Eighth International Conference on Construction in the 21st Century (CITC-8)
"Changing the Field: Recent Developments for the Future of Engineering and Construction"
May 27-30, 2015, Thessaloniki, Greece

Construction as Biological Cells: Implications of the Biological Cell Cycle for Managing Construction

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Abstract
The concept of a *cell* as a unit of construction is advanced exploring the notion of *construction as biological cells* metaphorically, inspired by the striking similarity of a biological cell as a building block of a multicellular organism with the hope of finding new ways of solving perennial construction problems given also that many have benefitted by learning from nature. As biological cells procreate through cell division, it follows a unique cyclic process with an astonishingly error-free cell division process despite the complexity of the process. This cyclic process consists of four phases with three checkpoints including a forced rest state. A critical incident with a quality problem was selected in order to examine the relevance of the biological cell cycle. Study finds that checkpoints at mobilisation and completion are invaluable. Results suggest there is potential for further exploration of the cell cycle to establish its value, reliability, and validity with the hope of developing a suitable cell cycle control mechanism for construction including the form and nature of the *embedded design* and *cell control checkpoints*.

Keywords: biological cell cycle, biomimicry, cell, cellular construction, metaphor

1. Introduction

The concept of a *cell* as a unit of construction is not difficult to understand. According to the Oxford Advanced Learner's Dictionary it is explained as a 'very small room, compartment in a honeycomb, a device for producing an electric current by chemical action, a small group of people forming a centre of (especially revolutionary) political activity; a terrorist cell' and also as a 'microscopic unit of living matter, containing a nucleus' noting that human tissues are made up of cells. The focus of this paper is the latter pursuing a metaphorical approach to explore the notion of 'construction as biological cells' (Abeysekera & Shelke, 2013, 2015).

The word cell can be used quite widely in construction to refer to (say) cylindrical concrete pipes in culvert construction, a floor or an apartment complex in a multi storey building (Abeysekera & Shelke, 2015), repetitive concreting operations in tunnel construction (Abeysekera & Shelke, 2013) or even as a project cell (Aquere, Dinis-Carvalho, & Lima, 2013) and a project management cell or nucleus (Abeysekera, 1986). Additionally, a feature of a *construction cell* is its repeatability as when constructing a brick wall with each course or a composite unit of a header and stretcher course representing a cell (Abeysekera, 2012) from a micro perspective, or as a single apartment in the construction of a multi- storey apartment complex from a macro perspective (Abeysekera & Shelke, 2013) - all culminating in the

formation of a multi-cellular structure using the *cell* as a building block. Interestingly, biological cells seem to show very similar characteristics when forming multicellular organisms say in human beings, the *cell* being the basic *building block* (Cassimeris, Lingappa, & Plopper, 2011, p. 4). Given this striking similarity, it transpired that exploring the notion of *construction as biological cells* may generate new insights on how construction could be managed given the perennial problems of construction whilst noting that biological cells procreate with astonishing accuracy (Karp, 2008; Kunkel, 2011) and that many have benefitted by learning from nature (Benyus, 2002).

2. Biological Cell Mechanism

In the quest to further explore Biological Cell Theory (BCT) to construction, Abeysekera and Shelke (2013) synthesised three concepts exploring the notion of *construction as biological cells*. These three concepts are *embedded design (DNA)*, *rate of cell proliferation* and *biological cell cycle*. As mentioned before, this paper focuses on the concept of the *biological cell cycle* and its implications for construction work.

According to BCT, new cells originate only from other living cells and the process by which this occurs is known as 'cell division'. As it procreates through division, each dividing cell passes through a series of defined stages known as the 'cell cycle' shown in Figure 1. It is an **ordered set of stages** that results in the **accurate division** of one cell into two with exactly similar properties (Cassimeris et al., 2011, p. 985); this is what is known as 'symmetrical' division although there can be asymmetric cell divisions too as in stem cells with different properties (Karp, 2008, p. 652).

