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A system model to repurpose slag into alternative brick solution for low-cost housing

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Abstract: The world's leading producer of Platinum Group Metal is South Africa and accounts for 94 percent of world's platinum. Platinum smelters produce around 10 525,90 tons of slag annual of which accumulates as stockpile, never utilised. More storage area is required for continuous operation of the smelters to store slag. The aim of the research is to repurpose the slag into bricks for low-cost housing. Any Logic simulation model specifically the Discrete Event Modelling (DEM) was employed for the modelling and simulation because of its capabilities compared to other models such as Flexsim, Vensim, ANSYS. The results indicate that 92 human resources are required to have functioning business that is able to manufacture and deliver bricks enough to build 326 houses per month. The operation is labour intensive to ensure more job opportunities are created and a total 368 personnel are employed permanently on all sites. The smelter potentially saves over R1,5 billion per operation and R5,6 billion across 4 sites over a decade by giving the slag away for free. The environmental pollution is improved as five heavy plant equipment is removed from the operation. The operation has potential to generate R392,2 million profit over 10-years.
Keywords: *Any logic, Environmental Impact, PGM, Slag, System modelling, Waste management.*

1. Introduction

The world's leading producer of Platinum Group Metal (PGM) is South Africa (SA) and accounts for more than 80 percent (%) of world's platinum [1-2]. According to research by Jones [3] and Goebel [4], in 1842 platinum electrodes was used to derive fuel cells for the first time because of its catalytic properties. The research also confirms platinum mining on large scale in SA started around 1926. There are eleven platinum mines in SA, this mineral naturally occurring chemical element and it is scarcer than gold (Au) [5]. Platinum processing includes exploration, development, mining, processing, smelting, refining and product [6]. The Anglo Platinum, Impala Platinum, Lonmin Platinum, Northam Platinum, all of SA, and Makwiro Platinum in Zimbabwe are five companies in the Southern Region where smelting of concentrate is carried out [6].

Six-in-line electric furnace is widely used to smelter PGM and electrodes are used and PGM melts at temperature range of 135-1600 degrees Celsius (°C) or higher [3]. The separation of noble metals from gangue happens during smelting operation where oxide and silica are discarded at the backhand of the furnace as slag and where sulphide minerals are collected on the frontend as concentrated matte. In addition, the outcome of the study indicate that molten concentrated matte has higher relative density compared to that of slag and limestone may be added to influence slag density to allow it to flow much quicker and to lower its temperature. Merensky Reef, Platreef, and UG2 chromitite layer are the three areas in SA where PGM are found in high concentration [7].

Figure 1 represents the distribution of PGM in SA showing different elements per area and those are Rhodium (Rh), Palladium (Pd) and Platinum (Pt).

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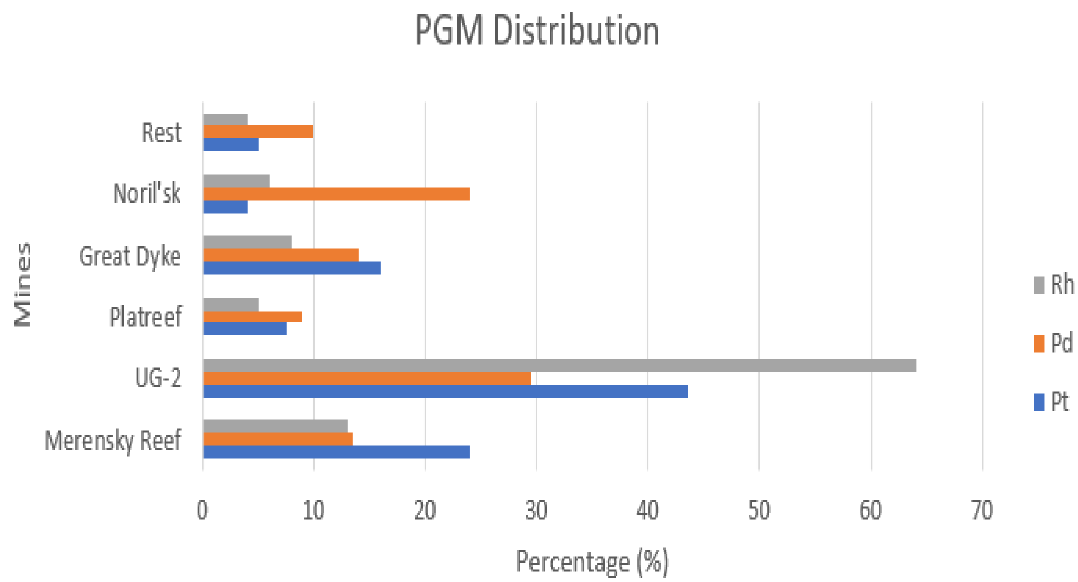

Figure 1.
PGM distribution in SA [7].

The slag produced yearly by platinum smelters accumulates on sites and requires proper handling/ storage to prevent environmental pollution. Platinum smelters produced 494.6 Tons (T) of Pt per annum and 19 418,54T of slag for financial year 2018/2019 and 2019/2020 alone as detailed in Table 1. [8].

The stock of slag that is currently on storage is calculated by assuming 4% yearly increment. The current stock is important in the model to determine the energy required to move the slag. This information determines how many bricks can be produced from the existing stock.

