Strategic considerations in the construction of a rare earth facility in Angola: A comparative analysis of modular ex-works construction and traditional stick-build approaches

S. Momberg[1], T. Marcus[1], and M. Dos Santos[2]

[1]ProProcess Engineering, South Africa
[2]Pensana Plc, UK

Rare earth elements (REEs) are essential for permanent magnets which are used mainly in offshore wind turbines and electric vehicle motors. Africa has several rare earth projects at various stages of development involving 13 deposits. LSE listed Pensana Plc plan to establish a new mine and processing facility near the town of Longonjo in the province of Huambo, Angola. The Neodymium-Praseodymium (NdPr) will be extracted from the Longonjo deposit, which is in a rural area in the west of Angola with the nearest urban area having only limited industrial capacity. The Longonjo REE site has limited access to appropriate local construction supplies and skilled labour resources necessary for this scale of project. The site is accessible by road and within proximity to a railway line, which means that all equipment and material must fit within the size and weight constraints of local road usage regulations. The Longonjo project presented an ideal opportunity for the comparison of ex-work prefabricated or modular systems vs more traditional site constructed stick-built solutions.

A risk assessment of the two construction approaches was conducted to analyse and quantify potential risks associated with the installation and operation of the plant. Evaluations of capital cost for specific mechanical equipment, electrical substations and one processing area were provided for the two options. Lastly, the construction time for the processing facility was looked at critically. This comprehensive analysis aimed to provide insight into the comparative advantages and challenges associated with each construction method.

Keywords: rare earth oxides, modular construction, risk rating, mineral processing

INTRODUCTION

Rare earth elements (REEs) are essential for permanent magnets which are used mainly in offshore wind turbines and electric vehicle motors (IEA, 2021). China contributes more than 70% of the worldwide rare earth oxide production. According to the International Energy Agency's Sustainable Development Scenario this sector is expected to double in size by 2040 (IEA, 2021). Given the economic significance, the search for a more sustainable supply is driving exploration projects elsewhere in the world. Africa has a large number (21 of 26) of advanced carbonate projects involving 13 deposits (Shuang-Liang Liu, 2023). The Great Rift Valley has huge potential for light rare earth elements resources (Wooley, 1987), (Yaxley, 2022). Other African REE projects to watch include Phalaborwa (South Africa), Lofdal (Namibia), Makuutu (Uganda), Nguallu (Tanzania), Songwe (Malawi), Steenkampskraal (South Africa) (Hollands, 2023).

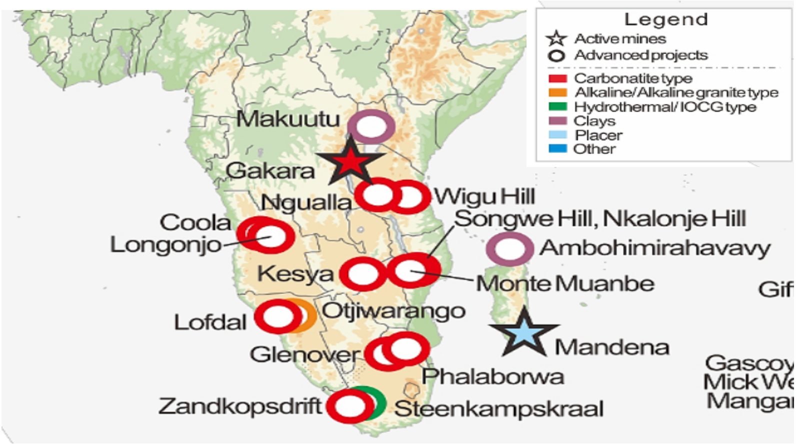

Figure 1. Current distribution of African REE projects (Shuang-Liang Liu, 2023).

Many of these deposits are in remote areas, where access to infrastructure, materials and skilled labour is limited. These factors may have a significant impact on both schedule and cost for any new project. This poses the question of whether using a traditional stick build approach, versus applying an ex-works modular skid construction methodology is more cost effective to build these facilities. This paper presents a techno-economic evaluation of the two construction methods for an REE facility in Angola.

Background on ex-works (modular) versus stick-built construction methods

The concept of using modular (ex-works) construction methods over the traditional stick-built approach in building is gaining traction in chemical processing plants. Many papers have been presented evaluating the advantages and disadvantages of the two construction methods.

Glasser *et al.*, (Glasser, 1979) examined the pragmatic elements associated with modular and barge-mounted plants. Their findings indicated that modularisation had the potential to streamline engineering processes, enhance plant efficiency and production flexibility, shorten time to market, and ultimately boost overall competitiveness.