As existing cells die, new cells are formed to maintain the balance. The timing and rate of cell division is crucial to normal growth. The frequency of cell division varies with the type of cell but the process remains the same; in this sense, it is a unique process. Not all cells divide however as some may remain dormant (e.g. lever cells) until an appropriate need arises (Reece et al., 2011, p. 242). Examples are nerve cells, muscle cells, or red blood cells, that are highly specialized and lack the ability to divide (Karp, 2008, p. 562).

Broadly, the ***cell cycle*** consists of ***two stages, Mitosis (M) – the stage where the cell divides into two cells, and the Interphase – the stage where the cell grows with this phase having three additional phases viz. G1, S, and G2*** In most cells, the "Gap" phases (labelled as G1 and G2) separates the M and the S phases, where S denotes the phase in which the DNA is synthesized (Cassimeris et al., 2011, p. 674), i.e. what this paper refers to as the 'embedded design'. These stages are shown in Figure 1.

Cell division cycles do not occur continuously although it proceeds on its own, driven by a built-in clock similar to the control device of an automatic washing machine. The entry into the cell cycle is controlled by both internal and external conditions just as a washing machine's cycle is 'subject to both internal control (such as the sensor that detects when the tub is filled with water) and external adjustment (such as activation of the start mechanism)' (Reece et al., 2011, p. 243). This is achieved by regulating the cell cycle at checkpoints; an interesting feature of the cell cycle control mechanism. Such control is required to ensure that the 'cell does not enter the cell cycle when resources are not available to complete the cycle. It would be equally disastrous were the … cells allowed to divide continuously without regard for what other cells around them were doing; organisms are said to be communities of cooperating cells, and the corporation includes strict controls on *when* cells divide. The consequences of breakdown in the controls in even a small number of cells can be seen in cancer, a disease of uncontrolled cell division [eventually killing the organism]' (Cassimeris et al., 2011, p. 674).

In all, there are ***three checkpoints*** as shown in Figure 1: G1 checkpoint, G2 checkpoint and the M checkpoint. In essence, these are stop and go-ahead points with signals coming from cellular surveillance mechanism inside the cell. 'For many cells, the G1 checkpoint – dubbed the *restriction point* in mammalian cells- seems to be the most important….If it does not receive a go-ahead signal at the point

[say due to lack of nutrients, growth factors or defective DNA] , it will exit the cycle, switching into a non-dividing state called Go (i.e. G zero) phase. Most cells in the human body are in the G0 phase … Mature nerve cells and muscle cells never divide [and] other cells such as liver cells, can be *called back* from the G0 phase to the cell cycle by external cues, such as growth factors released during injury [as noted earlier] (Reece et al., 2011, p. 243).