After smelting, the furnace mate is treated in converters where iron sulphide is oxidised to ferrous oxide and sulphur is oxidised to sulphur dioxide. The converter mate is cooled, milled and treated in base metals refinery. There are losses during the Pt processing, for instance, to produce one pure ounce of platinum, approximately 10 tons of ore must be mined [9]. Where one ounce is equal to 0.0283 kg therefore 1 kg of Pt requires 353,35 T of concentrate. Considering the fact that Pt is heavier than Au about 11% denser than Au, one cubic foot weighs a little more than 603.2779 kg. Environmental pollution is caused by various factors such as strong winds that blows lighter/ fine particles away from stockpile and during rainy seasons where some particles get washed away by rain water. The risks to human health have been increased over the years due to significant increase mining operation of PGM and its residue could be traced in different environment such as soil, water etc. [10].

Table 1 reflects the statistics of Pt production in SA by Department of Mineral Resources and Energy (DMRE) as contained in an annual report of 2020/2021 [8]. The slag to matte ratio varies and could be as low as 4:1 and as high as to 9:1 [11]. The maximum scale ratio of 9:1 is utilised to calculate slag over a period.

Table 1.
Pt Produced Per Year [8].

Financial year	Tonnes (T) of Pt produced	Tonnes (T) of slag produced at 1:9	Concentrate to be mined (T)
2019/2020	226.5	8 892,64	80 033,775
2018/2019	268.1	10 525,90	94 733,135
Total		19 418,54	174 766,91
Accumulative over 20 years		1517198,57	1686129,539

Based on the projection 1517198,57 T has been accumulated over the twenty-year period. The volume of slag can fill approximately 10 Hectare of land and that is the space that can be utilised for other purposes other than slag storage. From the accessed literature there is no evidence that platinum slag is being utilised to create any product. The literature detailed that there are four smelter plants in SA, therefore the total quantity of slag produced be divided by 4 to ensure that the study is per plant based.

When the status quo remains unchanged, more space is required to store slag. The plant equipment utilised keep adding to air pollution when handling/ levelling slag. Therefore, there is a need to develop a system capable of utilising or repurposing the slag to create a product that is able to minimise or eliminate problem identified. To achieve PGM stable supply the recycling efforts has to be intensified since PGM have been utilised in different industries. The research conducted experiment using pyrometallurgical and hydrometallurgical process to determine precious metal loss on the slag and samples were tested for 24 and 60 hours. The research results proved that Pt and Cr are in high concentrated in the alloy and the slag phases, respectively and the solubility of Pt in the slag increased with increasing Cr_2O_3 concentration [12]. According to research by Amdur *et al.* [13], the main source of Pt are copper-nickel sulphide ores and layered intrusions of ultrabasic rocks, precious metal are recovered in multi-stage processes which involves smelting furnace where concentrated matte is separated from slag and small % of Pt is lost in the process. The research experiment conducted reflect the decrease of precious metal loss when lime was introduced to increase slag viscosity. The results show that metal losses into slag were as the result of gas bubbles using flotation. Au and Pt extraction sulphide material by employing multi-stage process where matte and slag are separated where metal losses are in slag. The research experiment identifies flotation of matte droplets containing Au and Pt by gas bubbles as the main reason for losses and according to the data of chemical analysis, 5 to 35% of the total mass of Pt, 12 to 19% of Au, 7.5% of Cu, and 9.5% of Ni pass into the slag. The results found that the amount of Au in the slag increases with an increase in the S content in it, which is proportional to the matte mass, and reaches a constant value at high S contents [14]. Takashi and Katsunori [2], found that there will be shortage of PGM by 2030 if not recycled and ACC accounts for 60% of PGM global demand. The study indicates that concentration of Pd and Pt in the slag remain the same as sample collected 12 hours after addition of the extractant. The results indicate higher Pd and Pt recovery ratio and speed of suspended particles were higher using Cu_2O than when using Cu.

The novelty of this study lies in the idea of repurposing slag into alternative brick solution for low-cost housing which has not been sufficiently highlighted by the existing literature.

The research aim is to develop a system model to repurpose slag to manufacture bricks as substitute material to offer low-cost housing to low-income earners. To achieve this aim, the specific objectives of the study are to conduct simulation to determine if building material demand required by Department of Human Settlement (DHS) is met and to determine how many jobs are being created to produce bricks using the AnyLogic software, to demonstrate if the selected material to manufacture bricks is suitable and able to produce competitive product and determine how much revenue, the smelter might save by giving away slag to manufacture bricks. The significance of the study is to minimise mine waste disposal on land/ stockpile by repurposing the slag to create a unique product. The study demonstrates that smelter operation save money when waste is managed properly because less plant equipment is required to handle slag and require less space for storage. The study contributes by offering alternative material solution that is capable of producing a building material at competitive price. This product can enable government to deliver on the mandate to build low-costs houses for under-privilege South Africans. The study demonstrated how well the repurposing of the slag material improves the operation life cycle assessment (LCA).

This study adds to the existing literature by suggesting alternative ways in which mine waste can be managed. The study demonstrates that waste has potential to create unique or competitive product and can be used as raw material for future products. The accessed literature supports the narrative that waste is a great source of income when manage properly. This is achieved by changing the process or product life cycle from "cradle to grave" to "cradle to cradle". The study also empowers the smelter to decide what to do with the waste produced.

