Understanding the Relevance of Biological Cell Control Theory and Cell Control Mechanism for Solving Quality Problems in a Tunnel Construction Project

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Abstract
With construction industry grappling with quality issues despite implementing ISO certified Quality Management Systems (QMS) there is a need to infuse fresh perspectives to manage quality in construction. This paper aims to understand the relevance of a fresh perspective based on biological cell theory wherein the cells achieves astounding accuracy with minimal defects in replication to achieve a multicellular structure. For this purpose, the paper employs a metaphorical approach, essentially comparing the current quality management practice in construction with the procedures used in biological cells to generate new insights on how to solve the quality problem encountered in a tunnel project. A reflective analysis of a case study is conducted using this approach using notions of embedded design, uniform rate of cell proliferation, and biological cell control cycle with gated checks that induce a state of senescence for misbehaving cells. The findings show promise in that new insights can be generated through such reflection through a better 'embedded design': The significance of a lack of an initial cell for replication, the importance of incorporating a gated check by integrating quality management with time management to ensure the efficacy of cell replication to eliminate quality issues, and a multi-stage approach to cell proliferation rates all arose through this approach. Suggestions for further work include establishing the acceptability, the suitability, and the feasibility of the identified strategies.

Keywords
Biological cell theory, Cell, Construction, Metaphor, Quality Management, Rate

1. INTRODUCTION

1.

Construction quality problems are well documented. With the introduction of the ISO900 systems of quality management (QMS), many large construction companies have often based their management systems on such standards. Despite such efforts, problems remain, seemingly without new approaches on how to manage construction quality.

Drawing inspiration from nature to mimic the observed behaviour is not new. Though there are explorations in architecture and engineering, similar explorations in construction management studies seem rare. However, Abeysekera (1997) explored the use of Chaos Theory successfully to find a solution to a chaotic problem that was plaguing construction. The attempt was one of comparing two phenomena that had something in common but different in reality. This attempt led to further explorations where Abeysekera (2008) built five theories on monetary retentions using metaphors which led to the birth of what the author referred to as the 'metaphorical approach' in subsequent studies. Others including Midgley, Trimmer et al. (2013) and Abeysekera and Shelke (2015a) have also explored the use of

metaphor with beneficial results though not in construction management. Drawing inspirations from these studies, the authors thought fit to explore the notion of 'construction as biological cells' given that it was possible to identify many types of 'cells' in construction (Abeysekera and Mayur 2015a). Accordingly, the authors have been pursuing this topic for the last three years, and in this study, the biological cell theory is explored further as described later.

2. Biological Cell Theory (BCT) & Biological Cell Control Mechanism (BCCM)

In the quest to further explore Biological Cell Theory (BCT) application to construction, Abeysekera and Shelke (2013) synthesised three concepts exploring the notion of construction as biological cells. These three concepts are embedded design, the rate of cell proliferation and biological cell cycle. Abeysekera and Shelke (2015a) have further explored the concept of the biological cell cycle and its implications for construction work, wherein the identified construction cells are replicated to produce a 'multicellular' structure. However, unlike biological cells which replicate almost perfectly the construction cells do not replicate in an error-free manner

2.1 Embedded Design

Every cell of any living being interprets the DNA strand allocated in its nucleus to produce the proteins needs for the survival of the organism (Ortega-Sanchez and Tyrrell 1998)). Thus the manufactured proteins based on the deciphered instructions of DNA can be considered as a basic life-sustaining compound. This transformation is achieved by the process of Transcription and Translation (Reece, Meyers et al. 2012). While transcription refers to making a faithful transcript of the gene's protein-building instructions, the translation refers to the construction of amino acid sequence on cell sites based on the transcript. These instructions can be considered as the embedded design or programme for the overall process that the cell needs to follow for successful replication. With error rate in DNA duplication of the order of less than one mistake, every ten million nucleotides incorporated and correction of most errors quickly by an elaborate repair system that recognises the defect (Gerald 2010), the cell efficiency in achieving successful replication based on embedded design is indeed marvellous.