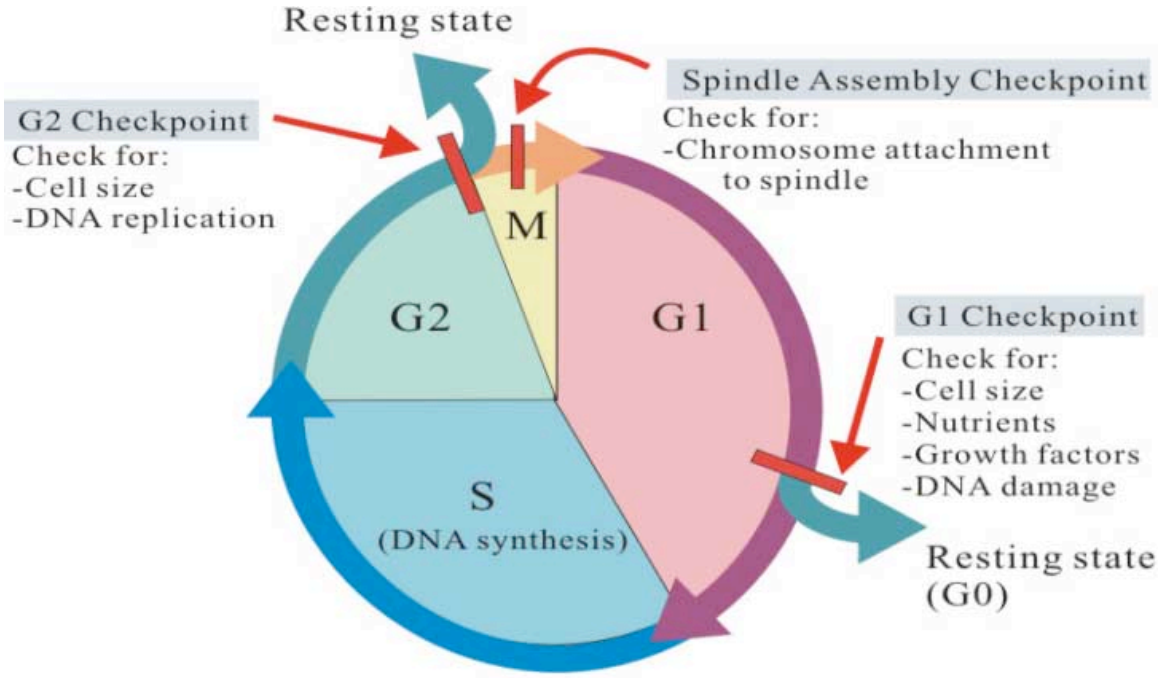


Figure 2: Cell Cycle Phases (G1-S-G2-M and Go) with the Three Checkpoints
(Source: http://blc.arizona.edu/courses/mcb422/PathFinderFolder/422_PathFinder_Intro.pdf)

In summary, cells growing cells procreate through division. This is controlled through the cell cycle which consists of an ordered set of phases, i.e. M, G1, S, and G2. These phases are regulated in both time and space through a surveillance mechanism known as checkpoints to ensure the correct order is followed and the fidelity of the cycle process ensured in order to produce an error-free cell. It is interesting to note that according to Cassimeris et al. (2011, p. 699) these 'check points may be essential only when cells are stressed or damaged but may also act during a normal cell cycle to ensure proper coordination of events'.

Reflecting on the above discoveries, one may raise the thorny question of whether in fact by emulating the biological cell's procreating mechanism which produce astonishingly error-free results (Karp, 2008; Kunkel, 2011), would construction professionals be able to overcome the perennial problems of construction?

3. Aims, Objectives and Methodology

This study adopts a metaphorical approach to explore the notion of *construction as biological cells* focussing specifically on the biological cell cycle to understand its relevance to construction. Previous studies have shown the value of the metaphorical approach to generate new insights and conceptual frameworks for solving complex problems (Abeysekera & Shelke, 2015; Midgley, Trimmer, & Davies, 2013).

The aim of this study was to understand the relevance of the biological cell cycle to construction. In order to do so, the procedure adopted was to select a construction problem and to see whether the problem

could be avoided if the biological cell cycle stages were followed. It was decided to select a quality related problem from an on-going construction project where the second author was a participant-observer. The problem was such that the quality defect has had a significant impact on time and cost despite the operation of a seemingly 'good' quality management system at this project.

The problem is presented through a case study. Different phases of the cell cycle was analysed to understand whether the problem being investigated could have been prevented if the biological cell cycle stages and the checkpoints were followed diligently given that the existing quality management systems had failed to detect the problem and the time period set for its completion had been exceeded significantly resulting in an additional cost to the client.

4. Case Study – Installation of Pulley Systems in a Conveyor System

4.1. Project details

This case is drawn from an Australian $300M project with the design supplied by the client to 'supply and build' coal stockyard consisting of five primary mechanical systems, ten electrical substation and a utility system. The mechanical system consists of a yard conveyor and a gantry stacker for conveying and stacking coal across the stock yard. A typical conveyor system layout is illustrated in Figure 2.