2. Methodology

The assumptions made for the study are as follow:

- The standard brick size is 390 x 140 x 190 (LBH) [15-16].
- 1500 block to complete one RDP house (kitchen, bedroom and sitting room) and has 36-60 square metres [17].
- Three bags of cement, a cubic metre of aggregate and 150 litres of water is enough to make about 400 bricks. The mixture must be wet enough to bind together when compacted, but it should not be so wet that the blocks slump (sag) when the mould is removed [18].
- Care to be maintained when removing mould to prevent bricks damages.
- Cement to have 42.5 N strength or higher [18].
- Borehole water may be used.
- Egg-layer type machine is used.
- Plastic sheeting to be used to cover blocks to prevent moisture loss.
- The distance where mine, neighbouring villages, town are within 50 km.
- Youth willing to work manual/hard labour instead of office work.
- Access to funds made available to source required equipment to start business.
- Government support business with required tools (guidance, finance) to make it sustainable and buys bulk of the product produced.
- The mines are willing to either give away slag free of charge as part of corporate social investment (CSI) or at a lesser fee to the business.
- Access to water is made available by local municipality or free from natural streams.
- Local Authorities (chiefs, government, private land owners) supports the course by offering land where business operate.
- Bricks manufacturing floor to have a slope of 1 in 100 for water drainage and 50 m^2 enough to store 1000 bricks [18].
- Local communities support the business by consuming product produced.
- To calculate slag stock level, use yearly product and work it backwards at 4% increment per annum.

2.1. Any Logic Modelling

Process Modelling Library (PML) provides a DEM library containing blocks you can use to rapidly simulate complex discrete-events systems like manufacturing processes with detailed shop floor layout, simple and complex service systems (e.g., banks, airports, etc.), business processes with activity-based costing and logistics and supply chain models [19].

The PML allows one to create flexible models, collect basic and advanced statistics, and effectively visualize the process you are modelling to validate and present your model.

The DEM paradigm adopts a process-oriented approach, the dynamics of the system are represented as a sequence of operations performed over entities [20]. The DEM application is mainly used in the manufacturing and business process using process flowcharts and heterogeneous systems

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may use more than one or combinations of simulation methods. In conclusion AnyLogic supporting all three modelling methods on a single platform [20].

2.2. Process Flow Diagram

Figure 2 reflects the envisioned process of how the bricks are manufactured and this enable the simulation to give more details about the process having considered all the input data.

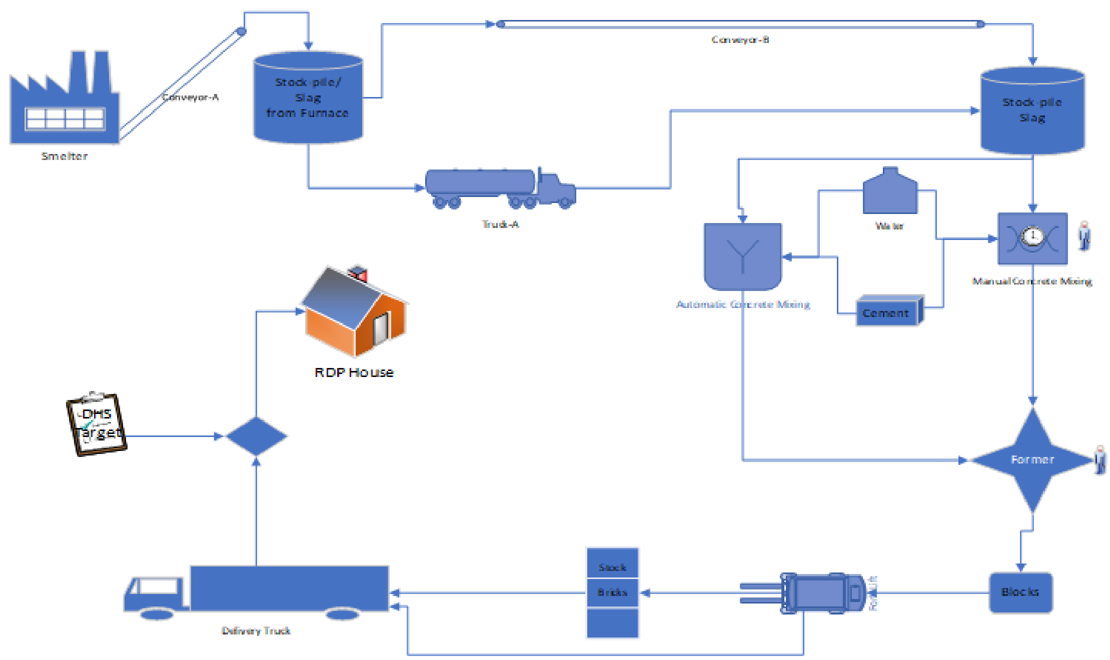

Figure 2.
Slag to bricks flow diagram.

Slag is produced from the smelter and transferred via conveyor belt to the slag pad. Manual hauling of slag is performed when there is problem with the conveying system. The slag has maximum storage capacity, slag pad is extended as and when required to accommodate more material. The trucks are used to move and level the slag pad in correct sequence, slope and height. The bricks manufacturing operation get slag from slag pad using both conveyor and trucks. This is to ensure that system is balanced and not only dependent on single mode of transportation. The operation slag pad is limited to 1000 m^3 to optimise space utilisation.

The slag is weighted using wheelbarrows to get the correct mixing ratios. The batch is mixed by both hands and auto mixing machines. The mixing ratio is 1 m^3 of slag with three bags of cement and 120 litres of water, this mix is capable to produce 400 hollow-bricks [18]. The ready mixture is casted onto the former to produce bricks, care to be considered to ensure that aggregate is not too wet [21]. The egg-layer type former is used and requires manual handling to move the machine after every casting made. This facilitate employing more personnel to carry out the task. The casted bricks be ready to be moved to storage area after a day or two depending on weather. The ready bricks to be delivered to the respective buyers via lowbed delivery trucks.

The research is classified as desktop study as the research work is limited to the available literature. No experiments were conducted to verify the slag/ cement ratio for optimum results to ensure that bricks satisfy or exceed the required specification to prevent houses collapse. Depth instead of breath as only one product is considered. The research is only limited to one product only which is hollow-bricks and no other alternative product have been considered. Various sources were accessed to get primary data required to complete simulation to obtain results.

