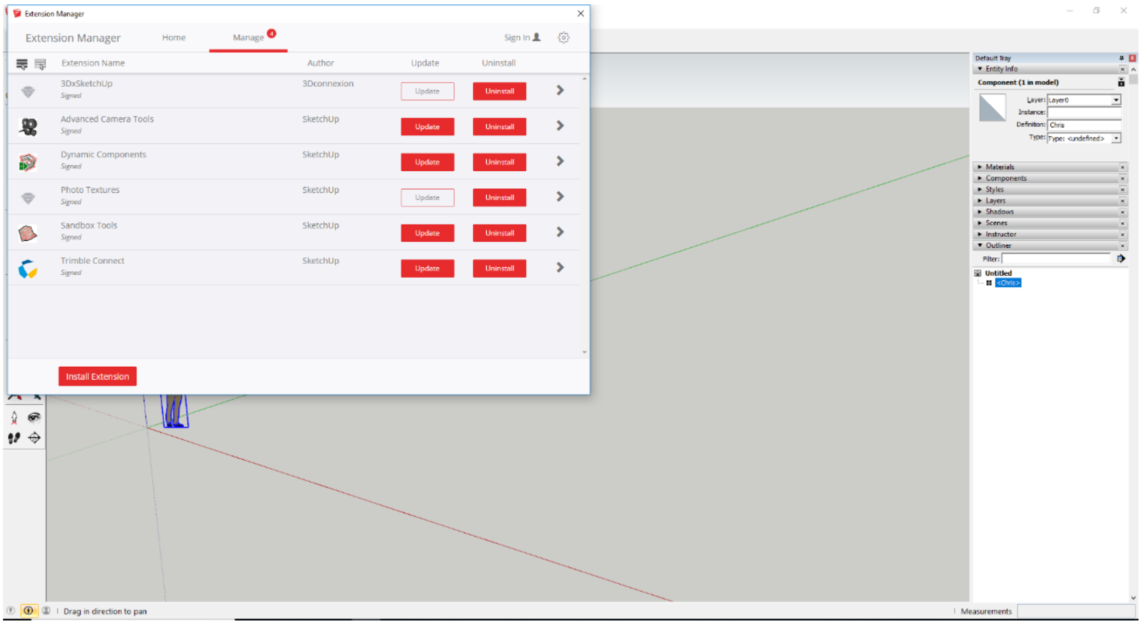

Figure 20. Extension Manager (SketchUp Pro 2017)

4.1.5. Components Used in the Simulation Process

Some of the components used for modelling in this research are available in the 3D Warehouse. Although, the model used in this research was provided by the case company, it is possible to find many of the components in 3D Warehouse. Furthermore, certain other components were sourced and converted by the researcher using Fusion 360, 3D Warehouse and GrabCAD. Some of the components used in this model include; mobile crane, flat-track containers, bottom ash, fly ash, chemical station, operation centre (control room), water system, Motor Control Centre (hereinafter, MCC), fuel feeder, chemical station, steam centre, howden twin 10MW, condense module, asphalt, concrete foundation and more. Two samples of the main components used in the simulation are shown below in Figure 21 and have both been sourced from GrabCAD.

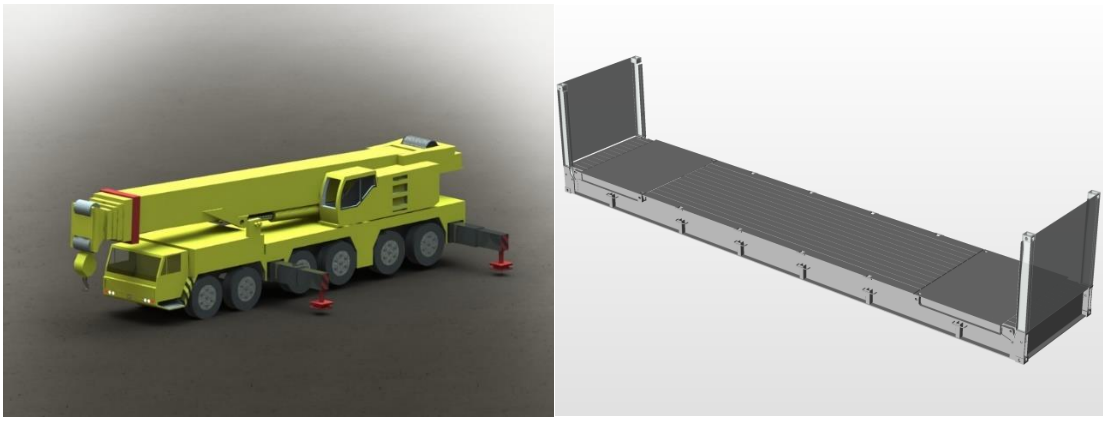

Figure 21. Mobile Crane and Flat Rack Container (GrabCAD 2018)

4.2. Simulation of WasteWOIMA's Modular WTE Power Plant for Layout Optimization

This section details the processes involved with the simulation of wasteWOIMA's WTE power plant using SketchUp Pro 2017. The model was divided into twenty-one groups and the simulation was done using the techniques suggested by Weber 2014; 152, in the research he made for the company Rheinbraun Brennstoff GmbH. He suggested that to properly plan a layout design in a waste to energy power plant, factors such as; technical requirements, architectural requirements, waste logistics, location space/foundation, Operations and Maintenance must be considered. The Figure below highlight's some of these requirements and techniques.

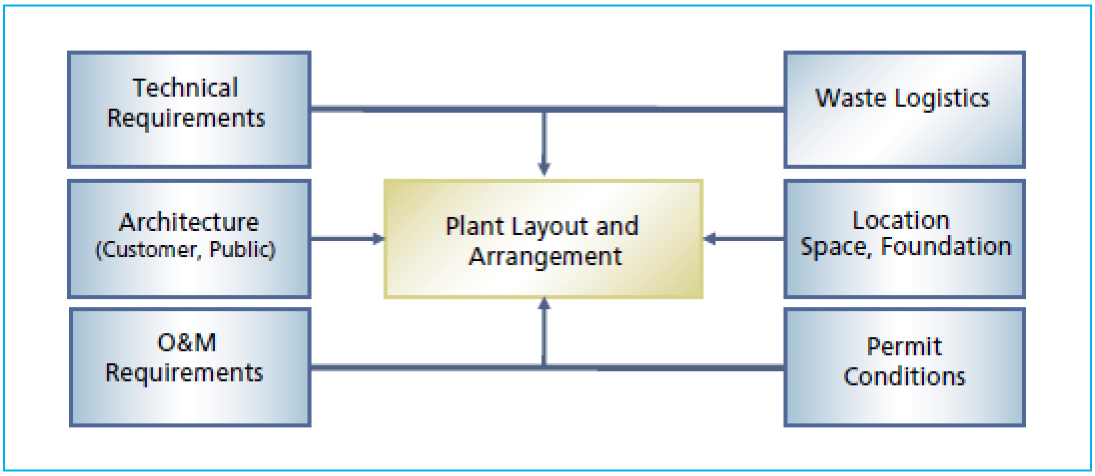

Figure 22. Influences and Requirements (Weber 2014; 152).

The following sections details the various stages of the modular WTE power plant design using SketchUp Pro 2017. These components are presented including their Bill of Materials (hereinafter, BOM), expected functions and mode of operations. It is based on the principle that one line of 15MW could already be fully operational before the remaining lines are installed. Hence, only one line of the power plant is represented below to avoid unnecessary repetition.