2.2 Cell Proliferation Rate

The cell proliferation rate is at a constant rate as established below leading to question if any acceleration or deceleration of the process has any impact. The increased cell division per se stimulated by external or internal factors is associated with the development of many human cancers (Martin, Pike et al. 1990); while the slower rate is leading to degenerative disease and atrophy (Simon 1996). Further, Martin, Pike et al. (1990) clarifies that increased cell division may imply an increase in the process of cell division activity above the baseline rate or division of subset of cells that would ordinarily not be dividing. According to Lax and Thomas (2002) in-situ cell proliferation of transformed cell whose behaviour is no longer under normal regulatory pathway forms a small focus continuing growth beyond its limited size by not only avoiding the surveillance of the immune system but redirecting the blood supply to continue its abnormal growth. Thus abnormal cell proliferation rate outside of regulatory mechanism of the cell is a certain drain on resources with the ability to cause harm to the organism in some cases.

2.3 Biological Cell Cycle and Control Mechanism

According to BCT, new cells originate only from other living cells *by the process known as 'cell division'.* As it procreates through division, each dividing cell passes through a series of defined stages known as the 'cell cycle' with checkpoints shown in Figure 1 with the phases and associated checkpoints. It is an ordered set of stages that results in the accurate division of one cell into two with exactly similar properties (Cassimeris, Lingappa 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).

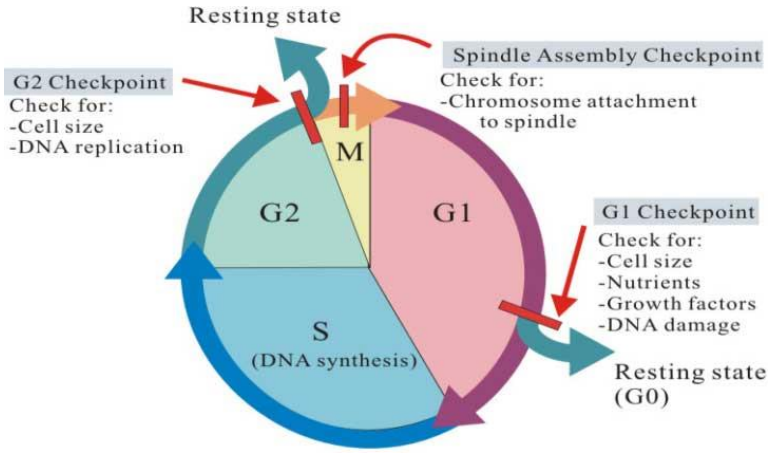

Figure 1: Cell Cycle Phases (G1-S-G2-M and Go) with the Three Checkpoints
(Source: http://blc.arizona.edu/courses/mcb422/PathFinderFolder/422_PathFinder_Intro.pdf)

The entry in the cell cycle is achieved by regulating the cell cycle at checkpoints; an interesting feature of the cell cycle control mechanism often compared with control mechanism of a washing machine cycle which monitors both internal and external conditions (Reece, Meyers et al. 2011, p. 243). 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. The consequences of a 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, Lingappa et al. 2011, p. 674). In figure 1 there are G1 and G2 checkpoints which impose control across various phases to ensure the accurate process for cell replication. Based on process progress the checkpoint G1 may induce a state of rest to stop cells from taking part in further replication.

Reflecting on the above discoveries like controlled entry into cell cycle consisting of an ordered phases which are regulated in time and space through surveillance mechanism like checkpoint to ensure error-free cell replication; one may raise the thorny question of whether in fact by emulating the biological cell's procreating mechanism which produces astonishingly error-free results (Karp 2008, Kunkel 2011), would construction professionals be able to overcome the perennial problems of construction?

3. Aim, Objectives, and Methodology

Given the quality issues that plague the construction industry despite having a robust QMS, the aim of this paper is to understand the relevance of the BCT which has exhibited astounding accuracy in replication of cells to develop a multifunctional structure based on an embedded design. The insights gained from BCT in constructing nearly flawless structure is used to understand its application and hence its relevance for the construction industry to identify likely means to improve upon its ability to replicate in an error-free manner the identified construction cells. A reflective analysis of slab construction in a tunnel project is considered to understand the relevance of BCM.