- Slag production rate per year [8]. Divide by number of production days to get material flowrate then convert to desired flow as per model.
- To determine brick sizes, bricks production, mixing ratios [18]. This information is plugged in the model as is.
- Slag chemical and physical properties [22-23]. To determine slag density, required to find volume or mass in the model.
- Employment status [24]. To determine the availability of human resources and impact in unemployment status.
- Housing demand [25]. To determine the need and demand of the product.

This information is sufficient to create the baseline model that can be altered to test different scenarios.

2.3. Simulation Guide

The first step to create a simulation model is to identify the problem, what is it that must be resolved. Evaluate if simulation can be applied to resolve the problem. This is to ensure that system or process can be represented in the model for configuration [26].

If no, different approach to be employed. The aim of the project to be clarified, requirements clearly understood and determine the cost and time required. Gather all the critical data required in the model. Build the simulation model that depict the real system or process. Create different scenarios and evaluate the results, confirm if the model produces properties. Confirm if targets are compiled, if not change the task. Ensure results can be applied in real life before implementing changes. That can be done by scrutinising the results without being biased.

2.4. Set of Collected Data

Table 2 presents some of the input variable required in order to perform simulation on AnyLogic to run the model and their sources.

Table 2.
Simulation Variable Input [6, 8, 18].

No	Operation type	Mode of transport	Process time	Distance
1	slag	trucks & conveyor	65 T/d, 2.74 T/h	500 m
2	slag storage (smelter)	queue	max	
3	truck		20 km/h	500 m
4	truck capacity		45 m^3	
5	wheelbarrow capacity		0.35 m^3	
6	Conveyor		1 m/s	500 m
7	slag storage (operation)		1000 m^3	500 m
8	Mixing ratio	50kg cement, 1 m^3 slag, 40 litres of water		
9	Concrete Mixing Pad (manual)	personnel (labour)	15-20 minutes	1 batch
10	Water	pump from borehole	max	
11	Cement	Bulk Supplier	500 bags/ 25000 kg	
12	Concrete Mixing Pad (automatic)	plant equipment/machine	40-55 min	2 batch
13	Former (manual)	batch	30-55 min	400 bricks
14	Brick forming	Former	2-3 min	4- bricks

15	Former (auto)	batch	30-55 min	800 bricks
16	Curing time	queue	1.5-2 days	
17	Storage	queue	max	
18	Truck loading	Forklift	10-15 min	1 pallet
19	Delivering Bricks	Trucks	45-120 min	50 km

The simulation model variables are changed to ensure optimal results are achieved. This is done by saving different simulation model and compare the results that are aligned to the objectives of the study.

2.5. Simulation Methodology

Table 3 represents the model as it is constructed using AnyLogic to represent the slag repurposing process.