There were more than a hundred components in the model but for the purpose of simplification, the researcher merged the components into twenty-one different groups based on functionality of the power plant. The groups were later labelled with names and numbers for easier identification and transformed into a 3D simulation.

To manipulate the model into a 3D simulation, the researcher used the section cut, section plane and the scene creation tools alongside other relevant but commonly used CAD tools. Below is a table designed by the researcher which shows the different stages with the corresponding numbers representing order of appearance of each component group, the acronyms and their meanings.

Table 5. Group of Components in Order of Appearance.

Number	Acronym/Short Name	Full Name	Cost of Key Components
1	Mobile Crane	Liebherr LTM 11200-9.1 Mobile Crane	€440/hr (max)
2	Foundation	Mixture of Asphalt and concrete	€94/m²
3	Stack 1	Smoke emitting stack on line 1	
4	FGT Reactor 1	Flue Gas Treatment Reactor on line 1	
5	Ash-Base 1	Bottom Ash on line 1	
6	Convection 1	Convection on line 1	
7	Grate 1	Grate collector on line 1	
8	Steam Drum 1	Steam Turbine on line 1	
9	DeNOx Control System	Denitrification	
10	Water System	Feed Water System	
11	Howden Twin 10MW	Howden Steam Turbine 10MW	€1Million/unit
12	MCC Centre	Motor Control Centre	
13	Staff Facilities	Staff Centre	
14	DG_LO Container	Dangerous Goods Container with Light Fuel Oil Tank	
15	Steam Centre	Auxiliary Diesel Generator	
16	Stack 2	Smoke emitting stack on line 2	
17	FGT Reactor 2	Flue Gas Treatment Reactor on line 2	
18	Ash-Base 2	Bottom Ash on line 2	
19	Convection 2	Convection on line 2	
20	Grate 2	Grate collector on line 2	
21	Steam Drum 2	Steam Turbine on line 2	

Arrival of Key Components

The simulation shows the order of construction. That is, which component is installed before the next and until the final one. However, before these components are assembled in the construction stage, they have been sourced from the manufacturers who have made these components according to the specified order.

The first items to arrive are ones with shorter lead time such as, Grate, concrete and asphalt for foundation while those with longer lead times like the steam turbine arrives last. The balance between cost and time is reached however, when the mobile crane arrives just before components with longer lead time and the power plant's construction process begins. The longer lead timed components will then be scheduled to arrive just before the lease period for the mobile crane is due and will be added to the power plant.

Mobile Crane

In the layout, there is a mobile crane which is well suited for the task of constructing this modular WTE power plan based on the technical requirements highlighted in section 2.1.3. The mobile crane which was considered most suitable for this power plant is Liebherr LTM 11200-9.1 Mobile Crane with maximum hoist of the crane's arm is 188 meters while the maximum radius is 136 meters and is enough to reach the most distant part of the power plant during construction. The crane from the final simulation is shown in Figure 23.

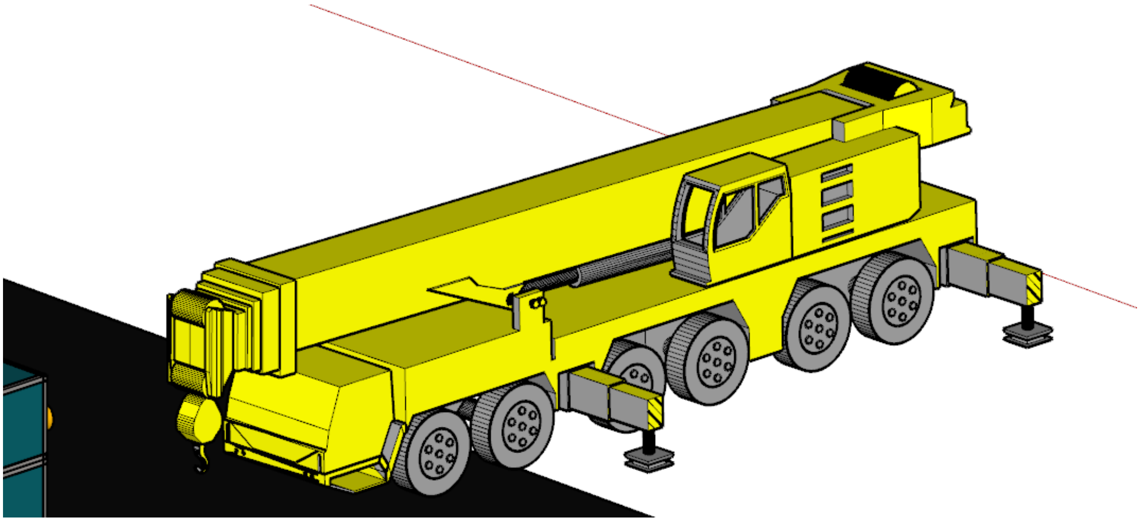

Figure 23. Mobile Crane from the Simulation

Foundation

Figure 24 shows the foundation which as expected will be the first stage of construction and is designed mainly using asphalt and concrete. The concrete area of the foundation is particularly useful for holding heavy components such as Stack and Ash Baseline in place.

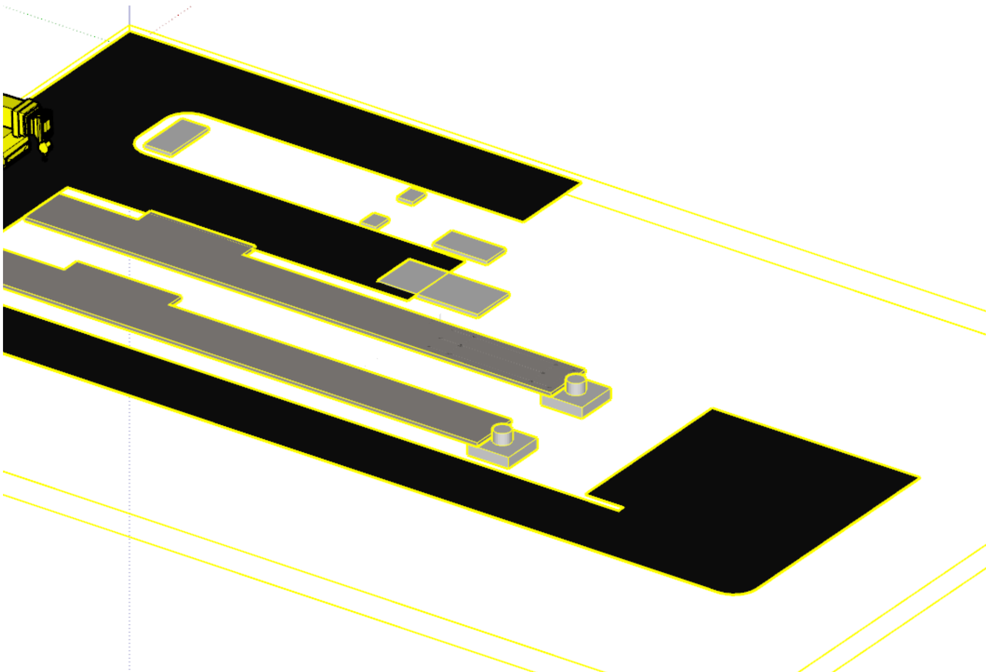

Figure 24. Top View of the Foundation

Stack (For Flue-Gas)

Figure 24 shows the Stack assembly component. The stack is the tallest and heaviest component for the crane to handle, hence, it is expected to be the first component built on the foundation. The stack serves as the chimney of the power plant from which treated flue-gas is released into the atmosphere. Below is a Figure of the stack used in this simulation followed by a BOM of the component's parts.