Oladipupo, Raman, Siirola, and Pekny conducted a comparative analysis between an expandable modular plant (EMP) and a stick built TiO_2 plant (Oladipupo, 2023). Their study concluded that modular plants offered benefits over traditional stick-built plants, such as increased flexibility and shorter construction times. The research primarily focused on developing markets, where regulatory uncertainties and market volatility posed challenges for long-term planning. The results indicated that EMPs could provide economic advantages over conventional large-scale stick-built plants, particularly in developing markets.

In her study, Dita Hořínková, concluded that every construction project presented unique considerations, making the choice of construction technology complex (Hořínková, 2021). She emphasised the necessity for a thorough decision-making process and evaluation, particularly during the design phase. This evaluation should consider the specific requirements of the project and site, rather than solely relying on the broad advantages and disadvantages of construction methods.

The research of Subramanya *et al.*, analysed different facets of modular construction techniques, delving into both their advantages and disadvantages (Subramanya, 2020). It highlighted benefits such as better project scheduling, cost efficiency, increased safety for workers, enhanced project quality and productivity, and environmental benefits. Conversely, limitations included challenges related to project planning, transportation logistics, public and expert acceptance, initial setup expenses, complexity-related costs, and coordination difficulties. Although the findings favoured modular construction due to its numerous advantages, further research is imperative to effectively tackle these challenges on a project basis.

Edwards explores the design of sustainable process plants, emphasising the advantages of modular plants (Edwards, 2023). These plants have units built offsite, which are then shipped and integrated into the site, decreasing labour costs and environmental impact while enhancing facility flexibility. Compared to traditional stick-built facilities, modular plants offer benefits such as sustainability, schedule efficiency, and worksite safety. The article underscores how modular plant design is enhancing sustainability, reducing environmental impact, and improving process plant safety.

Longonjo deposit

The London Stock Exchange-listed Pensana Plc plans to develop one of the world's largest and highest-grade magnet metal rare earth deposits. The project currently under development comprises an open pit, concentrator and recovery plants, tailings storage facility (designed to meet the requirements of the Global Industry Standard on Tailings Management), process water supply, bulk power supply, mine infrastructure, workshops, offices, accommodation village, recreational facilities, and other associated infrastructure.

The Longonjo REE operation will extract, concentrate, calcine and chemically refine the free dig material to produce a high-value mixed rare earth carbonate to be railed to the Atlantic port of Lobito for export (Pensana PLC, 2022). The Longonjo operation is expected to produce 45 ktpa of high value mixed rare earth from 1.5 mtpa feed ore obtained from surface mining. The initial estimate life of mine has been estimated at 20 years (Pensana PLC, 2022).

The deposit is in a rural area in the West of Angola approximately 320 km by road and rail from the nearest port (Lobito). The nearest urban area, the city of Huambo, which is 70 km away, has limited industrial capacity. The result of these factors is that the Longonjo site is isolated from access to significant construction supplies and skilled labour resources. The site is accessible by road and within proximity to a railway line, which means that all equipment and material must fit within the size and weight constraints of local road usage regulations.

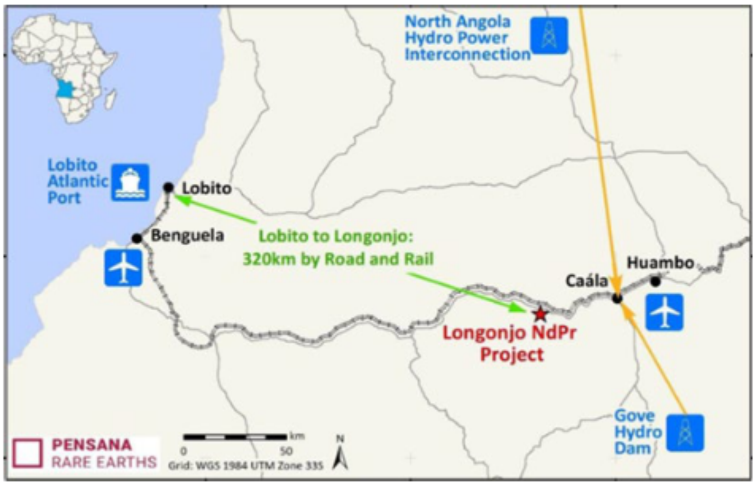

Figure 2. Location of Longonjo mine site in Angola.

The Longonjo project presented an ideal opportunity for the comparison of ex-work prefabricated systems versus more traditional site constructed stick-built solutions. Pensana has investigated and compared the possibility of constructing their processing facility of the Longonjo deposit via the two different construction methods. The comparison of the two construction methods is outlined in this paper.

