A construction manager's perception of a successful constructed wetland

1. Key performance indicators for construction projects

Construction projects, whether large or small, have some form of measurements to identify how successful they have been. One very popular concept used to assess such performances in construction is the adaptation of "Key Performance Indicators" (KPIs). By definition, KPIs are compilations of data measures used to assess the performance of a construction operation [1]. In other words, they are methods that management use to evaluate and assess the performance of the given task or activity. These evaluations are very useful when comparing actual outcome with estimated performance in many aspects including effectiveness, efficiency and quality of workmanship and final product [1, 2].

Performance indicators in construction have often been reviewed through academic works and industry-related publications. All these bodies of work have often suggested similar areas of focus, such as clients' needs, public interests, cost management and safety considerations. Table 25.1 presents excerpts of findings from performance indicators found over the years.

Performance indicators in construction projects have remained consistent over the years. The key recurring areas revolve around stakeholder interests (e.g., clients and public), productivity (time and cost) and safety considerations. By and large, these performance indicators and measurements are integral to projects in a similar manner to business management. Setting out clear targets from the onset of the project helps in the achievement of success. In other words, if the targets are not set, groups and individuals involved in the projects will not be able to assess their accomplishments.

The Building Research Establishment (BRE), a former UK government establishment uses benchmarking as a means of measuring project performance and subsequently achieving continuous improvement. Benchmarking provides a "yardstick" by which to judge your performance [8]. They recommend using bespoke KPIs for organisations that are new to the industry (i.e., organisations without prior project records) in order to be able to assess their progress and inevitably, project success or otherwise. They offer a KPI engine that provides comprehensive support for collecting, reporting and analyzing data. This engine allows organizations to benchmark their projects against a range of data sets including the following:

Latham (1994)	**Egan (1998)**	**Construction Productivity Network (1998)**	**Construction Industry Board (1998)**
Client satisfaction Public interest Productivity Project performance Quality Research & development Training and recruitment Financial	Construction cost Construction time Defects Client satisfaction (product) Client satisfaction (service) Profitability Productivity Safety Cost predictability (const.) Time predictability (const.) Cost predictability (design)	People Processes Partners Products	Capital cost Construction time Time Predictability Cost Predictability Defects Safety Productivity Turnover & profitability Client satisfaction

	Time (design	predictability	

- Client Satisfaction
- Defects
- Construction Time and Cost
- Productivity
- Profitability
- Health and Safety
- Employee Satisfaction
- Staff Turnover
- Sickness Absence
- Working Hours
- Qualifications & Skills
- Impact on Environment
- Whole Life Performance
- Waste
- Commercial Vehicle Movements

The output of the analysis is presented in tables, graphs and action plans. For organisations and construction teams without a firm grasp on performance indicators and measurement techniques, this serves as a very useful tool that can be used until a firm organisational strategy is put in place. Organisational strategies may be fully developed as the organisations gain experience in the industry and are subsequently able to create their own KPIs and benchmarking techniques.

2. Function and Values of Constructed Wetlands

Constructed wetlands are wastewater treatment systems, and are constructed in such a way to improve the water quality including domestic wastewater, agricultural wastewater, mine drainage, petroleum refinery wastes and pretreated industrial wastewater [9]. Constructed wetlands can be effective and provide a number of functions and values, though not all wetlands provide the same values, but all wetlands contribute to [9–13]:

- improvement of water quality;
- support of wildlife habitat;
- cost-effectiveness as for lower energy consumption;
- heat storage and release;
- trapping of sediments and other substances;
- ease of use, maintenance and operation;
- cycling of nutrients and other materials;
- education and research.

As discussed in a previous section, one of the crucial performance indicators of every construction is the client's needs, time and cost considerations and finally safety practices. Thus in order to achieve any of the functional requirements in the above list, stakeholders expect the project to be economical, safe and produced on time.