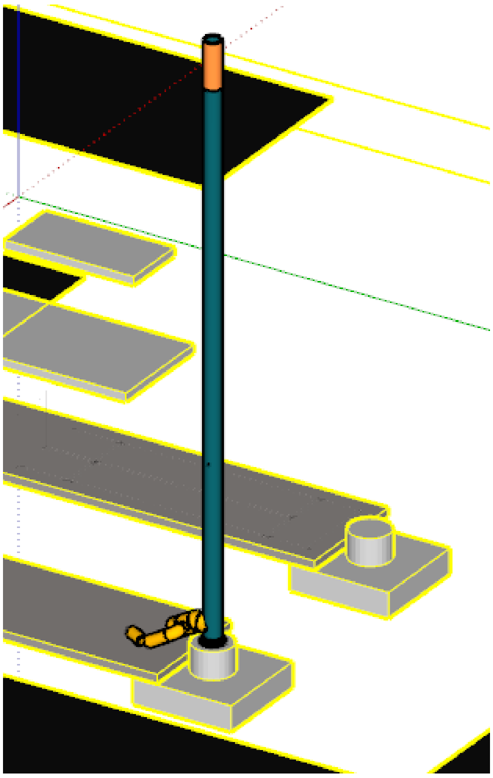

Figure 25. Stack.

Table 6. Stack's Bill of Material

S/N	Name of Component	Unit
1.	Insulation	4
2.	Recirculation Gas Line	1
3.	Stack Top	1

Flue Gas Treatment (FGT) Reactor

The Flue Gas Treatment (hereinafter, FGT) is the section of the power plant where the flue-gas is treated to a level that is deemed fit based on EU and world bank emission standard (wasteWOIMA 2018). Figure 26 below shows the FGT Reactor while the corresponding table shows the BOM.

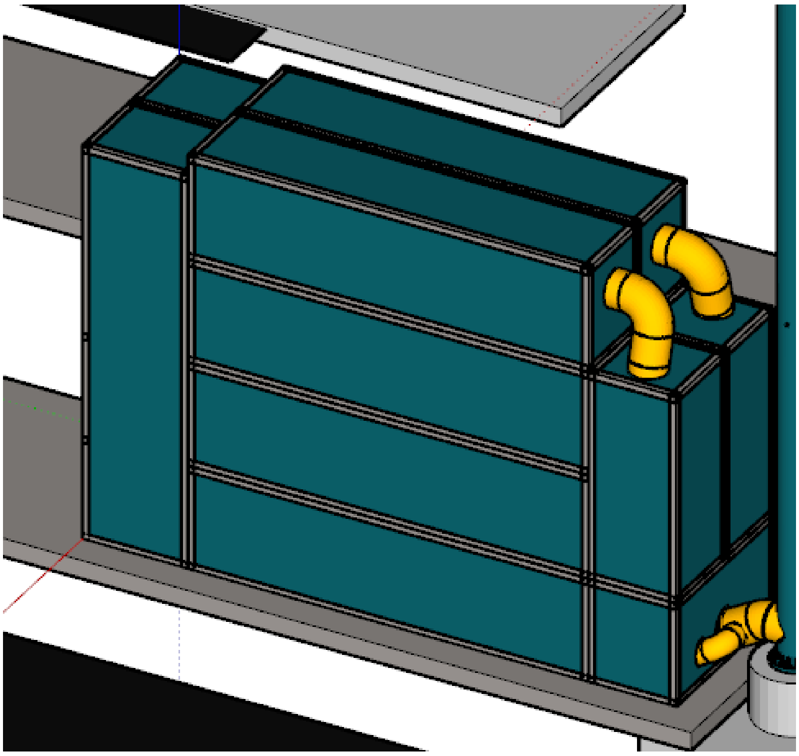

Figure 26. Flue-Gas Treatment Reactor

Table 7. Flue-Gas Treatment Reactor's BOM

S/N	Name of Component	Unit
1.	External Parts	1
2.	Fan	1

Ash Base (Bottom Ash)

Bottom Ash is the ash that falls to the bottom of the boiler. The ash is collected at the bottom to be later treated. There are three main parts to this component, and they are mentioned in the BOM while the bottom ash component is shown in Figure 27.

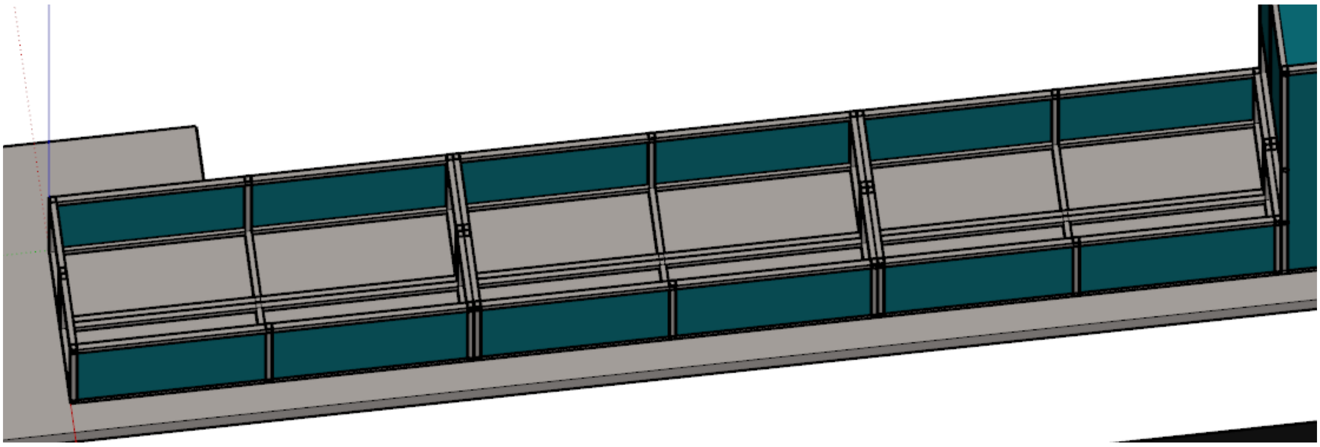

Figure 27. Bottom Ash Component

Table 8. Bottom Ash Component's BOM

S/N	Name of Component	Unit
1.	Eco Ash Back	2
2.	Eco Ash Front	2
3.	Eco Ash Bottom	2

Convection

According to Branchini 2012: 34, a convection is typically located in the post-combustion chamber and often contains, superheaters, evaporators and economizers. It could be designed either horizontally or vertically. The Figure below shows the convection component in the simulation.