Stick-built and ex-works construction methodology techno-economic evaluation

For the purposes of this evaluation, a stick-built plant was considered as one that is constructed or assembled piece-by-piece at the construction site, as opposed to factory built and assembled (Dictionary.com, 2024). Ex-works is usually referenced in terms of the incoterm defining the end of responsibility of the seller of a specific item. The contract is considered complete once the item, component or product system has been accepted by the buyer and packaged by the seller, ready for collection at the place of manufacture (the 'works'). In the context of this paper the term ex-works refers to the project execution strategy of factory building as much of the project as possible before transporting to site. In comparing stick-built against ex-works methodologies there were several important factors to consider. These included capex and revenue, schedule, production and availability, operational health and safety (OHS), and environmental impact (Schramke, 2011).

Risk identification

The identification and discussion of the various risks to the Longonjo project was the first step in evaluating the two methodologies. The severity or impact on capex and revenue, schedule, production and availability, OHS, and environmental impact was defined and evaluated against a probability of occurrence. Table I shows the risk rating matrix produced for the Longonjo project, where the severity of a risk was projected against the probability of the risk occurring. The risk rating as assigned in the table was used to identify the severity and likelihood of a specific risk for each execution methodology.

Table I. Risk rating matrix: impact versus probability

		Probability				
Impact		P1: Very low	P2: Low	P3: Moderate	P4: High	P5: Very high
		<7%	7-20%	20-33%	33-66%	>66%
	C5: Very High	C5P1	C5P2	C5P3	C5P4	C5P5
	C4: High	C4P1	C4P2	C4P3	C4P4	C4P5
	C3: Moderate	C3P1	C3P2	C3P3	C3P4	C3P5
	C2: Low	C2P1	C2P2	C2P3	C2P4	C2P5
	C1: Very Low	C1P1	C1P2	C1P3	C1P4	C1P5

Table II presents the definition of the severity of the impact on the various project risks identified.

Table II. Impact severity definition

	CAPEX / Revenue	Schedule	Production / Availability	OHS	Environmental
Very High	>10%	>12 Months >20%	Substantial or total loss of operation: >10% per year	Fatalities, permanent injuries or significant harm to the health of a large number of employees.	Unrecoverable damage to important and well-known natural resources.
High	6 - 10%	6-12 Months 15 - 20%	Partial or temporary loss of operation: 3-10% per year	One fatality or serious permanent injuries of one or more employees.	Major damage to ecosystem and/or long-term impact on natural resources.
Moderate	2 - 6%	3-6 Months 9 - 15%	Partial shutdown of operation (can be restarted): 1-3% per year	Lost time injuries which do not threaten the lives of employees but may affect their normal quality of life.	Medium-scale damage to area of high ecological importance, requiring many months of restoration.
Low	0.5 - 2%	1-3 Months 4 -9%	Brief disruption: <1% per year	Injuries requiring immediate medical treatment.	Minor damage which can be restored by the company's own resources.
Very Low	< 0.5%	< 1 Months <4%	No disruption to operations	Reportable injury not requiring medical emergency.	Insignificant short-term damage.

Risk during project execution phase

A side-by-side comparison of unmitigated risks for stick-built and ex-works construction methodologies during the execution phase of the project was produced and is presented in Table III.

Table III. Risk matrix during constructability and implementation phase of the project

	Risk and Causes	Consequences	Project impact	Stick-built Risk	Ex-works risk
On site construction time	Construction time is one of the costliest portions of a project budget. On-site construction is most susceptible to unplanned delays, such as weather, logistics, industrial action, criminal activity, etc.	Schedule delays Cost increases	Schedule	C4P4	C4P3
Labour	Access to skilled labour in remote areas is very limited.	Quality defects Schedule delays Cost Increases	Schedule	C3P4	C2P1
Transport	Construction in remote areas is heavily dependent on transport corridors, restricted by physical constraints as well as laws and legislation. Transport of abnormal loads certification, permits, transport routes, time on road and support vehicles.	Cost increases Schedule delays	Legal and Compliance	C5P1	C5P3
Access to construction material	Remote areas have limited access to construction material and consumables, necessitating that all material and equipment be carefully planned. Defects, missing items, and damage during transit result in significant delays to construction activities.	Cost increases Schedule delays	Schedule	C5P3	C5P1

The use of an ex-works construction methodology would partially mitigate the risks associated with on-site construction time, skilled labour availability and access to construction material. By fabricating and pre-assembly of a large portion of the equipment and structures in a factory in an industrial hub such as Johannesburg, the access to skilled labour and readily available construction material is significantly easier than having to source these resources from the rural area around the Longonjo site. Following on from this, any preassembly done in a controlled environment, such as a factory, does not need to be completed on site. This reduces the construction time on site and reduces the effect of site disruptions on these activities, as listed in Table III. However, transportation of prefabricated items is more complex than transporting raw material to site, requiring more planning and permits if abnormal loads are needed.