Beyond the functions discussed above, other interrelated factors must come together in order for a Constructed Wetland project to achieve its expected performance level.These factors depend on clients, legislation and society. The factors range from aesthetic value to users' health and safety. Design and service life, project cost, quality of finished project and environmental impactmust all be considered if the project is to achieve its desired performance level [14].

Performance gaps can be identified at several points in the projects. At the inception of projects,

clients and even designers may have over-ambitious ideas that cannot be realized. However, experience
and feedback processes can be used to identify such issues. Some of the challenges include those in the design phase, when performance targets are set (taking into consideration legal effluent standards etc.).The very important construction phase presents the most difficulty, as shortfalls often lead to compromise of the ambitious ideas conceived from the inception of the project. During the handover stage, workers tend to rush as they are pressured to commission the project and handover to the end-user. This rush can often affect end-user training and poor quality in final finishes. The final phase to identify performance gaps occurs during the system operation. At this stage, operators of the facility may need support to ensure the Constructed Wetland is set up for efficient long-term operation.

2.1 Constructed Wetland Components

Constructed wetland design is based on the integration of vegetation, substrate media, and hydraulic characteristics that are combined to remove the various constituents from wastewater. All these components come together to fulfil the requirements of clients. Successful performance of a natural treatment system not only relies on a good design, but also proper construction and sound operation.
Emphasis should be given to the enhancement of engineering efficiency, economy of scale, supply chain management and, more importantly, to the in-country value supporting nationalization processes. Under these sections, there are difference components:

Vegetation Both emergent/submergent plants (higher plants/reeds) and non-vascular plants (algae) are important in constructed wetlands. The root system of the plants is a critical parameter in the wetland's operation and efficiency, since it supplies oxygen and supports the microbial community that degrades the various wastewater pollutants, while maintaining the hydraulic conductivity of the bed [9].

Substrates Substrates used to construct wetlands include soil, sand, gravel, rock, and organic materials such as compost. Sediments and litter then accumulate in the wetland because of the low water velocities and high productivity typical of wetlands. The substrates, sediments, and litter are important for several reasons [9]:

• They support many of the living organisms in wetlands.
• They support the growth of the planted macrophytes.
• Substrate permeability affects the movement of water through the wetland.
• They stabilize the wetland bed (interaction effects with developed plant roots).
• Substrates provide storage for many contaminants.
• They provide filtration effects.
• Accumulation of litter increases the amount of organic matter in the wetland, which provides sites for material exchange and microbial attachment, and is a source of carbon, which is required for some pollutant removal processes in wetland systems.

Hydraulic characteristics Wastewater treatment by constructed wetlands depends on the retention time within the system. The actual retention time within a constructed wetland is usually unknown and may differ from the theoretically calculated, given that it is a function of the wastewater flow path and an extent of wastewater interactions with the wetland porous media and vegetation. Moreover, proper design of the wetland system (e.g., selection of appropriate media porosity, hydraulic load etc.) is crucial for the effective performance of the system.

3. Clear Deliverables of Project

In addition to being able to deliver a project that addresses client needs, regulations and societal necessities, every construction project manager or leader needs to understand the practicalities of the various milestones they set in their projects. Deliverables are the products, services, and results that a project produces. Thus, they are the cornerstone to project success. These help project teams identify the feasibility and practicalities of the projects. The key to the success of each phase in the process is the production of project deliverables [15].These include reports and documentation associated with each phase, e.g., engineering reports, proposals, design drawings and design documents. They act as the agent, which ensures the enactment of each phase as planned, concluding with the presentation of the deliverables at each end of phase review.

Deliverables are active working documents, which are subject to change throughout the majority of construction process. They can be in one of the following states [15]:

- **Initial:** preliminary information is presented;
- **Updated:** current information is updated;
- **Revised:** major changes/decisions will significantly alter the content and context of the deliverable; and
- **Finalized:** the information presented is agreed and is unlikely to change throughout the duration of the project.