In the quest to learn from the biological cells about its accurate replicating ability and to understand its relevance to construction, this paper has employed a metaphorical approach. The efficacy of such approach has been established to generate new insights and conceptual frameworks for solving complex problem (Midgley, Trimmer et al. 2013, Abeysekera and Shelke 2015a). The approach adopted is in essence about comparing the current quality management in practice in construction with the procedure adopted in the biological cells, so as to generate new insights on how to solve the quality problem encountered in the tunnel project.

Quality issues faced in the construction of tunnel project is selected where the first author was a

participant-observer. Despite robust system design to achieve construction intent or (as-built), there were quality issues in the construction of the slab in the tunnel project. These identified quality issues are presented through a case study and a reflective analysis carried out to understand whether such problems could have been prevented if the insights gained from the BCT like the BCCM and Embedded Design were to be applied. There was rework carried out on some of the identified defective works, and despite robust QMP and various processes to deliver quality outcomes, quality defects have crept in the constructed slab.

4. Quality Management in Large Construction Projects

This section will discuss the quality management practices normally prevalent in large construction projects, based on the experience of one of the authors who has been employed in quality management roles for a number of different construction projects in Australia. Such experiences have established that ISO 9001 Quality Management System (QMS) is the most popular system. Certification to that system is evidence of the company's existing quality system complying with the prescribed practices in the ISO standard. This invariably requires a documented Quality Management Plan (QMP) for the company to follow and calls upon the various relevant documented systems of the company. There is a requirement to document the various procedures and method to be followed to achieve quality in construction, and to that effect, the activity method statements are produced which layout the construction methodology to be followed at the coal face of construction.

Such activity method statement though primarily produced to assess, address and mitigate risk for each activity for the identified construction captures items like tolerances to be achieved and resource requirements like plant, material, and manpower. It covers construction timeline, quality requirement, safety requirement, any permits or approvals for the jobs, environmental issues and any community-related issues as also the manner in which the completed works will be documented. There is a section for a quality requirement listing various check sheets and test plans withhold points and specifications for the required activity which capture the technical (quality) requirements for the described job. No activity can proceed beyond hold point unless witnessed and approved by the client. Following review by other disciplines like construction, quality, safety as well as the client the activity method statement is certified for use on site. Any identified work which does not meet the relevant technical specifications qualifies as having product defect, while the system defect identifies the breach of any procedure or system which is applicable while executing such works. The identified defects are suitably addressed and rework carried out where necessary. There are mechanisms such as audits, surveillance, inspections to ensure process compliance. The weekly and monthly quality reports track key performance indicators like non-conformances, defect rectification cost, audits and corrective actions, status of work lots, quality frequency rate. Such reports serve the purpose of flagging any areas of concern for further investigation and corrective actions as required.

There is thus substantial system and process documentation available as described above with the intention of delivering quality outcomes; however, it is noticed despite such existing instructions (or design for delivering the product) there have been quality issues in the construction of slab-both product and system defects. There is an expectation of achieving congruence between the design intent and 'construction' intent. Isn't this shortfall between the two labelled as quality issues? Such quality issues and means to address these are explored in the case study of the slab construction next.

5. Quality Issues in Tunnel Slab Construction-A Case Study

This case study examines the quality issues in the construction of a tunnel slab which consists of a number of concrete shell segments cast-in-situ which are very similar and as such seen as 'cells'. During the construction of these repetitive concrete slab cells, there were 73 product quality issues identified (39 on incorrect thickness, 28 on improper curing, three (3) on the incorrect concrete finish, 2 for using concrete with higher slump and 1 for drainage pit not installed in-situ in one of the 350 concrete slab cells each 9m wide. Also, there were three (3) system related quality issues like documentation preparedness for the slab pour, improper recording of details in check sheet and

measurement of slump on adding additional water. Given that most of the quality issues are identified as product related (73 out of 76) when compared with system issues (just 3), it would appear that despite following the QMS, there are significant quality issues. Does this indicate insufficiency of the system design to deliver the required product quality, or is it the implementation and control of the system design causing such product quality issues? It appears that even minor amount of quality issues with the system have led to a significant number of product quality issues in the replication of slab (i.e. in replication of slab cells). Is this the case? These issues are discussed next based on the insight gained from BCT to understand if such problem could have been averted.