A similar side-by-side comparison of stick-built and ex-works execution methodologies during the plant operation phase was conducted at a high level and presented in Table IV. Three aspects were looked at on the project: the complexity of integrating the various processes together, the maintainability of the plant and the management of the risks associated with commissioning.

Table IV. Risk matrix for integration, operability and maintainability of operating plant

	Risk and causes	Consequences	Project impact	Stick-built risk	Ex-works risk
Integration	Stick-built facilities cater for flexibility in construction plans to adapt to site conditions. This can result in an increase in waste material and implementation delays. Ex-works systems are less flexible to changes in site conditions, relying heavily on the accuracy of early site activities. With adequate planning and quality control, the integration of an ex-works system can be completed seamlessly. Ex-works systems have an advantage in that they can be pretested to ensure all equipment is functioning according to design intent prior to departure to site.	Increased ramp up time	Production and reliability	C4P3	C2P2
Maintenance	Ex-works systems can require a compromise between maintenance accessibility and being packaged to allow for ease of transport. Stick-built facilities can be designed to optimise ease of maintenance while not compromising functionality.	Increased down time. Increased complexity of maintenance activities	Production and reliability	C2P1	C2P4
Commissioning	Pre-testing of ex-works systems significantly reduces trouble-shooting time on site.	Schedule delays	Schedule	C3P4	C3P1

The integration of multiple unit processes when implementing an ex-works execution methodology requires significantly more up-front planning than stick built options, as modifications to preassembled and pretested systems present numerous challenges over having fabricated structures and piping on site. However, proper planning and design review can mitigate this risk and significantly reduce the effort required on site.

Ex-works systems necessitate the skids to fit into transportation envelopes. This affects the layout of and accessibility of equipment. The equipment layouts for ex-works systems are significantly more complex than site-built alternatives and require careful consideration during the design phase.

Ex-works skids are extensively tested and most complex issues, including software functionality testing, are resolved prior to leaving the factory environment. Site commissioning of ex-works systems is significantly reduced.

Capital cost evaluation: Tanks

An evaluation of possible shop fabricated tanks versus equivalent volume site constructed tanks was conducted. Tanks of ≤ 50m^3 were deemed suitable for shop fabrication and transport to site, as these tanks were within the acceptable transport limit, in terms of width and height, for road freight. Most of the process tanks required were of small enough volume to favour shop fabrication and transport. Three storage areas fell outside of these parameters: the NdPr concentrate filtrate feed buffer capacity, sulphuric acid storage capacity and the clarified pregnant leach solution (PLS), ultra filtration (UF) and nanofiltration (NF) feed buffer capacity. A cost comparison for these specific storage capacities was developed to evaluate the preferred solution between transportable, prefabricated tanks and site constructed tanks. The comparison factored in material, fabrication, transport, and site erection costs.

The results of the evaluation are shown in Table VI, where the capital cost was normalised on the site erected value.

Table VI. Site constructed vs shop fabricated tank comparison

Description	Volume required, m^3	Stick-built: Site erected		Ex-works: Shop fabricated	
		Suggested# of tanks	Normalised cost factor	Suggested # of tanks	Normalised cost factor
NdPr concentrate filtration feed	140	2	100%	4	128%
Sulphuric acid storage	880	2	100%	18	329%
Clarified PLS, UF and NF feed	305	2	100%	6	140%

It was evident that for the larger tank sizes the site erected option was more cost-effective. However, once the risk factors identified in Table III and Table IV were considered, the higher price for the clarified PLS, UF and NF feed tanks was deemed acceptable to mitigate the additional risks to the project. For the NdPr concentrate filtration feed tanks, the process was re-evaluated and the number of prefabricated tanks was reduced to three transportable tanks. This resulted in the prefabricated option comparable regarding the equipment supply budget and had the added benefit of eliminating complications associated with site construction. Only the sulphuric acid tank was considered for site erection due the significant cost difference, as well as the process complexity associated with an 18-unit tank farm.