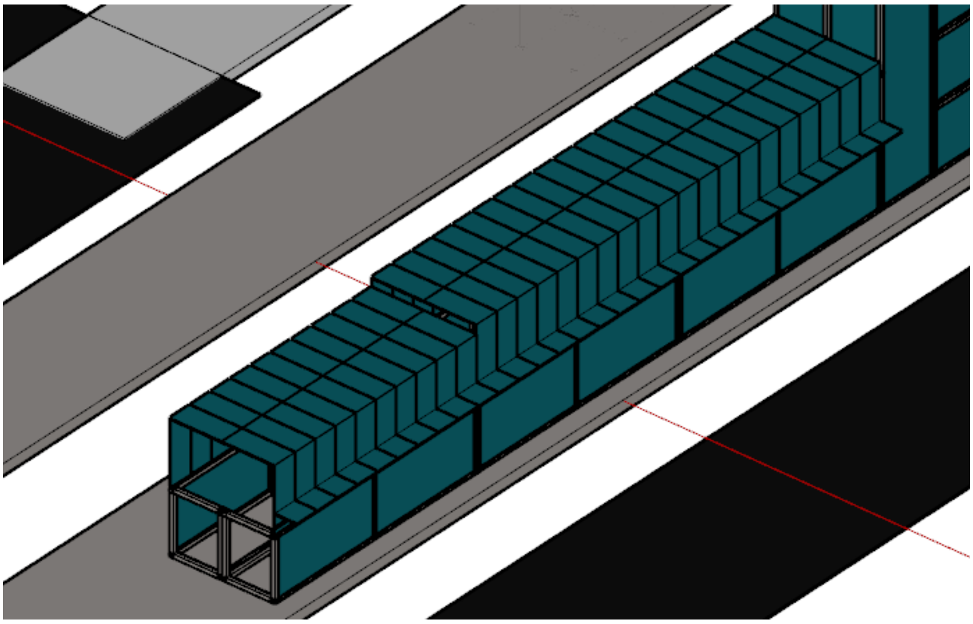

Figure 28. Convection

Grate

The grate is the segment where waste is converted to energy and is therefore, at the heart of the system. Figure 29 shows the grate component this design while Table 9 shows the BOM.

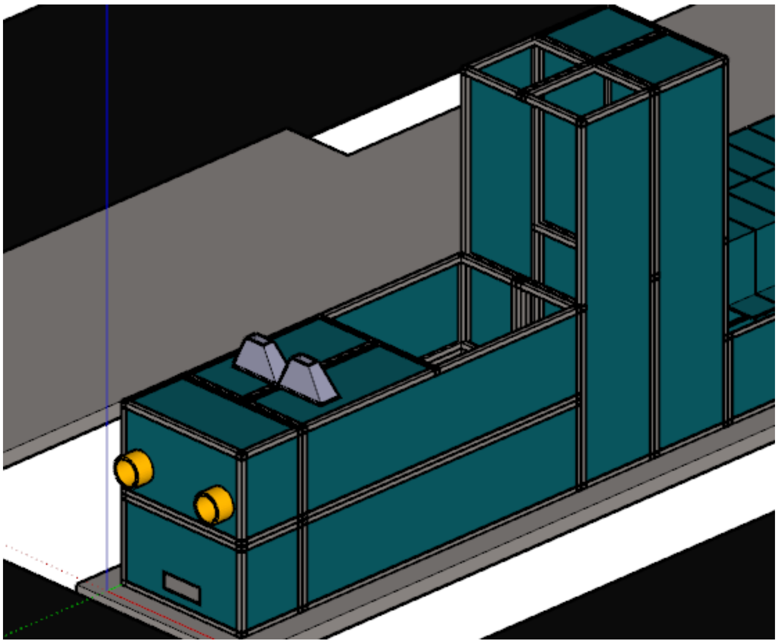

Figure 29. Grate

Table 9. Grate

S/N	Name of Component	Unit
1.	3rd Pass	2
2.	4th Pass	2
3.	Air Flow Module	1
4.	Bottom Ash	2
5.	C28 Steel Frame	1

Steam Drum/Generation

The drum serves the purpose of separating steam from water. Additionally, it serves as a storage for saturated water. It is possible to set the level of water in the drum to the required set point using the boiler automaton system (wasteWOIMA 2018.) The Figure below and the subsequent Table of BOM represents the steam drum and its modules.

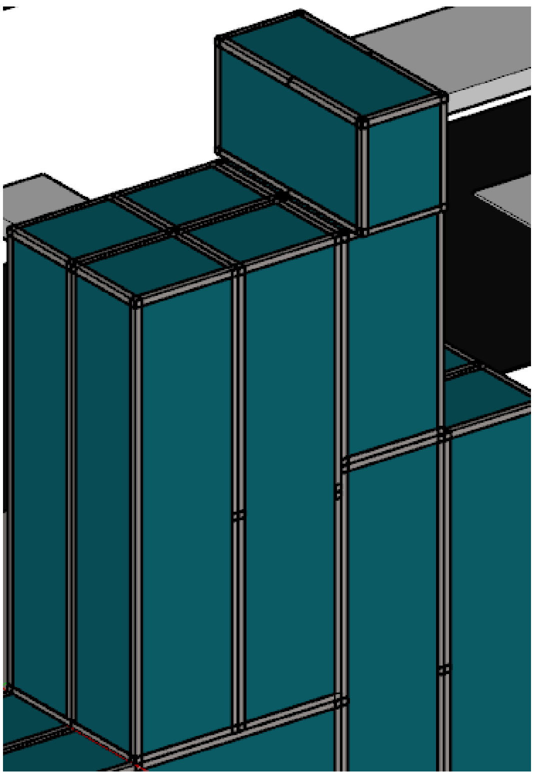

Figure 30. Steam Drum

Table 10. Steam Drum's BOM

S/N	Name of Component	Unit
1.	1st Pass	2
2.	2nd Pass	2
3.	Drum Support	2

DeNOx Control System

The incineration and combustion are completed in the second furnace when secondary and tertiary air is added to the flue-gas stream. With an estimated temperature of about 950°C in this compartment, there exists an ideal environment for Ammonia based Selective Non-Catalytic Reduction of NO_x. Subsequently, Ammonia will react with Nitrogen oxides and will be converted to Notrogen (N) and water vapour (H_2O). The chemical reaction at this stage is shown below with three possible scenarios followed by a Figure of the $DeNO_x$ Control System (wasteWOIMA 2018.) DeNOx process is also called denitrification.

4NO + 4NH3 + O2 → 4N2 + 6H2O (Nitrogen + Water)
2NO2 + 4NH3 + O2 → 3N2 + 6H2O (Nitrogen + Water)
NO + NO2 + 2NH3 → 2N2 + 3H2O (Nitrogen + Water)

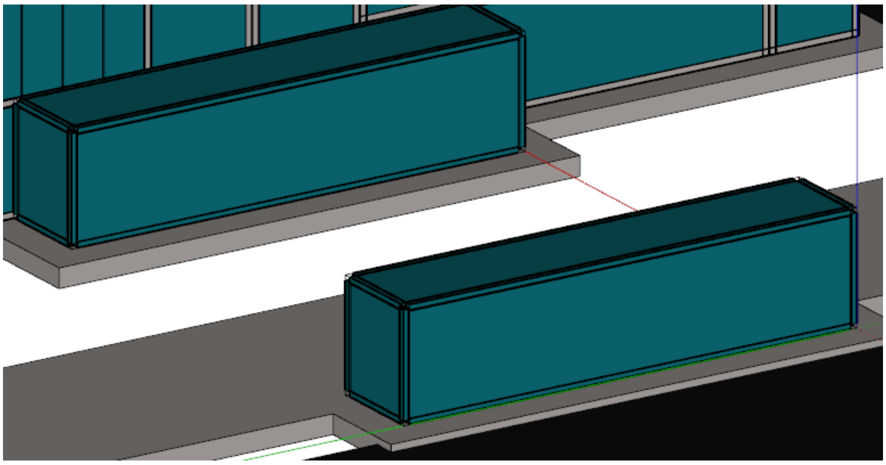

Figure 31. DeNO$_x$ Control System

Feed Water System

When condensates are transferred to the feed water tank from the condensate system, the feed water tank preheats the water and removes soluble gases from the water before it is moved to the boiler. The water capacity in feed water tanks are typically designed to last between 20 to 30 minutes run at full Maximum Continuous Rating (MCR) load. The Figure and Table below represent details of the feed water system (wasteWOIMA 2018.)