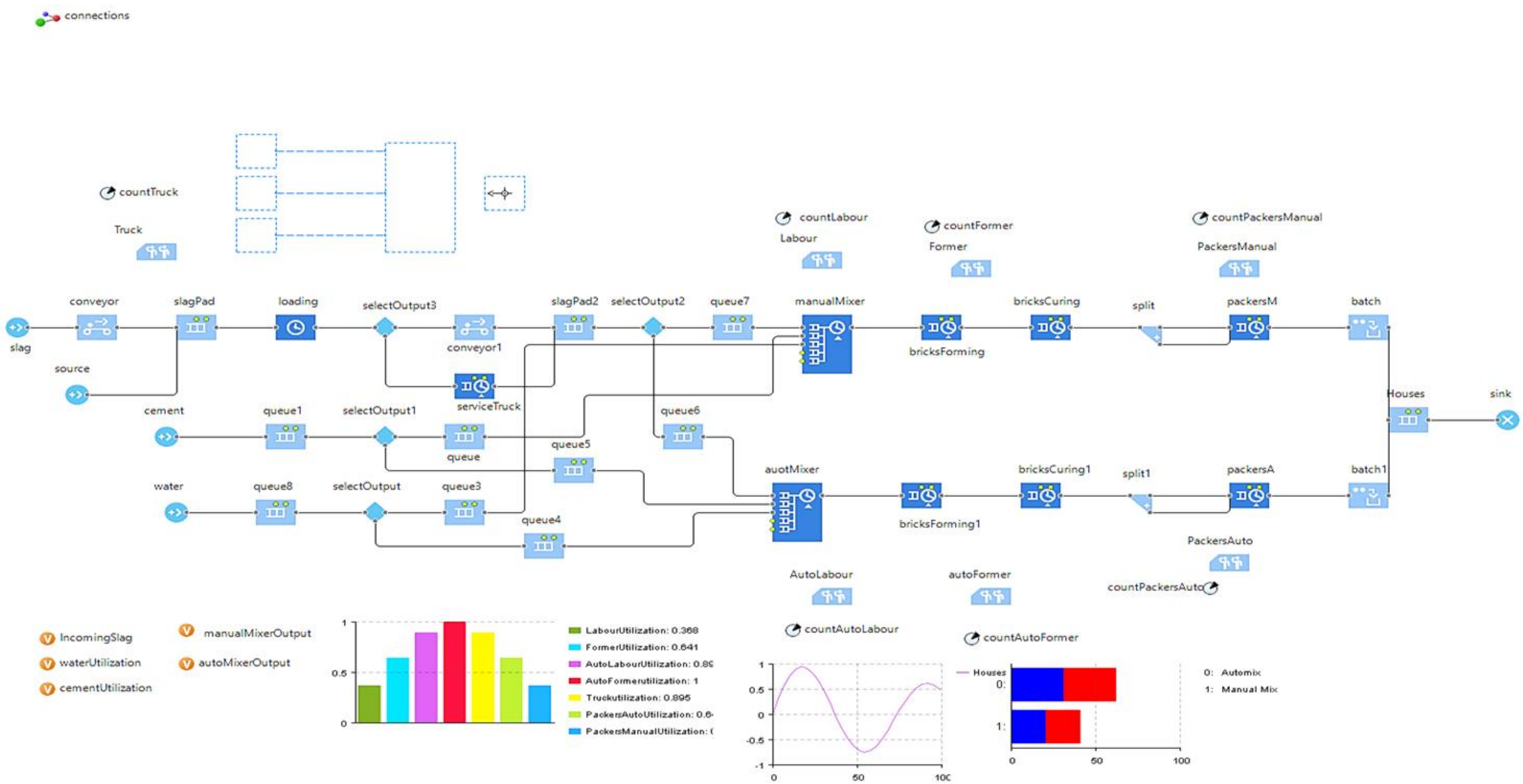

Figure 3.
The developed model using AnyLogic.

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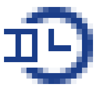
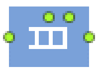
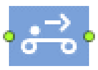
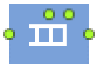
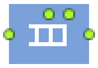
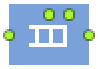
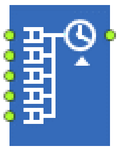
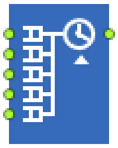
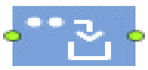
Table 3 shows the step-by-step on how to successfully build simulation model in AnyLogic.

Table 3.
Model Simulation Step-by-Step.

No	Action	Description
1		create a model, give a file name, select model time unit (min, hours, days) and save at specific location
2	**Save Model As** Save model as	allocate file name specify file location finish
3	Simulation: Main	specify starting date and time specify stopping date and time
4		Process Modelling Library
5	source 	select source to start model give specific name specify incoming flowrate units/time: 20 units/hour specify location of arrival/ source
6	SmelterConveyor 	give specific name specify conveyor length and speed select agent location for 3D animation
7	SmelterSlagPad 	specify storage capacity, select maximum because slag pad gets extended to accommodate more slag queuing, first in first out to prevent stock staying longer select agent location for 3D animation
8	OperationConveyor 	give specific name specify conveyor length and speed select agent location for 3D animation

9	Transporter 	give specific name specify queuing capacity: 90 resource set: truck Delay time: triangular (10, 15, 20)
10	 Resource Pool	give specific name: trucks specify capacity:1 speed: 20 km/h
11	OperationSlagPad 	specify storage capacity, limited space- 1000 T queuing, first in first out to prevent stock staying longer select agent location for 3D animation
12	Water 	select source to start parallel model give specific name specify incoming flowrate units/time: 10 units/minutes specify location of arrival/ source
13	WaterTank 	specify storage capacity: max queuing, first in first out to prevent stock staying longer select agent location for 3D animation
14	Cement 	select source to start parallel model give specific name specify incoming flowrate units/time: 10 units/ minute specify location of arrival/ source
15	CementStorage 	specify storage capacity, max capacity queuing, first in first out to prevent stock staying longer select agent location for 3D animation
16	MixingPad 	give specific name connect all parallel lines/ processes into one specify required quantity per line/ ratios required resource set: 1 specify delay time; triangular (35, 40, 45) minutes new agent: Mortar
17	ConcreteMixers 	give specific name: labourer specify capacity:3 speed: 1 m/s

18	assemblerAutomix 	give specific name connect all parallel lines/ processes into one specify required quantity per line/ ratios required resource set: 1 specify delay time; triangular (30, 45, 60) minutes new agent: Mortar
19	resourcePoolAutomix 	give specific name: Operator specify capacity:3 speed: 1 m/s
20	bricksForming1 	give specific name specify queuing capacity: max resource set: former operator: 3 delay time: triangular (110, 120, 130)
21	bricksForming2 	give specific name specify queuing capacity: max resource set: former operator: 3 delay time: triangular (110, 120, 130)
22	bricksCuring 	give specific name specify queuing capacity: max resource set: former operator: 3 delay time: triangular (1, 1.5, 2) days
23	split 	Specify number of copies: 3 (scale 1:100)
24	 batch	give specific name batch size: 15 // 15 pallets of 100 to complete 1 house delay time: triangular (30, 35, 40) minutes
25	packersM 	give specific name Capacity: maximum delay time: triangular (30, 35, 40)

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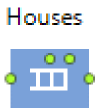
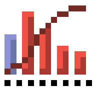
26		give specific name Capacity: maximum
27		to end the process
28		drag chart of your choice to represent stats of your choice rename chart name choose colour histogram data of your choice
29		build the model play the model
30		increase model playing speed
31		reduce model playing speed

2.6. Research Method Justification

The simulation modelling could offer a great potential in modelling and analysing business processes [27]. The research can run multiple experiments with different set of parameter values such as arrival rates or service intervals which can help in discovering process bottlenecks and investigating suitable alternatives. The simulation models can provide a graphical display of process models that can be interactively edited and animated to show process dynamics. The model represented the complete model representing the business process of order receipt to completion of a finished product where each service block represented a business process, with inputs of manufactured parts. The DEM has many advantages such as enabling the researchers to gain more insight through the activity diagram because they can see the logic sequence that linked the entities event and also to resources. DEM uses the animations and graphic in order to represent the entities and the event that occurs in the real system [28]. In conclusion, DEM is straightforward to be modelled once the problem that occurs has been clearly defined. The simulation helps to capture and visualise the interaction between different resources or entities in an earthmoving operation and defining the weak links in order to improve the efficiency of such activities onsite. The DEM is one of the most widely used simulation to mimic construction operations [29].