Ex-works to stick-build evaluation

For the comparisons that follow an ex-works/stick-built parameter was produced to compare the cost effectiveness of the two methodologies. The ratio was calculated using Equation 1:

$$\text{Ex-works} / \text{Stick-built} = X_E / X_S \qquad [1]$$

Where:

X_E = Ex-works cost

X_S = Stick-built cost

If the ex-works/stick-built parameter = 1, then the two methodologies have cost parity.

If the ex-works/stick-built parameter < 1, then the ex-works option has a lower cost.

If the ex-works/stick-built parameter > 1, then the stick-built methodology is more cost effective.

Capital cost evaluation: Electrical

A standardised containerised solution was developed for all the electrical substations on the Longonjo project. The substation cost amounted to approximately 3% of total project value. A normalised cost comparison was developed to illustrate the difference between the ex-works substations versus site erected brick-and-mortar motor control centre rooms.

The capital cost estimate for the site erected substations was developed by removing the container cost and providing factorised values for civil, structural, and electrical construction contracting (Bilfinger Tebodin, 2020). The following assumption were made for the estimation of stick-built substations:

- Civil requirements are equivalent to 32% of electrical equipment cost. The difference in requirements for load bearing civils between stick-built and ex-works was assumed to be negligible and as such these costs are the same for both building methods.
- The structural requirements differ for the two construction methods. The structural requirements for the stick-built method are equivalent to 26% of electrical equipment cost which includes all floor, interior and steel structures. The structural costs for the ex-works option are included in the modified container cost.
- The substation building is equivalent to 10% of electrical equipment cost. Again, this only applies to the stick-built option, as the modified containers serve as housing for the substations in the ex-works option.

- Electrical contracting requirements are equivalent to 52% of electrical equipment cost. This too only applies to the stick-built option, as the electrical contracting costs are already included in the modified container costs.
- The difference between transporting preassembled, containerised substations vs transporting the equipment and panels to site is negligible.
- All equipment sent to site arrives damage-free and in good working order, therefore no allowance was made for replacement items.

Using the percentages the cost for stick-built substations was determined as per Equation 2:

$$X_S = E \times (1 + 32\% + 26\% + 10\% + 52\%) = 220\% \times E \qquad [2]$$

Where:
E = Electrical equipment cost

For the Longonjo project ex-works option, the substations were designed to be housed in containers. The cost for ex-works substation was determined by Equation 3:

$$X_E = E \times (1 + 32\%) + n(C_c + C_s) = 132\% \times E + n(C_c + C_s) \qquad [3]$$

Where:
X_E = Ex-works substation cost
E = Electrical equipment cost
n = Number of containers
C_c = Modified container cost
C_s = Container support structure cost

The results of the comparison for each substation on the project are shown in Table VII.

Table VII. Substation cost comparison

Substations	Ex-works/ stick-built parameter (calculated by Equation 1)
140-MCC-001	0.77
140-MCC-002	0.89
140-MCC-003	0.83
140-MCC-004	0.97
140-MCC-005	0.94
140-MCC-006	1.96
140-MCC-007	1.22
12020-MCC-01	0.60
12050-MCC-01	0.56
12060-MCC-01	0.60
13010-MCC-01	1.00
13100-MCC-01	0.71
12050-MCC-02	0.60
Control & server room	1.00
Project total	**0.85**

The determining factor whether the ex-works method was more cost effective compared to the stick-built option was the equipment density that could be housed in a container. The cost associated with a container is fixed regardless of the amount of equipment installed within the container. Once the space required for the equipment exceeds the practical limit for one container, a second container is required. If a substation requires relatively little or low value equipment, the container becomes the driving cost of the system, which in some cases make the stick-built option more cost-effective. However, the installation time, testing and other site-specific issues are not accounted for.

Capital cost evaluation: Unit process package

An indicative cost comparison was developed to show the impact and differences in expected cost for stick-built and ex-works plants. The comparison only looked at a single processing unit, specifically the tailings flocculant reagent package. The indicative costs for the project were developed by adding the direct costs, indirect costs and engineering and project management costs. The two methodologies were compared to each other using the ex-works/stick-built parameter shown in Equation 1.

A framework for the direct costs was developed based on quoted equipment costs, detailed fixed and firm cost estimates for packaged plants and factors utilised for fluid-based process plants as outlined in the Conceptual Cost Estimating Manual for refinery type plants (Page, 1996). The average factors stated in the Conceptual Cost Estimating Manual for stick-built and ex-works plants as a percentage of the process equipment costs are shown in Table VIII. These were used to develop a comparison between the two methodologies.

For the stick-built method, the factors have been taken directly from the Conceptual Cost Estimating Manual for refinery type plants (Page, 1996). The ex-works factors were calculated from budget quotes obtained during the front-end engineering design (FEED) study that was conducted on the project.