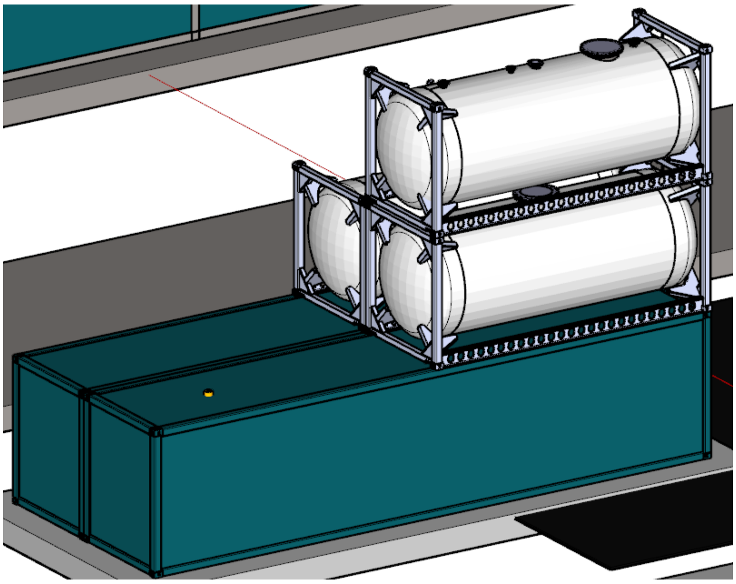

Figure 32. Feed Water System

Table 11. Feed Water System's BOM

S/N	**Name of Component**	**Unit**
1.	Pump Station	1
2.	Tank Container	1
3.	Make-Up Water Tank	1
4.	Raw Water Tank	1
5.	Water Sampling Centre	1

MCC (Motor Control Centre)

In commercial and industrial applications, electrical motors are not required in many quantities and there is a preference to control most or all the motors from a central location. Motor control centre MCC is the apparatus designed to meet this purpose (EEP 2019.) Figure 33 below is that of the MCC used in the simulation.

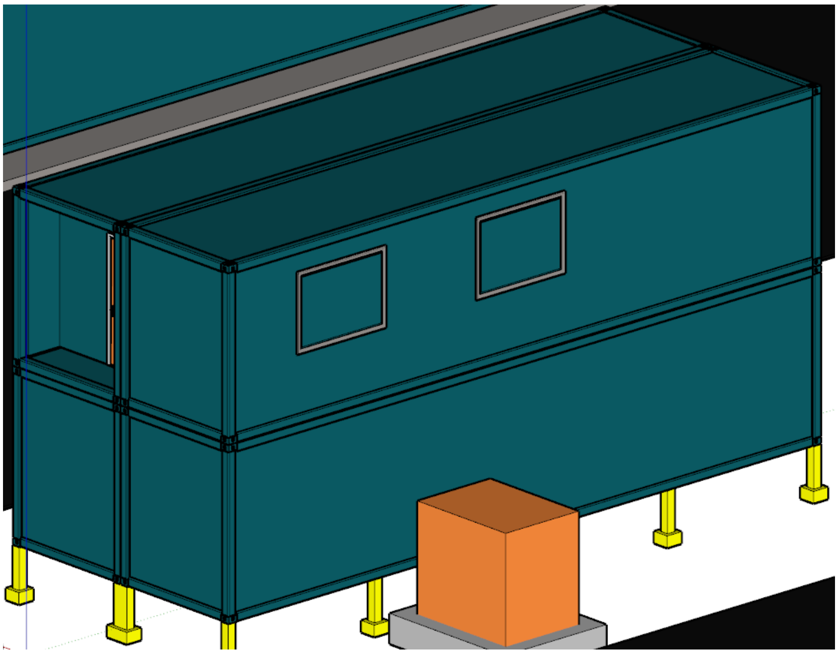

Figure 33. Motor Control Centre

Staff Facilities

The staff facilities are designed for on-site staff who carry out maintenance and monitoring tasks on the site of the power plant. The Figure below shows the staff facility component and the corresponding BOM Table.

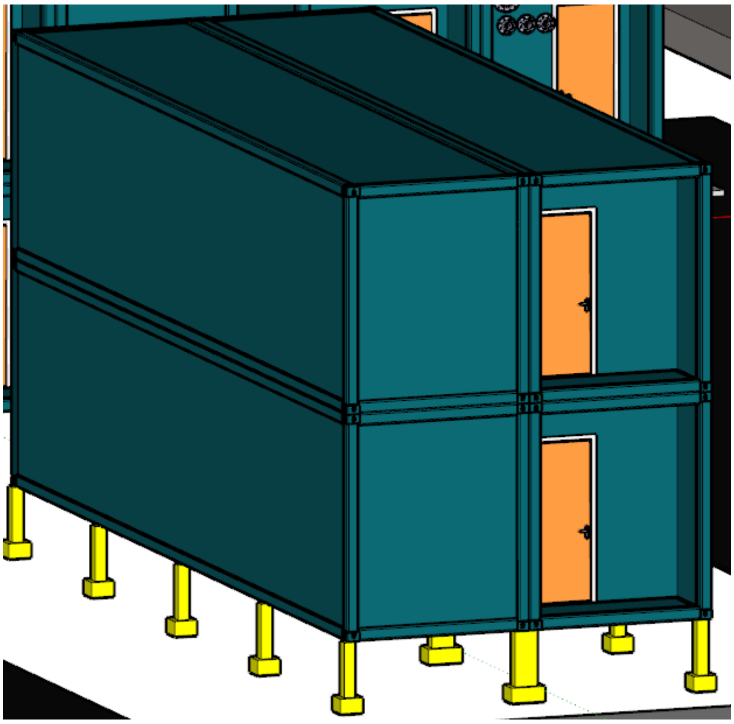

Figure 34. Staff Centre

Table 12. Staff Centre's BOM

S/N	Name of Component	Unit
1.	Cafeteria	1
2.	Sanitary Containers	1

Diesel Engine

The diesel engine is enclosed in a dangerous goods style container. These containers are typically used in the maritime industry to transport goods that are easily prone to damage over long distances. However, it may be modified for other uses including as a modular unit in this power plant. In this section, it has been combined with a Light Fuel

Oil (hereinafter, LFO) tank at the top. The corresponding Figure and Table are shown below.