Since deliverables are active documents, it is important that all involved parties in the project have "real time" access to any changes in order not to create any ambiguities. Scope of work forms an integral part of a constructed wetland and includes, but is not limited to, the following:

- Characterization of wastewater through sampling and analyses program.
- Identification of pretreatment requirements: a comprehensive review of existing water separation facilities for wastewater, including assessment of treatment effectiveness.
- Specifying all required facilities to enable treated water re-use in irrigation or other requirements.
- Preparation of construction documents with a review process, including:
  – Construction grade survey
  – Geotechnical site evaluation
  – Permitting and approvals
  – Final site selection
  – Preparation of specifications
  – Integration engineering design including controls specification, permit review and preparation
  – Cost estimates that include life cycle analysis.
- Development of Operational Manual: key element of final design.
- Final design manual.
- Integrate appropriate elements into design to allow fully-functional treatment facility to be used at demonstration, safe for visitors and environmentally friendly.
- Specify sampling and monitoring requirements.
- Specify protocols.

3.1 Health and Safety Considerations in Construction Projects

Most countries with developed infrastructural planning methods have comprehensive safety frameworks.

The Health and Safety Executive (HSE) offers guidelines that broadly prescribe the general duties for employers, employees and the self-employed through the CDM regulations 2015. Due to the common practices amongst Commonwealth nations, many countries around the world have adopted aspects of these regulations. Furthermore, the CDM regulations are built upon EU directives of workplace safety.

Historically, the fundamental principles on which CDM Regulations are based are as follows [16, 17]:

- Safety must be systematically considered throughout the course of the project.
- Every member who contributes to the health and safety of a project needs to be included.

• Proper planning and coordination need to be undertaken from the commencement of the project.
• Individuals in charge of the provision of health and safety need to be competent.
• Communication and sharing of information between all parties must be undertaken.
• A formal record of safety information for future use must be made.

As stated, under these regulations, not only is the contractor responsible for the health and safety of workers; all stakeholders, including the client have a duty to ensure works and activities are carried out
under safe conditions. In contrast, contractors were also left with the sole responsibility of handling health and safety matters under previous regulations. Table 2 presents the various stakeholders and their roles under CDM Regulations 2015.

Table 2 Summary of duties under CDM Regulations 2015 (adapted from HSE, 2016)

CDM Dutyholders* – Who are they?	**Main duties**
Commercial clients – Organisations or individuals for whom a construction project is carried out that is done as part of a business.	Make suitable arrangements for managing a project, including making sure: • other dutyholders are appointed as appropriate • sufficient time and resources are allocated Make sure: • relevant information is prepared and provided to other dutyholders • the principal designer and principal contractor carry out their duties • welfare facilities are provided
Domestic clients – People who have construction work carried out on their own home (or the home of a family member) that is not done as part of a business.**	Though in scope of CDM 2015, their client duties are normally transferred to: • the contractor for single contractor projects • the principal contractor for projects with more than one contractor However, the domestic client can instead choose to have a written agreement with the principal designer to carry out the client duties.
Designers - Organisations or individuals who as part of a business, prepare or modify designs for a building, product or system relating to construction work.	When preparing or modifying designs, eliminate, reduce or control foreseeable risks that may arise during: • construction • the maintenance and use of a building once it is built Provide information to other members of the project team to help them fulfil their duties.
Principal designers - Designers appointed by the client in projects involving more than one contractor. They can be an organisation or an individual with sufficient knowledge, experience and ability to carry out the role.	Plan, manage, monitor and coordinate health and safety in the pre-construction phase of a project. This includes: • identifying, eliminating or controlling foreseeable risks • ensuring designers carry out their duties Prepare and provide relevant information to other dutyholders. Liaise with the principal contractor to help in the planning, management, monitoring and coordination of the construction phase.
Principal contractors – Contractors appointed by the client to coordinate the construction phase of a project	Plan, manage, monitor and coordinate health and safety in the construction phase of a project. This includes: • liaising with the client and principal designer • preparing the construction phase plan