AnyLogic was utilised in this study to create the same system where multiple experiment are conducted until desired results are achieved. The input data utilised is gathered from different reliable sources and plugged in the model to ensure that it is the true representation of the system. Various inputs are modelled to ensure that a model is capable of integrating all the

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possible solutions that could be employed in the process of making bricks. Run multiple experiment to ensure that all possible scenarios are examined and considered during decision making.

3. Results and Discussion

3.1. Production Output

The smelter produce slag at a rate of 65.7 T per hour and slag is transported via conveyor to slag pad area. The estimated accumulated slag volume to date is 1,517 Mega T. The slag pad has maximum capacity and is continuously extended to meet operation requirements. The total stored material on slag pads can fill approximately 10 hectares.

Table 4 presents the slag production per site per annum and accumulative slag over 20-year period.

Table 4.
Smelter Slag Production.

		Mass (T)	Volume (m^3)
Total Accumulative Slag Mass (T)	over 20 years	1517198,57	526805,06
No of Smelters		4,00	
Total Slag Mass per Smelter (T)	per year	379299,64	131701,26
Slag Production (2023)	per year	92217,02	32019,80
Maintenance days per year	days	15,00	
Days in a year	days	365,00	
Hours in a day	hours	24,00	
Slag Production per site	per year	23054,26	8004,95
Slag Production per site	per month	1921,19	667,08
Slag Production per site	per day	65,87	22,87
Slag Production per site	per hour	2,74	0,95
Slag Density	kg/m3	2880,00	

This information is used in the model whereby slag feed ratio is required to ensure that model is accurate. Once the selected experiment is chosen, this information is also critical to determine slag production versus usage. Two modes of transport have been selected to move material across to site where bricks manufacturing takes place. The conveyor collects the material as it comes from smelter and transfer it across to new site. The front-end loader (FL) is used to load slag onto the tipper trucks and tipper trucks transfer stock to new storage area. The tipper truck can either have single or double trolley to transport more material. This site storage area capacity is only limited to 1000 cubes. There is no need to cover the material during transit with plastic as it does not pose any risk to environment and personnel. Care must be practiced and not overload the trailer and cause spillages alongside the road. Bigger storage area is required to store casted bricks to allow natural curing before being packed on pallets and ready for dispatch. The bricks stay in this area for a minimum of 24-hours to ensure moisture has been totally removed and required dryness achieved. The bricks can further cure while being packed on pallets to allow space for casting more bricks. Different weather conditions affect the curing time, during rainy season bricks stay longer before reaching required dryness. Plastic covers are utilised to prevent product damping before dryness is achieved. The total of eleven (11) experiments run on the model to select the most suitable combination which results in optimal results. The experiment is set to run for only thirty days or one calendar month. The results are then multiplied by number of calendar month in the year to get annual figures. Frist run the simulation with manual operation only and increase number of teams to increase product output.

This is followed by running the simulation with automatic operation only and select different equipment sizes to increase product output. Finally run simulation with both operations in parallel to ensure optimal solution is selected.

Table 5 presents different simulation/ experiments results.

Table 5.
Simulation results.

No	Combination	Exp Code	Slag	Cement	Water	No of batches	No of Bricks	No of houses
1	Manual Line x1	M1	335	1,005	1,005	333	130800	87
2	Manual Line x2	M2	669	2,007	2,007	666	243000	162
3	Manual Line x3	M3	1,003	3,009	3,009	999	363500	242
4	Manual Line x4	M4	1,295	3,888	3,888	1,295	490300	326
5	Auto Linex1	A1	364	1,092	1,092	362	122700	81
6	Auto Linex2	A2	724	2,172	2,172	721	245700	163
7	Auto Linex3	A3	1,086	3,258	3,258	1,082	368000	245
8	Auto Linex4	A4	1,34	4,023	4,023	1,34	490900	327
9	Combined Autox2 Manualx1	A2M1	363	1,089	1,089	361	122600	81
			724	2,172	2,172	721	245500	163
			1087	3,261	3,261	1082	368100	244
10	Combined Autox2 Manualx2	A2M2	678	2,037	2,037	678	245000	163
			689	2,07	2,07	689	245000	163
			1367	4,107	4,107	1367	490000	326
11	Combined Autox2 Manualx3	A2M3	680	2,043	2,043	680	272000	181
			684	2,055	2,055	684	244400	162
			1364	4,098	4,098	1364	516400	343

Based on the results achieved a combination on automatic mixing machine that is able to process 2 cubes at the time with two teams mixing the concrete manually. The total of 1367 cubes of slag, 4 107 bags of cement and 20 535 litres of water is required to produce 490 000 bricks. The average price bag of cement is R100, that means R410 700 worth of cement will be purchased within the year. That means1087 m^3 of slag is used and 667 is equivalent produced per annum. The produced slag is 33 % and used slag is 67 % of slag annual production. Therefore, the operation intends to use annual slag produced, and balance from the existing slag pad. From the experiment, the automatic mixing operation is able to meet same output as it were when running alone. The reason for the loss is unknown and requires further investigation.

According to research by Sathiyabalan and Vidhya [26], a queuing model of a system is an the representation of the system's ability to meet service demands whose occurrences and durations are random. The research process involves constructing a queuing model that is rich enough to reflect the complexity of the real system, yet simple enough to permit mathematical analysis is an art. The results are that ultimate objective of the analysis of queuing systems is to understand the behaviour of their underlying processes so that informed and intelligent decisions can be made in their management. The duration each resource spent on the system is

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represented by either actual or random duration and the capacity of the queue is specified to ensure maximum space is available.