5.1 Reflective Analysis vis-à-vis BCT and BCCM

Quality issues have crept in the construction of repetitive slab cells despite an apparently robust QMS, various codes of good practices, approved design and procedures and documented knowledge. The various procedures and practices within the company and established system are used to translate the design intent to construction intent, and all such relevant information can be considered as 'embedded design' for the construction of the slab. This can be considered as similar to the design in a biological cell which is coded in the DNA (Section 2.1). However, the similarity of the slab construction cell appears to end here when compared with the astonishing replication accuracy and efficiency of the biological cell. BCT is further indicating cellular control for successful proliferation or growth, (Section 2.2 and 2.3) and this concept is explored to gain an understanding of the quality issues.

The Figure 2 below is the plot of the concrete pour over the duration of the project to determine the average rate of pour (or pour-cell) and how it has progressed (cumulative pour completion) with quality issues were identified for each pour plotted in a cumulative manner over the pour completion. Within 25% of total concrete poured 86% of QA issues have been identified and within the first half of the job has 94% of QA issues associated while the balance half of the job has 6% of QA issues attributed to it. This can be considered as representing the experience curve or learning curve with activities not yet under full control which is likely to lead to variations in production rate and by extension adverse quality issues.

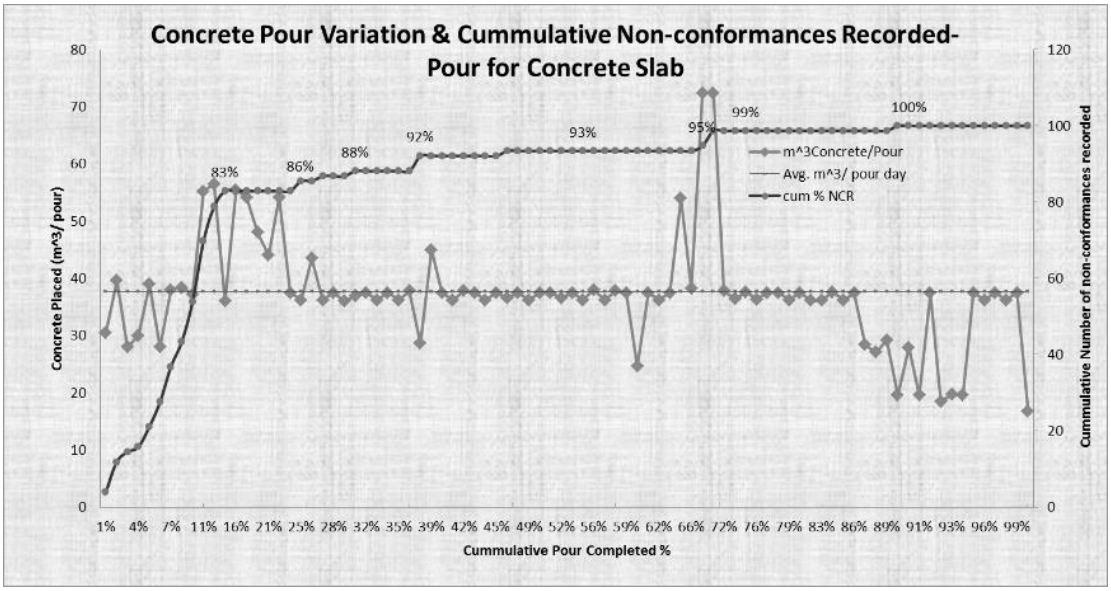

Figure 2: Variation in concrete poured per day and quality issues recorded

The cell theory has established any variation either higher or lower than uniform rate is abnormal with activities beyond cellular control. When viewed together with the learning curve, this suggests the importance of controlling the activities, especially at the start, as demonstrated in the first 25% of concrete pour which has more that lion's share of quality issues. Analysing further the instances of deviation from average pour rate based on figure 2 above has an interesting outcomes with respect the occurrences of the quality issues with minimum number of QA issues (13%) identified when the pour

rate was closer or equal to the average pour rate (6% of pour); 36% of quality issues have been recorded for pour rate lesser than average (45% of pour) and 51% quality issues have been identified when pour-rate was higher than the average pour rate (49% of pour).