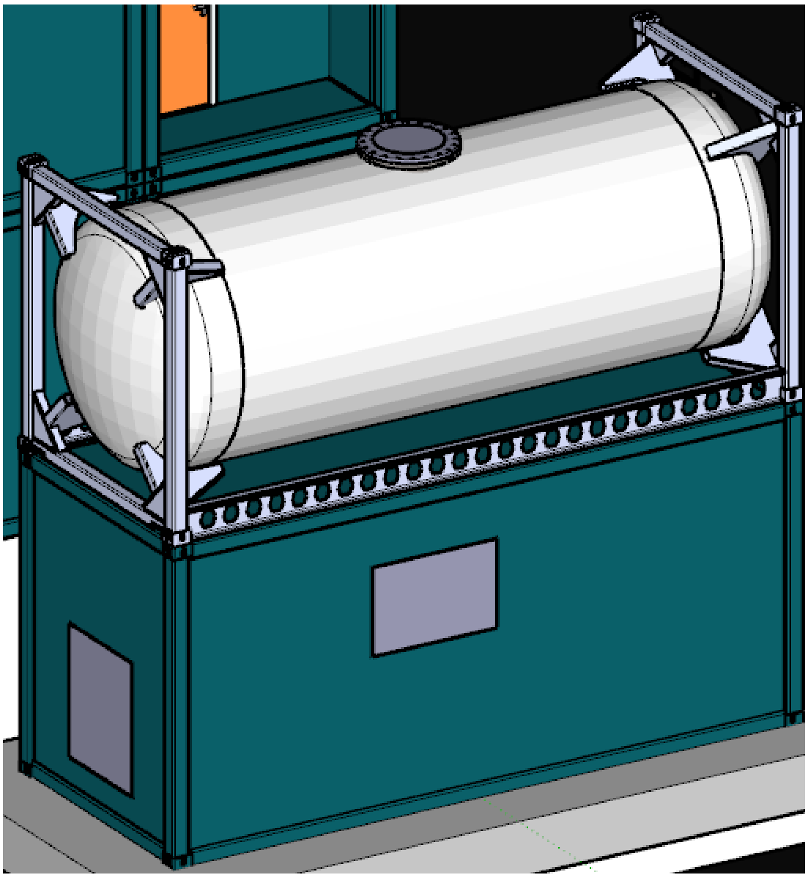

Figure 35. Dangerous Goods Container with Light Fuel Oil Tank

Table 13. Diesel Engine's BOM

S/N	Name of Component	Unit
1.	Damaged Goods Container	1
2.	LFO Tank	1

Auxiliary Diesel Generator

An auxiliary diesel generator is used in WTE power plants to run the conveyor belts and air lowers and they are mainly applied during the start-up and shut-down processes in the plant. Additionally, during maintenance it can be used to power local operations which helps to reduce dependency on external sources power (Woima Corporation

2019.) The Figure and Table below shows the diesel generator and BOM as used in the simulation respectively.

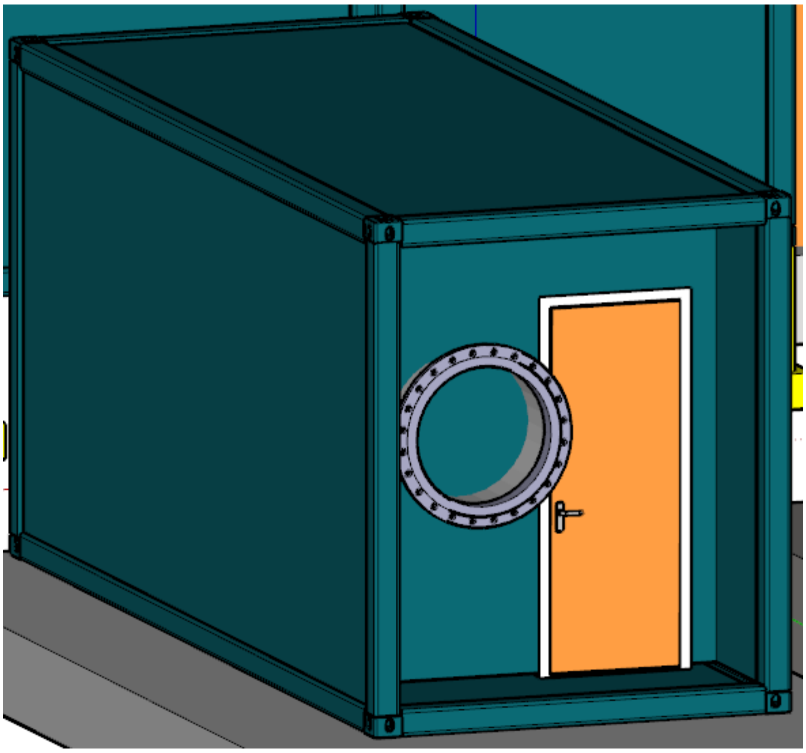

Figure 36. Auxiliary Diesel Generator

Table 14. Auxiliary Diesel Generator's BOM

S/N	Name of Component	Unit
1.	20ft High Cube Container	1
2.	Bypass System	1

Howden Steam Turbine

The Howden steam turbine with an output of 10MW receives superheated steam from the superheaters. Inside the steam turbine, thermal energy is expanded and further converted to mechanical rotation energy by the blades and turbine shaft. Steam turbines are often either condensing steam turbine (electric production only) or back pressure turbine (combined heat and power production) (wasteWOIMA 2018.)

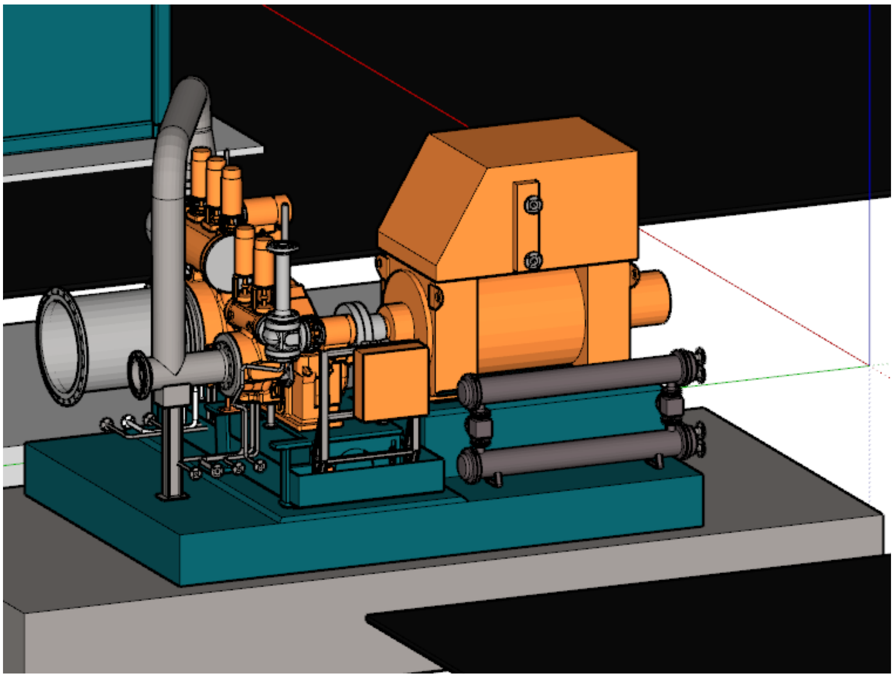

Figure 37. Howden Steam Turbine 10MW

4.3.Presentation and Dissemination of Results

In any given research, the results must be disseminated in ways that makes it readily available to all stakeholders. The two primary deliverables of the research are to make a 3D simulation of the module construction of wasteWOIMA's modular WTE power plant such that it can be previewed in video format and on a VR headset.