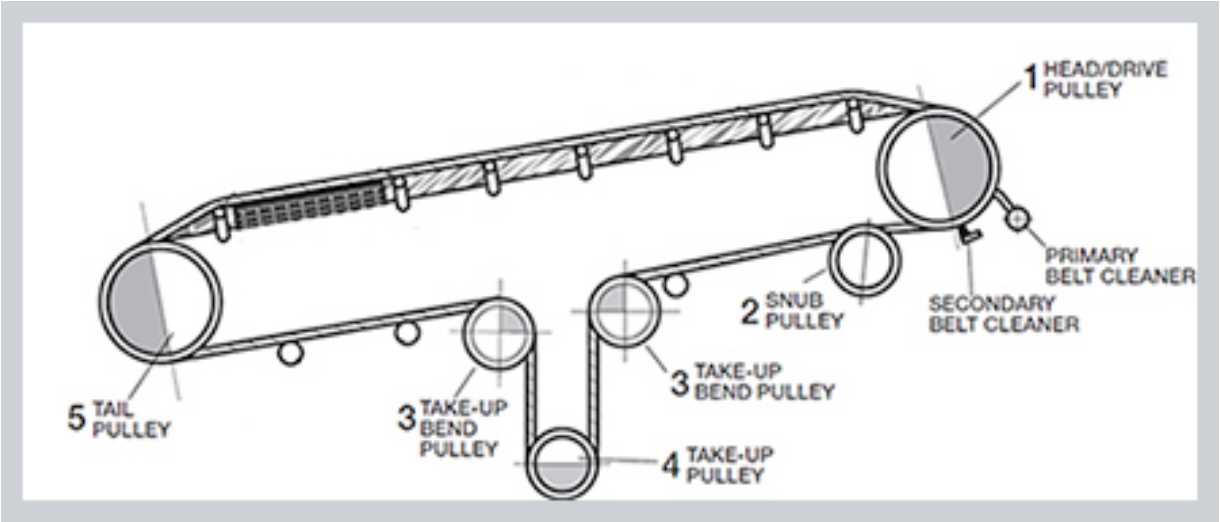
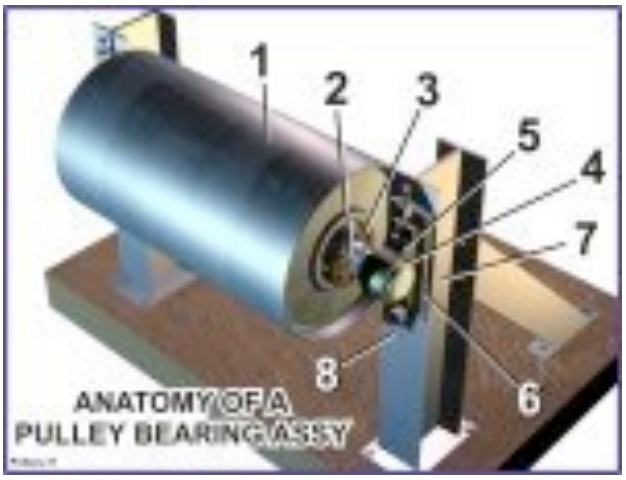


Figure 2:
Typical layout of conveyor belt system with pulleys http://velaan.com/services.html

The layout shows contours of the belt supported by rollers and pulleys. The pulleys which are supplied by the client are attached to the support structure (or mechanical frame) and are electro mechanically driven to form an endless loop of the conveying belt which effectively provides a pathway for coal. Typically, the distance between the head and tail pulley is around 1000m with a number of frames in between. The attachment between the pulleys to the frame are through two sole plates, one in the pulley system as shown in Figure 3 and the other in the frame. The scope of the contractor included installation of forty six pulleys of varying diameter ranging between 1000mm and 1300mm across the various systems are shown in Table 1. As seen from this table, there are different types of functional systems and each one of these use different types of pulleys ranging from Pulley Type 1 to 8 based on design but there are many similarities in the pulley systems and functional systems making it possible to identify *construction cells* – an issue that is not discussed in this paper.