where it involves more than one contractor.	• organising cooperation between contractors and coordinating their work Make sure: • suitable site inductions are provided • reasonable steps are taken to prevent unauthorised access • workers are consulted and engaged in securing their health and safety • welfare facilities are provided
Contractors – Those who carry out the actual construction work, contractors can be an individual or a company.	Plan, manage and monitor construction work under their control so it is carried out without risks to health and safety. For projects involving more than one contractor, coordinate their activities with others in the project team – in particular, comply with directions given to them by the principal designer or principal contractor. For single contractor projects, prepare a construction phase plan.
Workers – Those working for or under the control of contractors on a construction site.	Workers must: • be consulted about matters which affect their health, safety and welfare • take care of their own health and safety, and of others who might be affected by their actions • report anything they see which is likely to endanger either their own or others' health and safety • cooperate with their employer, fellow workers, contractors and other dutyholders

** Organisations or individuals can carry out the role of more than one dutyholder, provided they have the skills, knowledge, experience and (if an organisation) the organisational capability necessary to carry out those roles in a way that secures health and safety.*
*** CDM 2015 applies if the work is carried out by someone else on the domestic client's behalf. If the householder carries out the work themselves, it is classed as DIY and CDM 2015 does not apply.*

3.2 Hazard Identification and Risk Screening

The hazard identification and risk screening process is a key to the effective implementation of HSE Management Systems (HSEMS).The processes described ensure that all hazards and potential effects for the construction of the wetland are fully evaluated. The key processes are shown in Table 3.

Table 3 Hazard identification and risk screening processes considered during the a constructed wetland project.

Integrated Hazard Identification and Risk Screening	
1	Carry out a HAZID exercise with project personnel to identify the hazards associated at each site/facility and quantify the risk into High, Medium, and Low Categories.
2	Carry out and ENVID exercise with project personnel to identify the hazards associated at each site/facility and quantify the risk into High, Medium, and Low Categories.
3	Carry out an Occupational Health Risk Assessment (OHRA) exercise with project personnel to identify the hazards associated at each site/facility and quantify the risk into High, Medium, and Low Categories.

4	Carry out Risk Screening
5	Populate Hazard and Effects Register
6	Develop Bowtie Diagrams

3.3 Securing the Project

Securing construction materials and components are of high priority during the construction phase. This is because of the financial worth of these materials and components. As a result, site storage and handling of equipment and materials are considered as high risk aspects of projects [19]. Estimates from the United States alone indicate that between 1 and 4 billion dollars' worth of materials, tools, as well as large and small equipment are stolen every year from construction sites [20, 21].With such high figures, it is therefore understandable why securing projects against theft and vandalism is not taken lightly.

Theft This is when people steal from construction sites. Many construction sites (large, medium or small) experience high levels of thefts annually. The compilation of financial losses incurred by construction firms is so significant that many contractors have to pay high premiums for their risk insurance coverage. Workers have to implement proactive measures to help prevent theft of equipment,
materials and building components. The use of lockboxes, security fencing, warning signs,
removal of unused equipment and use of night security forces are all measures that are used. With regard to theft of machinery and equipment, workers park equipment and machinery in well-lit areas and in a specific formation in order to prevent thieves from driving them off site. Finally, some companies
modify the ignition or fuel lines of their machinery so that they cannot be stolen.

Vandalism This is considered to be a nuisance crime. However, this is does not cause as much financial loss as theft, but is still a cut-back on profits. The types of vandalism found on construction sites include the following:

• broken glass;
• destruction of in-place materials;
• damage to construction equipment; and
• vehicle damage vandalism.

Small to medium-sized companies have been found to experience higher losses from incidents of vandalism. This may be as a result of the inability to provide high level surveillance and security on their projects.