Table VIII shows the cost factor associated with the direct material cost of the physical equipment and construction equipment required to build the plant. The subcontracting costs refer to skilled or specialised resources and professional services required on the project. The direct labour covers the semi-skilled and general labour required during execution and is a prorated cost to the project.

Table VIII. Direct cost ratios for stick-built plants versus ex-works plants

Direct cost description	Stick built			Ex-works		
	Material	Subcontract	Labour	Material	Subcontract	Labour
Process equipment	100.0%	44.5%	7.8%	100.0%	35.6%[1]	7.8%
Site preparation	0.0%	0.3%	2.8%	0.0%	0.3%	2.8%
Site improvement	1.0%		1.1%	1.0%		1.1%
Concrete	4.5%	0.1%	12.8%	2.1%[2]	0.1%	6.0%[3]
Structural steel	8.2%		3.7%	9.8%[4]		4.5%[5]
Buildings	1.2%	2.3%	1.7%	0.6%[2]	2.3%	0.8%[3]
Underground piping	1.2%		1.4%	1.2%		1.4%
Above-ground piping	33.5%	0.8%	21.9%	33.5%	0.8%	18.2%[6]
Underground electrical	0.4%		0.7%	0.4%		0.7%
Above-ground electrical	79.0%[7]		6.2%	79.0%[7]		6.2%
Instrumentation	82.5%[8]		3.4%	82.5%[8]		3.4%
Insulation	4.8%		7.5%	4.8%		7.5%
Painting	1.6%		4.0%	1.6%		3.3%[9]
Paving	0.5%		0.7%	0.5%		0.7%
Constr. Equip. pro-rated	1.1%		2.9%	1.1%		2.9%
Rental/purchase	15.0%			15.0%		
Service labour	4.0%			4.0%		
Fuel, oil, grease, supplies	12.0%			12.0%		
Direct costs subtotal	**350.3%**	**47.9%**	**78.3%**	**349.0%**	**39.0%**	**67.1%**
Total direct cost		**476.6%**			**455.0%**	
Ex-works / stick-built parameter (Equation 1)	**0.96**					

1. On-site subcontracting requirements are approximately 20% less for ex-works over stick-built, as the on-site time requirements and the associated costs are significantly reduced when equipment is shop-assembled and tested.

2. The concrete and building requirements for an ex-works project are approximately 47% that of a stick-built project due to the floor structure, building envelope, interior structures and steel structures all forming part of the modular design (Bilfinger Tebodin, 2020).
3. The labour requirements are significantly less for ex-works construction than stick built.
4. Ex-works structures are expected to require 20% more steel (Waanders, 2019).
5. The labour requirements for structural steel are more for ex-works construction than stick-built.
6. Using an ex-works model typically includes a large portion of site piping being included in the factory fabricated module. This in turn results in a large portion of welding being performed under controlled shop conditions, minimising rework, and maximising welding efficiency.
7. The costed value for electrical equipment was used for both stick-built and ex-works.
8. The costed value for control and instrumentation equipment was used for both stick-built and ex-works.
9. Prefabrication of equipment modules includes corrosion protection of the modules before release.

Using the factors shown in Table VIII, the ex-works/stick-built parameter for the direct costs on the Longonjo project was calculated at 0.96, showing that for the package reviewed the ex-works methodology was more cost-effective.

The Conceptual Cost Estimating Manual (Page, 1996) calculates the indirect costs for a refinery type project using the direct labour costs based on ratios presented in Table IX.

In a 2013 McKinsey & Company article titled “Saving time and money” a time saving of 10%-20% for the ex-works construction, (Hart, 2013) is stipulated. The authors state that by adopting an ex-works project execution methodology, a large portion of the typical on-site construction activities are moved to a shop or factory environment, where schedule and task efficiency are better managed. Response times to issues such as spare parts or additional material required is much faster in a factory environment than on site, due to the fabricators being near suppliers.

The direct labour costs from Table VIII and a time saving of 10-20% were used to calculate the indirect costs for this processing unit and the results are presented in Table IX.

Table IX. Indirect cost ratios for stick-built plants vs ex-works plants

Indirect	Recommended ratio of direct labour costs (Page, 1996)	Stick-built	Ex-works with 10-20% time saving incorporated
Direct labour cost		78.3%	67.1%
Salaried indirect cost	10	7.8%	5.4%-6.0%
Office hourly indirect cost	16	12.5%	8.6%-9.7%
Field hourly indirect cost	5	3.9%	2.7%-3.0%
Temporary construction facilities	15	11.7%	8.0%-9.1%
Burden and benefits	27	21.1%	14.5%-16.3%
Small tools and consumables	7	5.5%	4.7%[1]
Other indirect cost	15	11.7%	8.0%-9.1%%
Indirect costs	85	74.4%	51.9%-57.8%
Stick built / ex-works parameter (Equation 1)		**0.70 – 0.78**	

[1] The quantity of consumables used is not dependent on the construction time. The same quantity of consumables will be consumed in a shorter period for ex-works plants.