Figure 4 presents the slag utilisation versus what the operation is able to process in a calendar month.

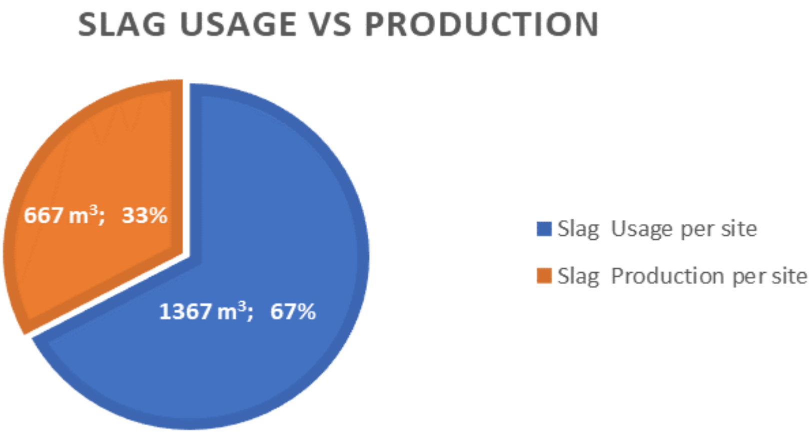

Figure 4.
Slag utilisation.

This means the A2M2 is able to utilise twice as much the slag is produced per month. This means the operation will be able to process what smelter produce and balance from the stockpile.

According to research by Zankoul *et al.* [29], the model saves information on edit-boxes when running experiments and these can be filled by the user to specify the number of each of the resources. The data obtained from running experiment can be imported to excel for analyse the results. The final step before analysing results is to verify and validate the models, and one tool to perform that would be visualization. In conclusion, the models are run and the visualization is observed to see whether the behaviour reflects the desired and the actual process.

Figure 5 presents the plant performance graph. According to Figure 5, the number of bricks is directly proportional to the number of houses that can be completed. The higher the number of bricks produced, the higher the number of houses completed. Based on the results, M4, A4 and A2M3 achieve maximum results and can reach 350 houses per month. A2M2 also produce high number of houses with only 17 houses less the maximum performing experiment.

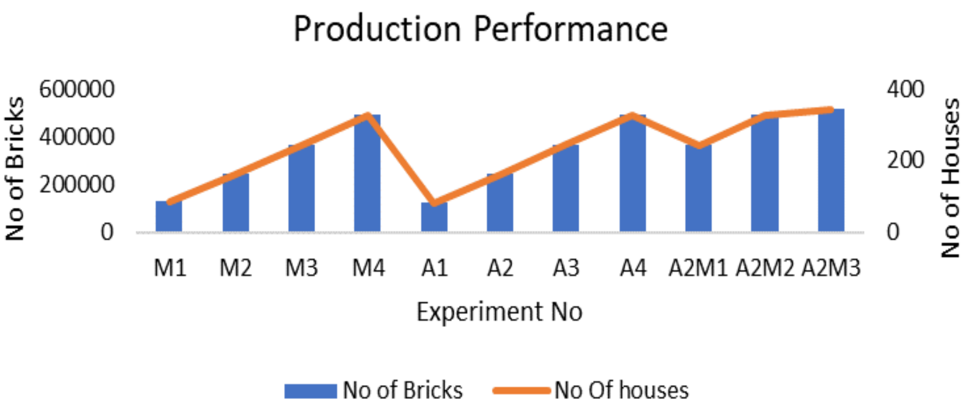

Figure 5.

Plant performance graph.

Figure 6 presents experiments performance over 30 days. The result also shows a direct relationship between the number of bricks produced and the number of houses completed for the period of 30 days.

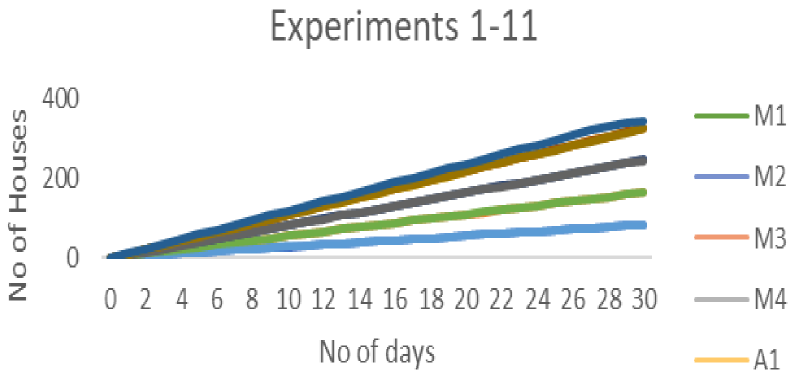

Figure 6.
Experiment results.

Table 6 presents the profitability of the operation over 10-year period.

Table 6.
Business financial performance.