SketchUp provides the possibility to create scenes and export the scenes in video format of different qualities by animating multiple scenes using the fly-camera embedded in the software for movement. Subsequently, each scene was merged and exported as .mp4 video format after which it was edited, to add subtitles and sound. The video length is about 1.50 minutes. Figure 38 shows the end page of the video after it was uploaded to YouTube with unlisted visibility to ensure that search access is limited to only those with the specific page link. In addition, the simulation uses time-based assumption and the timing in the simulation does not represent the real-time of the power plant’s construction.

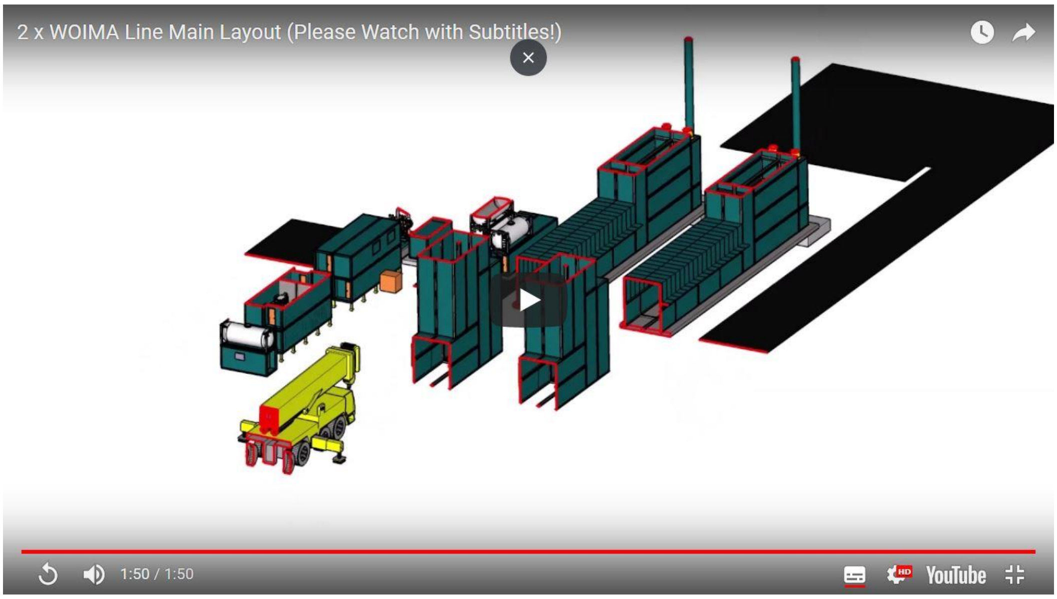

Figure 38. End Scene of the Simulation Video

VR played a critical role during the research because it helped to view the model in more detail. When a 3D simulation is viewed on the computer screen, the level of intuition is generally lower compared to VR preview, therefore, VR was used to help determine the ideal position for the mobile crane. The challenges with positioning were determined and rectified using the 3D software after the VR model inspection. The Figure below represents the visualization process for the mobile crane which was done using the HTC Vice VR system in the University of Vaasa’s VR lab.

The order of appearance of each component was determined based on metrics such as lead time, weight and safety. The most expensive rental component in the power plant as observed during the simulation is the mobile crane. The mobile crane is a critical component because all the listed metrics affect its sourcing and operation. Moreover, wasteWOIMA’s target market is in developing economies where it is often difficult to source for mobile cranes.

Two other components which need to be considered are the Stack and Steam turbine respectively because, installation of both components depends on the crane's availability. The stack is the heaviest and one of the most distant components from the crane but also the tallest component. It is recommended that the stack be installed before any other component to avoid collision and reduce the risk of accident. Among all the components, the steam turbine has the longest lead time for delivery by the manufacturer. Therefore, the logistics related to the component's delivery should be factored to coincide with the rental duration of the mobile crane.

Figure 39. VR Session to determine an Ideal Crane Position

Other components other than the mobile crane also required detailed view using VR. One of such components is the DeNOx Control System and the position had to be carefully planned with many details considered. Figure 40 below shows the visualization process for the DeNOx using VR glasses.

Figure 40. VR Session to determine an Ideal Crane Position

Another reason the VR sessions were important is because when a power plant of this design is being installed, VR will play a decisive role and help with the decision-making process. Managers will be able to make better decisions which affect financing and strategic management using VR inspection while engineers will also make mission critical decisions before and during the installation of this power plant because of the detailed view which VR provides.

An example of the level of detail which can be achieved using VR is demonstrated in the Figure below when the DeNOx Control System component was viewed using VR glasses. The researcher observed not only the details of the modular container unit encasing the DeNOx Control System, but also the relative scale in real life.

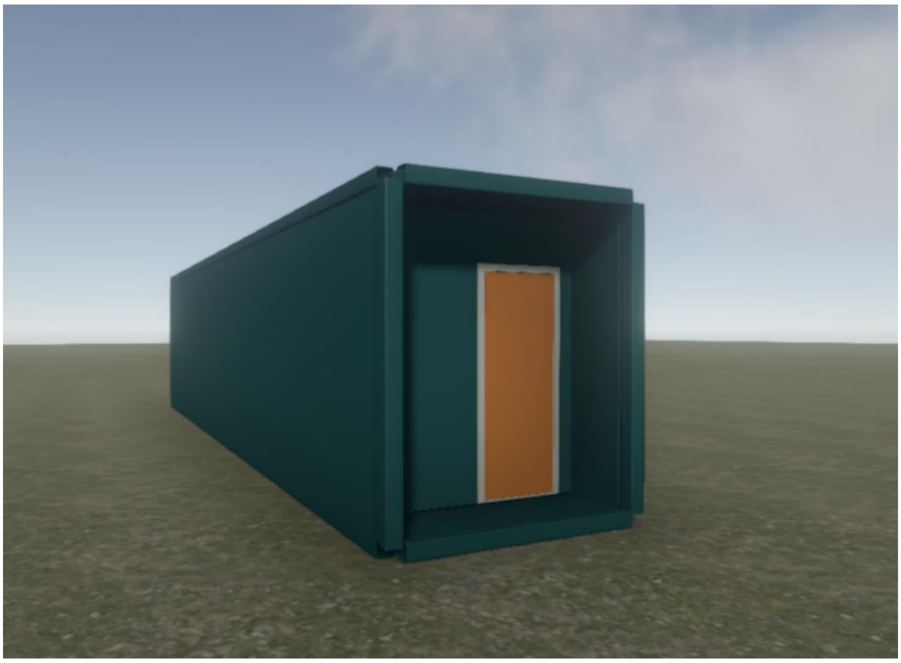

Figure 41. Modular DeNOx Component as Viewed with VR

Ergonomics

Safety of the entire power plant construction is another priority for stakeholders. VR helps to observe each component at a high level of detail while also giving a wholistic view of the entire power plant at a realistic scale. This level of detail will significantly help to reduce accidents during the construction.

Finally, the use of VR preview during the research provided a ratio 1:1 scale view of the component. On a scale of 1:1, the components are viewed on a realistic and immersive scale such that the researcher climbed into the driver's compartment of the mobile crane in VR preview, and he did fit perfectly inside it. This form of preview was done as a means to inspect the overall safety of the mobile crane usage. The Figure is shown below.