Pulley installation support structure consists of the pulley shell (1) is fixed to the pulley shaft (2) by means of locking elements (3). The shaft is supported in bearings (4) which are housed in plummer blocks (5) to enable the pulley to rotate freely. The plummer blocks are secured on sole plates (6) which are welded to the pulley support structure (7). The stainless steel sole plates enable the pulley to be aligned by adjusting the jacking screws (8).

Figure 3: Pulley Installation on Support Structure
(Source: http://www.ckit.co.za/secure/conveyor/troughed/pulleys/pulleys_bearings_basics.html)

Table 1: Break of Pulleys as per Functional System in Contractor's Scope of Work

Functional System/Pulley	Pulley Type 1	Pulley Type 2	Pulley Type 3	Pulley Type 4	Pulley Type 5	Pulley Type 6	Pulley Type 7	Pulley Type 8	Total
Conveyor-Yard	1	4	1	1	3	1	0	0	11
Gantry Stacker	0	0	0	0	0	0	1	1	02
Reclaim Tunnel A	1	2	2	1	4	1	0	0	11
Reclaim tunnel B	1	2	2	1	4	1	0	0	11
Surge Bin	1	2	1	1	5		1	0	11
Total	4	10	6	4	16	3	2	1	46
% Pulley Types	**9%**	**22%**	**13%**	**9%**	**35%**	**7%**	**4%**	**2%**	**100%**

4.2. Construction *cells* and the *embedded designs*

Evidently, there is a replicating unit (i.e. the building block, or the *cell*) which is identical, namely, the pulley assembly and the frames, which are replicated as per the *embedded designs*. It comprises of (presumably) all the technical and management plans detailing sequence, methodology, tolerances, procedures for controlling quality such as inspection and test plans (ITPs) and inspection test check sheets (ITCs), etc. which are required to unfurl the *embedded design*. Thus, it specifies not only what is required, but how it will be achieved, and what checks should be in place to achieve the cell replication correctly.

4.3. Critical incident

All pulley system cells within and across the system were replicated successfully but for the installation of Pulley Type 3 in both the Reclaim Tunnel system. The quality defect arose due to improper matching between the sole plates of the pulley and that of the supporting structure. The supporting structure sole plates had an uneven surface thus not allowing proper installation of the pulley. The quality management team failed to pick up the problem as it was detected by project engineers. Subsequently, a non-conformance report was produced by the quality team yet the defective frames were installed. Discussions with the relevant project engineer of the contractor clarified that the call to carry on with the installation was made with the 'hope' of client accepting the assembled pulley structure based on review of the as built survey report. However, the client, on inspection, rejected the pulley installation. This led to

dismantling the assembled works on one structure (as other pulley was then not installed) and carrying out required repairs in-situ to the supporting structure at a height of nearly twelve meters above the ground. Not only there were greater risks due to working at this height, the overall duration of the pulley installation increased to nearly twenty days for both the systems-Reclaim Tunnel A and B! Could this have been arrested if the client insisted on a sign-off at a relevant stage with a group of personnel with different expertise? Should such checks be ensured strictly?

A study was undertaken to identify the reasons why the quality team failed to identify the problem initially: Although a check item was there for the sole plate in the ITC for the pulley system, it was discovered that there wasn't one for the frame with the defective sole plate. In other words, the *embedded design*, i.e. the ITC for the framework was **faulty**. **Control** exerted by quality system was insufficient as unfit item identified in non-conformance report was used. Additionally, **communication protocols** between the two cells (pulley and frame) seem weak too (a design fault) as the two check-sheets missed the opportunity to mirror each other in relation to the sole plate check.