Fixed Costs per Year				
Item	**Each**	**Quantity**	**Value**	**Per Year**
Fork Lift	500000	1	R500 000,00	R550 000,00
Mobile Plant	1500000	2	R3 000 000,00	R3 300 000,00
Portable Plant	10000	1	R10 000,00	R11 000,00
Former	859000	4	R3 436 000,00	R41 232 000,00
Office Containers	15000	3	R45 000,00	R49 500,00
Groundworks	5000000	1	R5 000 000,00	R5 500 000,00
Mixer	105000	1	R105 000,00	R115 500,00
				R50 758 000,00
Other (10% contingency plan)				R5 075 800,00
	Total fixed costs per decade			R55 833 800,00
	Total fixed costs across 4 -sites per decade			R223 335 200,00
Running Costs per Year				
Cement	100	4107	R410 700,00	R4 928 400,00
Water	1,2	20535	R24 642,00	R295 704,00
Labour	18000	88	R1 584 000,00	R19 008 000,00
Drivers	25000	3	R75 000,00	R900 000,00
Management	35000	3	R105 000,00	R1 260 000,00
electricity	2500	1	R2 500,00	R30 000,00
Diesel	18750	2,5	R46 875,00	R51 562,50
PPE	2500	92	R230 000,00	R2 300 000,00
				R28 773 666,50
Other (10% contingency plan)				R2 877 366,65

	Running Costs per site per annum			R31 651 033,15
	Running Costs across 4 sites per annum			R126 604 132,60
Sales per Year				
	Unit cost	Quantity	Total	
Bricks	8	490000	R3 920 000,00	R3 920 000,00
	Sales per site per annum			R47 040 000,00
	Sales across 4 sites per annum			R188 160 000,00
Profit per Year				
	Profit per year across 4 sites			R61 555 867,40
	Profit per Year per Site			R15 388 966,85
	Profit over 10 years			R392 223 474,00

Based on the calculations made, the business will generate a profit of R 15,38 million per site per annum. The total profit of R392,2 million will be realised over 10-year period after settling the operation running costs and equipment costs.

Table refers to the research beneficiaries and benefit they stand to gain due to successful implementation of the research.

Table 7.
Research Beneficiaries.

Beneficiary	Benefit
SMME	• To create jobs and make profit in the process.
Locals	• Considered for job opportunities within which the operation exists. • Improve living conditions for +350 households. • Will receive free RDP houses as promised by DHS. • Will have alternative bricks supplier at reasonable price.
Smelter	• To save money and have options on what to do with waste generated. • Improve environmental air pollution compliance as more plant is removed from operation.
DHS	• Will have alternative bricks supplier at reasonable price. • Reduce the unemployment rate in respective Provinces and improve the GPD of the country.
Cement suppliers	• Will make sales valued at R410 700,00 per year and generate profit.
Security companies	• Get job to keep the operations secured at all time.

3.2. Implementation Requirements

For this operation to be implemented, a proper business proposal is required that stipulate how the business will function and remain competitive in the market. The proposal to include the engagement with smelter companies to negotiate the possibilities to outsource the management and disposal of waste material (slag). The government to provide funding or guarantees for the operation to acquire required resources in order to kick-start the operation. By so doing, the government would have been instrumental to reduce the unemployment rate by +350 people that are required to run the operation. It is the moral responsibility of waste producers to develop effective waste management practises [30].

4. Conclusion and Recommendations

The purpose of this study was to repurpose the slag into bricks for low-cost housing. This was achieved by implementing the Discrete Event Modelling (DEM) in the AnyLogic software. The results achieved from running multiple experiments are captured and analysed. The simulation experiment A2M2 is selected based on the number of bricks produced per calendar month when compared to other experiments. The operation will consume what the smelter produces per year and also consume same output of what has been accumulated over the years. The houses delivered is less than 17 compared to highest production output but A2M2 uses less resources compared to A2M3. This experiment has potentially to create +90 job opportunities per site and +360 overall direct employments. This is based on the 24-hour operation whereby 45 personnel are required per 12-hour shift. This experiment has manufacturing output capacity of 326 houses in thirty (30) days and 3 912 houses per year. This means all operation has total capacity of 15 648 houses per annum. That is 47% of building material (hollow-bricks) required by the DHS to deliver by 2024. The smelter has potential to save over R1,4 billion per decade by giving the slag free for bricks manufacturing. The smelter will enjoy this benefit for as long as they are in business. The operation has positive environmental impact as it has potential to eliminate the use of five earth moving plant equipment (dozer, compactor/roller, water can and two haulers) from the smelter operation. This has potential to significantly reduce air pollution over time. The operation has potential to generate R392,2 million over 10-years in profit. The initial investment pay-back period is 3 years with NPV of R 247 million.

The study contributed positive to the body of knowledge by demonstrating the benefits that can be potential realised when implementing the findings of the study. The are multiple beneficiaries that are linked to the successful implementation of the findings.

This study is limited to simulation modelling and did not conduct any laboratory experiment to obtain quantitative and qualitative data. Future work is recommended whereby laboratory experiment be conducted to verify mortar mixing ratios for optimum results. The prepared samples to be subjected to testing to ensure that bricks have minimum required strength and satisfies all the South African Bureau of Standards (SABS) requirement. The business aspect of the operation is recommended to quantify the real value that can be generated by repurposing slag into bricks to ensure that business is sustainable. This to include the start-up funds required to get the operation running and finance injection required to upscale the operation to produce maximum results. To demonstrate how long it take for the business to start generating profits after paying for start-up costs.

- The unavailability of experimental data limited the evaluation of the developed model to the use of simulated data. Future work can consider the use of primary data set for the evaluation of the developed predictive model.
- The use of student version limited the experiment running time as it stopped when maximum units have been reached. Future simulation to be modelled on the full version for extended running period.
- The bricks curing time is estimated. The recommended future work is to conduct experiment as different weather patterns are experienced in SA. Understand the effects of quick curing as some areas in Limpopo experience too much heat.

- The environmental impact assessment could not be finalised. Future work to include measuring the exact quantity of emissions released by each plant. This to consider the physical condition and engine capacity for each plant.
- This study was completed using DEM only. Future work to use multiple modelling such as ABM, SDM and combination of system to compare results.
- The health impact due to handling the slag is unknown. For future to conduct study to determine minimum health & safety requirement that needs to be in place to protect employees from suffering in long term due to exposure or handling slag.

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