Table IX shows that the indirect cost range for the ex-works/stick-built parameter was 0.70 – 0.78. This indicated that the ex-works construction method was more cost-effective for a processing unit.

To obtain the final project cost estimate, the home office costs need to be included. These include engineering design services and project management. The engineering design requirements for ex-works type plants are expected to be 20% higher than for stick-built plants due to the requirements of designing and engineering the individual modules (Waanders, 2019). The home office costs as a percentage of the process equipment costs are presented in Table X.

Table X. Engineering costs and total project costs as a factor of process equipment costs

Engineering and home-office costs	Recommended ratio of direct + indirect costs (Page, 1996)	Stick-built	Ex-works
Direct + indirect		551%	507%-512.9%
Engineering/design services	12%	66.1%	73%-73.9%
Construction services	0.2%	1.1%	1%
Project general management	1.1%	6.1%	5.6%
Total project cost as % of process equipment		624.3%	586.6%-593.4%
Stick built / ex-works parameter (Equation 1)		**0.94 – 0.95**	

A 0.94 – 0.95 ex-works/stick-built parameter was obtained, indicating a cost saving on the project when using ex-works methods over stick-built methods.

In this instance the ex-works project execution methodology proved to be more cost-effective over the traditional stick-built method. Each project should however be evaluated independently to determine the most appropriate project execution methodology. The evaluation used conservative estimates for the differences between the two methodologies.

Capital cost evaluation: Schedule

The 2013 McKinsey report claimed it possible to standardise at least a third of all modules that make up even the most complex systems (Hart, 2013). This resulted in an installation time saving of up to 20%. For the Longonjo project a time saving range of 10-20% was assumed to indicate the financial benefit of the modular build. This time saving was applied to the expected 24-month project execution timeline and resulted in overall time to completion being reduced by approximately 2.4 to 4.8 months. The reduction in execution time enables production to start earlier by the same margin and results in getting product to market earlier.

It is important to note that while the benefits of the ex-works method can result in cost and time savings it does place the engineering, planning and project management burden in a very time-sensitive window at the start of the project. It is critical that the engineering and planning is completed early in the project to allow the completion of fabrication and transport to site to coincide with the completion of earthworks and civil activities on site.

CONCLUSIONS

The Longonjo project presented an ideal opportunity for the comparison of ex-works prefabricated systems versus more traditional site constructed stick-built solutions. The deposit is in a remote area, where access to infrastructure, materials and skilled labour is limited.

The risk rating of building a processing plant at the location was prepared for the project and showed that the risk rating during the execution phase and plant operations was higher for the stick-built methodology in both instances. This showed that a modular construction approach was associated with less risk than the traditional method of building.

Capital cost evaluations for large tanks, electrical substations and unit process packages showed that in most cases a modular build was beneficial to the project, especially once the risk profile was incorporated into the considerations. It was deemed beneficial to build the sulphuric acid system on site.

The factorised estimate of packages for the Longonjo project showed that a 5-6% cost advantage can be expected when using an ex-works modular approach to execute the project over a stick-built approach. A conservative approach was utilised when applying the factors, and as the engineering and design are developed further it is expected that the advantage will increase.

When using the modular construction methodology, a 10-20% decrease in project execution time of the processing facility is expected. In the Longonjo example, this results in the modular plant starting up 2.4 - 4.8 months prior to the stick-built method. The production schedule resulted in getting product to market earlier, thus reducing the required working capital needs of the project.

The process for the Longonjo REE project lends itself to a modular approach as the equipment requirements for the various areas are repeatable, meaning that the same tanks, pumps, skids and substations are utilised in multiple locations, which significantly reduces the engineering requirements when these units are standardised and modularised. However, this project will be a hybrid of the stick-built and ex-works approaches as certain equipment does not lend itself to modularisation; for example the thickeners and sulphuric acid tanks which will need to be assembled on site.

The ex-works approach of executing a project has many advantages but it is important to investigate the suitability of this approach for each project. The approach should not be applied without the necessary considerations of engineering resource availability, supplier readiness and logistics constraints, as this execution approach places a large burden on the planning and engineering teams at an early stage of the project.