4.4. Case analysis vis-à-vis the biological cell cycle (BCC)

Arguably, one of the building blocks, or cells, of this conveyor system is the pulley system. Just as much as biological cells produce multi-cellular organisms, the pulley-cells combine to produce the conveyor system integrating with other cells. As mentioned before, in the case of biological cells, the process of creating new cells (through division) is tightly regulated by ensuring that a cell goes through the four phases controlled by the checkpoints. Could this construction problem have been avoided if a cyclic process similar to biological cells had been adopted? This analysis is carried out using the BCC framework to consider how it would have handled the replication of the construction cell. This is shown in Table 2. The labels given for the construction cell stages are those perceived by the authors but ideally this is a matter that needs to be agreed in consultation with industry (currently underway).

Table 2: Exploring the Biological Cell Cycle to Construction

Phase	Biological Cell	Construction Cell (as interpreted by the authors)
M (Mitosis) and M checkpoint	Produce two nuclei each with complete copy of entire chromosome in original cell: Cell division. Checkpoints to ensure chromosome segregation is complete in order to produce two identical cells (i.e. before dividing)	**Embryonic stage** Production of the previous cell is complete and accepted. Beginning of a new cell. Embedded design is ready to be replicated **only if perfect** **Embryonic stage checkpoint: Readiness for mobilisation** Cannot proceed with sign-off Establish sign-off procedure by *Production Team*
Go	Cells in state of rest; do not take part in replication, stays in non-dividing phase if checkpoint Go signal is not received.	**Stop Notice** No construction activities until approval is received
G1 and G1 checkpoint	Cell grows. Awaits to proceed to next stage if all nutrients are in place and DNA (embedded design) is not damaged/ compromised with checkpoint in place.	**Mobilisation and Mobilisation Checkpoint; Check feasibility of embedded design** Checkpoint to confirm readiness to start the job. Sign off required. If ok- permission to go to next stage, else in Go i.e. does not take part in further cell replication. **Perhaps, the G1 checkpoint is more suited at the S stage than here.**
S	Replication of DNA (embedded design). **Crucial step** for cell.	**Construct cell; Plan for next cell cycle** (Checkpoint needed?) **Synthesise embedded design for next cell**
G2	Cell grows and prepares for mitosis with checkpoint at end.	**Construct cell** **Production comes to an end**
G2 checkpoint (and Go)	Checkpoints for cell abnormality Provides go, no-go signal. If no-go signal is received sent to Go	**Completion Sign off - Work complies with embedded design. Stop Notice in case of non-compliance.** Sign off required. Defects to be fixed before next cell construction

It was mentioned earlier that the *embedded design* was faulty citing reasons. How could this have been prevented? How could the BCC be helpful in creating a multicellular structure (with the pulley cell and the framework cell)?

The purpose of the BCC is to ensure that the *embedded design* is perfect, and adhered to strictly. Any deviations from the design would be detected through the checkpoints resulting in either halting the propagation (i.e. construction) or completely discarding the cell. As mentioned before, the Quality Team failed to identify the problem. This identifies the need for a Production Team (consisting of relevant parties) to *sign-off* on the *embedded design* for each *cell* (e.g. pulley system, and framework). As per the BCC, this needs to be done at the Embryonic Stage in the first instance (i.e. the M stage). The *Readiness for Mobilisation Checkpoint* would be useful to ensure that the embedded design has been checked out amongst other things.

Furthermore, it is obvious that validity of checkpoints is compromised with detrimental effect in absence of **strict enforcement** as seen in this case. While BCC ensures the checkpoints are adhered to **strictly**, in construction the checkpoints are side tracked to achieve site production targets. However, bypassing such checkpoints may lead to proliferation of cells which are outside of cell control and face quality issues at the least. As to the form, structure, and the content of the *readiness check*, there is a need for further research: It is worth noting that traditional hold-points (checkpoints) in quality management systems were inadequate mainly because (a) critical checkpoints were missed in this case despite a seemingly good quality management system in place (b) the tendency to not honour hold-points diligently as it is easier to go past given the absence of a proper mechanism to implement such 'hold' and for risk assessment, (c) it is individual dependent (i.e. a person may decide to follow or bypass a hold point), and (d) it is not limited to quality only but other parameters such as time and cost including the availability and flow of resources. If such an approach was adopted, this problem could have been avoided.