4. Critical Points in Constructing Wetlands

There has been much research on constructed wetlands, but the optimal design of constructed wetlands for various applications has not yet been determined [9].This means that there is not a widely accepted or applied design. Each wetland design is based on the specific wastewater characteristics and origin, as well as client needs and targets. As mentioned earlier, this chapter will not focus on the operational aspects of the wetlands, but the design and construction phases. Since wetland designs attempt to mimic natural wetlands in overall structure, many of the considerations made while designing them are relatively different from traditional construction projects. Some of the main design considerations for successfully constructing wetlands include [22]:

• Keep the design simple. Complex technological approaches often invite failure.
• Design for minimal maintenance.
• Design the system to use natural energies, such as gravity flow.
• Design for the extremes of weather and climate, not the average. Storms, floods, and droughts are to be expected and planned for, not feared.
• Design the wetland with the landscape, not against it. Integrate the design with the natural topography of the site.

• Avoid over-engineering the design with rectangular basins, rigid structures and channels, and regular morphology.
• Give the system time. Wetlands do not necessarily become functional overnight and several years may elapse before performance reaches optimal levels. Strategies that try to short-circuit the process of system development or to over-manage often fail.
• Design the system for function, not form. For instance, if initial plantings fail, but the overall function of the wetland, based on initial objectives, is intact, then the system has not failed.

The key success points for constructing wetlands and traditional construction projects have some similarities in some areas, but could not be more different in others. In some construction projects, designers tend to use simple designs that can be produced by the construction teams. However, in many other cases, designers showcase their creativity and produce outstanding projects that require very few and capable teams to bring to reality. Furthermore, clients' briefs often produce challenges because of what they want, how they want it and when they want it. Making use of natural energies is commended in construction, e.g., making use of sunlight and rainwater harvesting techniques. These fall within the broad categorization of sustainable designs. However the design may not always embrace nature as planned and, hence, may have to be altered accordingly. With regard to extreme weathers, any infrastructure is designed using the knowledge of existing structures in the area in addition to the environmental contexts. For example, a construction near the coastline will take salt spray from the sea into consideration and, thus, not use components and materials that are highly susceptible to rust. Although over-engineering is regarded as a waste of resources, designs that do not conform to the norm are commended.
The final two points are critical in both designs. In traditional construction, time is often limited and workers are forced to finish in very tight timeframes. However, constructed wetlands are designed to offer allowance for time. Some designs can be given years to deliver their purpose. Finally, constructed wetlands are designed for function. However, many construction designs are based on ostentatious ideas. The function of every aspect of the construction should deliver as expected, unlike constructed wetlands where the bigger picture is considered, i.e., "If initial plantings fail, but the overall function of the wetland, based on initial objectives is intact, then the system has not failed".

5 Summary

This chapter has briefly discussed the areas that are considered to be critical to construction success of a constructed wetland project. The key performance indicators of construction projects, i.e., setting up benchmarks and other means of measuring if the project has been able to deliver all the proposed objectives in the project were discussed. In addition, the functions of constructed wetlands and their various components were presented, highlighting how important it is for every facet of the constructed wetland to carry out a specific role and possess unique qualities. While constructed wetlands
should perform a certain function, the design and construction phases of projects need constant review and these must be recorded in project documents and portfolios, namely project deliverables. One area that both traditional construction and constructed wetlands consciously try to adopt is natural resources. Both areas prioritize environmental impacts of the projects although by sheer size of projects, the constructed wetland is less harmful to the environment. Securing project sites is also of much concern to construction teams. This is not intensively highlighted in constructed wetlands projects probably because of the location of the projects, e.g., usually away from human settlements to blend in with nature. The health and safety aspects considered in constructed wetlands is mainly about public health as an aftermath of the wetlands treating the municipal or industrial wastewater. Health, Safety and Environmental Services form an integral part of the design, construction and operation of a constructed wetland. The actual practices of the teams that build constructed wetlands can be explored in great detail for empirical evidence in future.

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