REFERENCES

Armstrong, R. (1972). Better ways to build process plants. *Chemical Engineering*, 79:86–94.

Aromada, S., Eldrup, N., Øi, L., (2021). Capital cost estimation of CO_2 capture plant using Enanced Detailed Factor (EDF) method: Installation factors and plant construction characteristic factors. *International Journal of Greenhouse Gas Control,* Volume 110. (103394).

Bilfinger Tebodin. (2020). *Construction Cost Analysis: Industrial Projects Central and Eastern Europe,* s.l. Bilfinger Tebodin.

Bloemen Waanders, H. v. B., (2019). *Modular Design vs Stick build (Field Erect).* https://www.linkedin.com/pulse/modular-design-vs-stick-build-field-erect-herb-van-bloemen-Bloemen Waanders/ [Accessed 18 03 2024].

Dictionary.com. (2024). *Stick-built definition.* https://www.dictionary.com/browse/stick-built [Accessed 10 03 2024].

Edwards, D. (2023) Sustainability in modular process plants. AIChE Process Development Symposium,

Hollands, C. (2023). *Rare Earth Projects to Watch in Africa.* https://energycapitalpower.com/rare-earth-projects-to-watch-in-africa/ [Accessed 10 03 2024].

IEA. (2021). *The Role of Critical Minerals in Clean Energy Transitions.* https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary [Accessed 18 03 2024].

Hart, J., Phaf, N. and Vermeltfoort, K., (2013). Saving time and money. *McKinsey & Company*, Article December 2013.

Hořínková, D., Advantages and disadvantages of modular construction, including environmental impacts. IOP Conf. Ser.: Mater. Sci. Eng. 1203 032002.

Glaser, L.B., Causey, E.D., Kramer, J., (1979). Modular plant concepts-practical aspects of modular and barge-mounted plants. Chemical Engineering Progress, 75(10):49–55

Lier, S., Worsdorfer, D., Gesing, J., Business Models and Product Service Systems for Transformable, Modular Plants in the Chemical Process Industry. *Product-Service Integration for Sustainable Solutions*; LNPE, 2013; pp 227– 238.

Oladipupo, P., Raman, A., Siirola, J., Pekny, J.,(2023)., Comparative analysis of an expandable modular plant and a stick-built TiO_2 plant. ACS Omega 44724–44732 https://doi.org/10.1021/acsomega.3c05599 [Accessed 13 05 2024]

Page, J. S., (1996). Ratio Estimating Factors. In: *Conceptual Cost Estimating Manual.* Burlington: Elsevier, Burlington, MA, USA. pp. 316-324.

Pensana PLC, (2022). *Breaking Ground on the World's First Rare Earth Processing Hub. BMO Rare Earths Supply Chain. June 2022.* Pensana PLC.

Schramke, M., (2011). *Comparing Modular Construction vs. Stick-Built Construction.* https://www.bastiansolutions.com/blog/comparing-modular-construction-vs-stick-built-construction/ [Accessed 10 03 2024].

Shuang-Liang Liu*, Fan, H., Liu, X., Meng, J., Butcher, A., Yann, L., Yang, K., Li, X.,(*(2023). Global rare earth elements projects: New developments and supply chain. *Ore Geology Reviews, Volume* 157. (105428).

Subramanya, K., Kermanshachi, S., Rouhanizadeh B.,(2020). Modular construction versus traditional construction: Advantages and limitations: A comparative study. *Creative Construction e-Conference*, 978-615-5270-61-1 https://repozitorium.omikk.bme.hu/items/8a2f1d10-6700-4db7-96e9

Wei, Y., Wang, D., Liu, J., Yu, C.,(2014). Modularization technology development prospects. *Applied Mechanics and Materials*, Volume 509, pp. 92–95.

Wooley, A., (1987). Alkaline Rocks and Carbonites of the World. Part 3: Africa. *Geological society of London. London, UK.*

Woolley, A. and Kjarsgaard, B., (2008). Paragenic types of carbonite as indicated by the diversity and relative abundances of associated silicate rocks: evidencec from a global database. *Canadian Mineral,* Volume 46, pp. 741-752.

Yaxley, G., Anenburg, M., Tappe, S., Decree, S., Guzmics, T.,(2022). Carbonatites: classification, sources, evolution, and emplacement. *Annual Review or Earth and Planetary Science,* Volume 50, pp. 261-293.

Sean Momberg

Project Manager
ProProcess

Project Engineer with over 10 years of experience in Project management, mechanical engineering and design experience in water treatment and hydrometallurgy related projects from prefeasibility studies through execution and commissioning.