In the event the *readiness for mobilisation* checkpoint (or any other is not complied with, according to the BCC, the cell will need to be put in a state of 'rest' stage, or a state of senescence (Go state). In essence, what it means is that construction will be halted with the issue of a *Stop Notice* – a practice used in safety management particularly when failing to comply with statutory provisions. Strict compliance would be required according to BCC.

If the go-ahead is received, then the cell can grow moving into the G1stage – *mobilisation stage* – where arrangements will be made to proceed. A mobilisation check is advocated according to BCC but that could be better suited at the S stage (in the case of construction), i.e. during the growth stage where the DNA is expected to be replicated without error.

Conventionally, The S stage is where all the management systems come into play including the quality management system with the DNA, i.e. the *embedded design* replicated without error. Perhaps, there is a need for a checkpoint(s) at this stage when it comes to construction (unlike in biological cells). Failing to meet requirements, would put the cell into a *state of rest* bringing construction to a halt. However, in construction, it seems that the current focus of meeting time targets often pushes the team to overcome such 'hold' points (especially those related to quality, safety, and environment) with adverse consequences. Defects will be fixed later – in the worst case – during defect liability period; hold-points will be dishonoured – safety will be compromised, and construction will proceed with make-do arrangements. This would not be the case with biological cells as there is strict compliance with the embedded design and the checkpoints. Finally, the S stage is useful to synthesise design for the next stage and plan it for it too. In the case considered, the *cell* should have been put on a state of rest until the defect was fixed without proceeding with the fabrication. Strict compliance would be required. As to the nature and form these checkpoints and how many would be required, and a mechanism for implementation needs to be researched. This leads the last stage (G2) along with the G2 checklist which is a known practice in construction. The finished product will not be accepted without passing these checkpoints.

5. Conclusions

The purpose of this study was to establish the relevance of the biological cell cycle to construction using a critical incident as a vehicle. It was discovered that the *embedded design (the DNA in biological cells)* used in the coal conveyor system project was faulty. Its implementation led to the problem described by p assign checkpoints. However, the nature of the biological cell cycle control mechanism is such that a faulty design would be intercepted through checkpoints. This was not the case with the chosen problem, reinforcing the importance of getting the design right and having a checkpoint in place with strict compliance. Accordingly, there is no doubt that the Embryonic stage in the proposed construction cycle (i.e. the M stage in the BCC) is an invaluable stage for detecting 'design' issues of each *cell*. As to the nature of the design and how this may be achieved for a particular cell, needs to be investigated.

The logic of having G (growth) stages in the cell cycle is easy to fathom. As to whether there is a need for a mobilisation stage or the growth stages require checkpoint(s) need further study. This could be established through a series of in-depth interviews with experienced industry professionals supplemented with more case studies as this study did not provide any insights on the G cycles; so was the case with the S stage too. An in-depth study on how the G & S stages work in biological cells may be useful including the M stage. The usefulness of the S stage where the focus is on the embedded design of the next cell while the cell is growing makes sense too. In short, the biological cell seems a logical one and it may pay to re-structure ITPs and ITCs based on the cell cycle stages as a trial.

Finally, it is anticipated that with further research, it may be possible to re-define, synthesise, or re-interpret the meaning of the different stages of the biological cell cycle given its apparent value. There is a need to understand the nature of the *embedded design* to synthesise an appropriate cell cycle control mechanism for construction ensuring the replication of the design correctly through *checkpoints*. Additionally, communication characteristics between cells may need to be understood too.

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