With deviation from average pour rate, 45% of pours lesser than average and 49% of pours greater than average system pour rate the incidence of Quality issues recorded are 36% and 51% respectively, i.e.,.87% of Quality issues have occurred when the pour rate has deviation away from the average. Meanwhile, for 6% of pours close to the average pour rate, the Quality issues recorded are the least at 13%. This seems to highlight that deviation from the average system (pour) rate or proliferation rate, implies in terms of BCT, an operation out of the control of the cell cycle control mechanism. While those pour within the ambit of the apparent cell cycle control mechanism has minimum errors or tendency to proliferate in a (less) error-free manner or achieve a right-first-time in replication, as indicated by BCT. This concept of biological cell cycle control mechanism (BCCM) is discussed next.

5.2 BCCM and Cell Replication Quality

The sequential progression of events in a biological cell through various phases was discussed in Section 2.3. Each phase has a gate where quality checks are carried out for compliance with the required parameters. In fact, BCCM can delay processes to achieve synchronisation of activities within the cell cycle to achieve successful replication. In construction, it is the schedule or the programme which drives the construction activity with various interdependencies of activities identified thus highlighting the likely constraints for construction. However, there is a lack of emphasis on the gates (which are present in BCCM) and the ability to check the outcomes of activity regarding quality parameters and impose order to fix the same. A comparison between practices adopted in biological cells and the significance for construction (metaphorically) are shown in Table 1.

Table 1: Biological Cell Practices for Replication and Significance for Construction Cell

	BCT and Concept of BCCM, Embedded Design	*Construction Cell*	*Significance for Construction*	*Remarks*
1.	An initial cell is available for replication based on the DNA or embedded design.	Initial cell for replication is not available and needs to be built.	Documented processes or design when executed leads to an initial cell in space and time, Construct mock cell for replication	In construction, initial cell is available only in abstract form i.e. in procedures, plans, design documentation, methodology
2.	BCCM is a sequential controller with phases scheduled sequentially with each phase subject to a gated check for readiness of next phase	The controller of the sequence is embedded in the project schedule. However, it does have focus on quality of the completed activities	Integrate quality with (time) schedule; it needs to be deliberate than accidental or 'business as usual' activity	The controller of the sequence is the plan of activities in space and time with interrelated activities and dependency. Quality compliance is not its focus, but interrelation of activities to achieve as-built.
3.	If the state is unready for replication, the cell is put into a state of senescence.	Rarely ever complied with; schedule more important than quality ethos prevalent	Develop a schedule (design) that simulates senescence.	This can be achieved by building in time slots for overcoming product and system defects
4	Cells proliferate at a uniform rate	Concepts of rate, rhythm, harmony are rarely explored (Abeyesekera 1997)	Explore the possibilities of developing schedules using these concepts	Cell replication within a phase to be uniform; different rates can apply for different phases of the same activity/operation
5.	BCCM is controlling system which is proven to achieve nearly error-free replication	The system or process capability needs to be established for every project given the unique nature of every project activity, despite identification of cells for repeatability	Important to have proven processes which work successfully. However, needs reestablishment for every new project. Agility and ability to evolve based on past lessons and implementation is important to minimise errors	Re-establish process or system capability for every project. The achieved project outcomes are a likely measure of such capability.