Figure 42. Mobile Crane Unit as Viewed with VR

4.4. Validity and Reliability

Reliability mainly deals with replication and consistency of the results given that a researcher can replicate an earlier research and get similar results. On the other hand, validity helps to justify the credibility and suitability of the measures used in the research. Validity also deals with the result's accuracy, analysis and the possibility to make general use of the research findings.

Being a single case study, the conclusions derived from the research cannot be generalized. A reliable source of primary data used because the thesis was done for the company while secondary data on the other hand was not very reliable because free internet sources were used. The quality of data affects the reliability and validity of results in a given research, and the concepts of reliability and validity are typically observed during the process of searching, collecting and interpretation of data used in the research. Therefore, the results from the thesis was verified with the case company to avoid misrepresentation.

5. CONCLUSIONS

This section presents key findings of this research while it also draws conclusions about the whole research. The latter part of this section presents managerial implications of using 3D simulation while the final sub-section makes recommendations for future research.

5.1. Key Findings

The research was done in order to understand how 3D modelling, simulation and VR technology could be applied as an optimization tool in the module installation of a modular WTE power plant's layout owing largely to recent advancements in both computing power and 3D optimization technologies. The results derived from this research show that the methods above have potential to help improve safety, reduce cost and lead time when the construction of the power plant begins in real life, because possible errors could be discovered and corrected more easily during the simulation process.

How can the construction process of wasteWOIMA's modular power plant be optimized using 3D simulation and visualization?

Based on the results of the research, it was discovered that it is possible to optimize the module installation or construction of wasteWOIMA's WTE power plant. Optimization can be achieved through improved safety and understanding of the component's lead times. Additionally, it is important to predetermine which component is installed first during construction and where to place those components considering factors such as safety and lead-time. The results were disseminated using 3D simulation VR.

From the 3D simulation analysis and VR visualization, the mobile crane and steam turbine were understood to be the most critical components. The mobile crane is the component which require most attention concerning safety on building site because it affects the overall ergonomics of workers during construction. The turbine is the most expensive component and the one with the longest manufacturing time.

VR sessions were carried out during the research to help identify areas for possible improvement because VR glasses present an opportunity to view the entire model in more details. Additionally, VR allows people from less technical background like business managers to understand and interact with the model. This process will help to guide their decision making in the long-term. VR is also used for presentation purposes because it provides and immersive experience which cannot be seen by viewing the simulation or video on computer alone. Therefore, VR is could be applied as a marketing tool.

Which procedure is optimal for constructing wasteWOIMA's modular power plant?

A scaled down representation of a fully functional two-line modular power plant was simulated, considering factors such as cost, lead time of components, safety, installation order, visual representation and layout optimization. During the simulation process, some earlier versions of the simulation were made but after careful observation, some errors were detected with both the installation order and visual representation in the first and second simulation respectively. Therefore, the final simulation was the third one. In the final simulation, the grouped components were constructed to reflect the fact that in a real-life situation, it is possible for one line of the power plant to fully function while the remaining three lines are being constructed.

The installation procedure is such that each group of components appear in the order which the mobile crane places them. This procedure was preferred because it helped to answer this research question by simulating the appearance of components. The order of appearance of each component was determined based on metrics such, lead time, weight and safety.

While the cost per unit of the components may not have much influence on the actual simulation, it was important while the various components were being sourced from the manufacturers. The mobile crane is not only safety critical but also cost sensitive when the average rental cost per hour is factored. Rental cost per hour could be as high as €450.

5.2. Managerial Implications

In any given academic research, many organizations and managers are often on the lookout for any managerial implications they can learn and adapt to their strategic business development decisions. The results and findings from this research would go a long way to help the energy industry realize the need to consider using 3D simulation considering the advancement in 3D visualization technology and computing power. Using this approach will help prevent unwanted errors and allow organizations to plan projects before real-life implementations are made since. Additionally, managers and other stakeholders can make informed decisions relating to the viability of a project. Considering the miniature scale of the 3D simulation, using a VR glass will allow for a fully immersive and interactive experience with a user without the need for any engineering background or technical knowledge. Using the VR glasses for rendering a simulation does not require any technical interpretation but allows the managers to make decisions based on the immersive experience in the 3D world.

The most critical component in the power plant as observed during the simulation is the mobile crane. wasteWOIMA's target markets are in developing economies where it is often difficult to source for crane and due to the relatively high cost because a new unit of this mobile crane with full features could cost up to €11.2 million to purchase. Therefore, the best available option would be to rent a mobile crane. The crane must be rented in as short time as possible to minimize cost while ensuring that safety and quality is not compromised, because it could cost up to €440/hr to rent a crane.

Two other components which needs to be considered are the Stack and Steam turbine respectively. Installation of both components are directly linked to the use and availability of the crane. The stack is the heaviest and one of the most distant components from the crane but also the tallest component. Therefore, it is recommended that the stack be installed before any other component to avoid collision and reduce the risk of accident. Of all the components, the steam turbine has the longest lead time for delivery by the manufacturer. Therefore, the logistics related to the component's delivery should be factored to coincide with the rental duration of the mobile crane.

Safety of the entire construction or module installation process is another priority for stakeholders and the crane is also the most critical component here. In Singapore (a developed economy) for example, cranes tend to cause 24% of construction related accidents as seen in Chapter 2. Therefore, in developing economies where infrastructure is generally less safety industrial environments, the use of cranes must be strictly observed and planned to avoid unnecessary work-place accidents.

5.3. Limitations

Owing to the challenge of limited computing power, only two of the four possible lines were used in the simulation. It was not necessary to simulate additional lines because it would amount to repetition. Furthermore, using more lines would significantly add to the total file size. In a real life scenario, it is possible for one line of the power plant to be fully operational while other lines are being constructed in the same power plant, because one line represents an output of 15MW of electricity and each power plant has the possibility to generate a maximum output up to 60MW of electricity by using four lines of 15MW each.

5.4.Recommendations for Future Research

During the research process, two key areas that would require further investigation and research were discovered. They are explained below;

The first observation is the calculation and understanding of the required computing power for a 3D simulation project of this scale. Computing power requirement for 3D simulation is often huge and this project did not come out as an exception. The maximum hardware specification used in this research was Windows 64/bit Operating System with a processor speed of 3.1 GHz (four units), Graphics card – NVIDIA GeForce GTX 960, RAM memory of 8GB and intel core i5 processor. However, some challenges were encountered such as the software crashing during simulation and freezing of the computer severally due to an overload of the computer memory. Additionally, it was very difficult to reduce the polygon count on the entire model when it is converted to .stl file format which is the most common format for objects to be printed in 3D format. Therefore, it is evident that there exists a need to further investigate the computing power requirement necessary to deliver a quality rendering in a 3D simulation environment.

The other observation is that further research needs to be done on the concept of applying 3D simulation tools in the construction of modular WTE power plants. Combining modularity with WTE power plants is a completely novel idea from Woima Corporation and to ensure the success of this new concept, more research work is needed to better focus on specific aspects of the power plant and the components. While modularity would bring many opportunities to the WTE industry, it is also important to understand the possible unforeseen challenges and gains which could be made through the unique concept of combining modularity with WTE.

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