	BCT and Concept of BCCM, Embedded Design	*Construction Cell*	*Significance for Construction*	*Remarks*
5.	DNA (design) codes transcription is accurate within the nuclear envelope. The DNA by itself does not take part in construction, however, has direction for near perfect replication	The design is a set of processes or system documentation coded to achieve desired project outcomes.	The equivalent of transcription in construction is generating a copy of the desired processes for identified activities in construction. Is this accurately done? Where is it done? Design is documented by separate team to construction	Similar to a biological cell, design in construction has codes to deliver agreed upon acceptable project outcomes.
6.	DNA translation is the process of transferring the design from nuclear envelope to the cell construction site to assemble required building blocks for the cell survival and growth. This is achieved despite DNA codes are in different chemical language (nucleotides), while the as-built blocks on cell construction sites are made of amino-acids.	For actual construction on site such 'translation' of design is the various documentation like methodology, check sheets, and test plans.	Implies the need for design translation using a robust system to deliver instructions to the construction site to call upon various processes and material to achieve desired outcomes. Establish congruence between the design intent, transcription of design and translation of design codes to achieve agreement between the design intent and construction outcomes.	The 'translated' documents are used on the construction site to assemble or build the product. These call for processes to assemble the building blocks or material to achieve the construction cell growth.
7.	Embedded design has an intent- which is manifest in the construction intent wherein in building blocks are used as per the codes in embedded design. Though chemical language of design is different to construction language on cell site, there is congruence observed in terms of design and construction intent-i.e. successful replication of cell in an error-free manner	Similar to a biological cell, there is a design intent which is coded to be later used for achieving the construction intent. There is significant mismatch observed (quality issues) wherein the design intent, and construction intent is not aligned.	While the language of codes may be similar, English in most cases, there is significant mismatch observed (quality issues) wherein the design intent and construction intent are not aligned.	Focus is required on this process of translation of design codes to understandable construction codes. There is a significant loss in translation from design to construction. Simplification of process documentation, use of visual to convey the design codes easy to refer and work to on-site.

The above analysis shows that BCT has significant insights on offer with this case analysis highlighting likely areas for application to achieve error-free replication of construction cell.

5.3 Application of Insights gained from BCT and BCCM

To articulate the application of concepts described in items 1 to 5, Table 1 above considers the case of a simplistic case of constructing 500 columns in 20 days. One possible approach for completing this project would be to construct 25 columns daily which would include the following sub-activities in one 'column cell', namely, fix reinforcement, install formwork, concrete, cure, remove formwork. This is a 'scheduling cell'. This cell is expected to be replicated 500 times for the as-built. Quality assurance activities are expected to be carried out while the operation is on-going without a formal attempt to correct quality issues that may occur in each cycle. However, this is not the cellular approach if one is to reflect on the biological cell approach. While it maintains a uniform rate of proliferation, it does not show the how the gated quality checks can be integrated (deliberately) with the time schedule. This is achieved as shown in Table 4.

In essence, the cell replication starts slowly and then reaches the uniform rate when the cell replication is perfect. What is proposed is that in Phase 1, the cell output increases uniformly, with number of cells in Day 1 set at 10, and Day 3 set at 20, and on Day 5 set as 30, and then during the Phase 2, the rate of cell proliferation remains a constant but what is important to note is that the gated quality checks are inbuilt to the schedule with Days 2 and 4 used as gated checks. For instance, on Day 2, a thorough quality evaluation is made, lessons learnt, and corrective action designed for further check in Day 3. The same

is done on Day 5 with the further investigation until perfection is reached.

This approach also takes into account of the fact that in construction an initial cell is not available for replication (as in biological cells). The initial cell in construction is in an abstract form as noted before, embedded in coded forms in various system and process documentation. This initial construction of cell in space and time appears to present a significant challenge because despite recording 4% quality issues in system implementation there were 96% product quality issues identified. This focus on developing an initial cell, keeping in mind its existence in abstract form embedded within the various codes is one of the ways likely to help in achieving error-free replication of a 'perfectly' developed initial cell along with the gated checks built into the time schedule thereby integrating time scheduling with quality management particularly in complex construction projects such as this.

Table 2: Sample Construction Approach based on BCT

Phase	***Day***	***Activity***	***Remarks***
PHASE 1	Day 1	10 columns	Construct Cell 1
	Day 2	Quality gate checks 1	Modify process to overcome quality defects and ensure replication is defect free
	Day 3	20 columns	Construct Cell 2
	Day 4	Quality gate check 2	Modify process to overcome quality defects and ensure replication is defect free
	Day 5	30 columns	Construct Cell 3
	Day 6	Quality gate checks 3	Modify process to overcome quality defects and ensure replication is defect free.
PHASE 2	Day 7 – 20	31 columns per day	Construct Cell 4; replicate the 31-column cell for the next 14 days *AT A UNIFORM RATE*

6. Conclusion-Strategies for Defect Free Replication

The foregoing reflective analysis leads to the following strategies for further exploration. These strategies evolved only by the use of the metaphorical approach described above influenced by biomimicry paving the way to develop new insights on how to manage quality on construction projects.
:

a) Synthesise physical and/or scheduling cells for creating a multi-cellular product using the concepts of uniform rate of cell proliferation and embedded design for cell replication.
b) Integrate quality with time and resource management (perhaps breaking 'flow' as required to avoid costly and time-consuming quality issues).
c) Incorporate a gated check approach (similar to biological cells) simulating cell senescence with deliberate breaks for perfecting cell replication (i.e. to eradicate product and system defects).
d) The above may introduce a dual rate approach to cell proliferation through a multi-phase approach as outlined before with initial phases focussing a low rate of build to perfect the replication eventually leading to a stable rate of build. (Note that this is not linked with learning curve effect observed in projects with repetitive units.)
e) Assess the risks associated with the lack of an initial cell which exists as an abstract form embedded within various processes and documentation. This required and enhanced diligence for the construction of the first cell is important, especially given the loss in translation of the design intent despite having a robust system and documentation to avoid quality issues.
f) Review the current practice of transmitting the design intent to the construction site. There is a significant loss in translation or perhaps scope for misinterpretation. There is a need for congruity between design codes and translated codes at the construction coal face. More efforts may be required to embed the construction codes (translated from design) at the construction site.

As part of future work, it is planned to explore the above conclusions through further case studies and discussions with industry personnel to understand the importance of the above-mentioned strategies, their suitability, acceptability, and feasibility.

References

Abeyesekera, V. (1997). Innovative Approaches for the Preparation of Overall and Detail Work Programmes First International Conference on Construction Industry Development. A. U. National University of Singapore in association with CIDB (Singapore), ACI (Australia), ACI (UK). Singapore: 281-291.

Abeysekera, V. and M. Shelke (2013). Managing Quality in Construction: Construction as Biological Cells. Proceedings of the 19th CIB World Building Congress, Brisbane 2013: Construction and Society, Brisbane, Australia.

Abeysekera, V. and M. G. Shelke (2015a). Construction as Biological Cells: Can Construction Cells be similar to Biological Cells? Construction in the 21st Century; Changing the Field: Recent Developments for the Future of Engineering and Construction. Thessaloniki, Greece

Cassimeris, L., et al., Eds. (2011). Lewin's Cells, Bartleet Publishers.

Gerald, K. (2010). Cell and Molecular Biology-Concepts and Experiments. United States of America, John Wiley & Sons, Inc.

Karp, G. (2008). Cell and Molecular Biology, John Wiley & Songs, Inc.

Kunkel, T. A. (2011). "Balancing eukaryotic replication assymetry with replication fidelity" Current Opinion in Chemical Biology 15: 620-626.

Lax, A. J. and W. Thomas (2002). "How bacteria could cause cancer: one step at a time." Trends in Microbiology 10(6): 293-299.

Martin, S., et al. (1990). "Perspectives in Cancer Research." Americal Association for Cancer Research 50: 7415-7421.

Midgley, W., et al., Eds. (2013). Metaphors for, in and of Education Research. UK, Cambridge Scholars Publishing.

Ortega-Sanchez, C. and A. Tyrrell (1998). "Design of a basic cell to construct embryonic arrays." IEE Proceedings-Computers and Digital Techniques 145(3): 242-248.

Reece, J. B., et al., Eds. (2011). Campbell Biology. Australia, Pearson.

Reece, J. B., et al., Eds. (2012). From Gene to Protein. Campbell Biology. China, Pearson Australia Group Pty Ltd.

Simon, H.-U. (1996). "Molecular mechanisms of programmed cell death." Apoptosis 1(2): 107-109.