Managing Quality in Construction: Construction as Biological Cells

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Abstract

Construction is noted for handing over projects with defects with associated quality problems plaguing construction. Available models seem inadequate to ensure quality. Given this background, this study explores a new approach inspired by the high level of accuracy successfully achieved in the replication and proliferation of biological cells.

Construction operations are in many ways repetitive in nature. Hypothetically it can be broken down into basic repetitive units or 'cells' which undergo replication to constitute the 'whole' with similarities with biological cell. However, replication in construction is less error free when compared with the replication and proliferation of biological cells to produce a functional multicellular organ with an abnormally low error rate. As such, this study investigates this phenomenon with the aim of finding a better way for managing quality in construction by focussing on the replication of repetitive 'cells' (units) in construction.

A detailed study of the biological cell theory identified two new concepts relevant for construction (amongst others), namely, 'embedded design' and 'rate of proliferation' which impacts on cell-quality.

The relevance of these two concepts are explored further through the case study methodology: The first case study examines the impact of variation in the rate of poured concrete in a tunnel construction project whilst the second case study investigates the embedded design concept for planning and scheduling repetitive units in a multi-storey residential apartment complex providing two interim conclusions: Firstly, it is seen that variation in rate of production indicates presence of issues which have the potential for causing serious quality problems calling for closer attention whenever the rate of production changes. Secondly, the 'embedded design' concept is a relevant and viable concept for managing quality in construction which demands further exploration.

These two case studies have identified the need to examine the two concepts described herein further including other relevant concepts of the Biological Cell Theory with the

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intention of developing a new model for achieving an error free repeatability of construction units or cells.

Keywords: biological cell, embedded design, quality, repeatability, replication

1. Introduction: Quality in Construction

Despite the standard recipe of implementing quality management systems, experience shows that construction industry is saddled with projects with defects so much so that moneys due are held back for work performed lest something goes wrong with quality of work. Moreover, moneys are held during the defects liability period as well in what seems to be a defeatist and a punitive approach for achieving 'quality'.

The construction industry is characteristically chaotic in nature (Bertelsen Oct 2004), rendering it susceptible to quality issues. Historically, the principles of quality management have been developed in the relatively stable and controlled environment of production, which is in contrast to the chaotic nature of construction (Bertelsen Oct 2004), rendering it susceptible to quality issues. Thus the quest for better approaches for ensuring quality must therefore continue to change the status-quo.

This paper will present lessons learnt from biological cell theory relating to replication of cells to construct a functional multicellular unit in nearly error free manner to manage quality in construction. The construction operations are repetitive in nature and can be hypothetically broken down to basic units or cells which are replicated. However, unlike biological cell which achieves the replication with high level of accuracy, the same cannot be said for construction. The study of biological cell has led to two concepts relevant to construction. Firstly, the rate of cell proliferation and the detrimental impact of variation in cell proliferation rate variation on quality and secondly the concept of embedded design based on the DNA of the cell to achieve robust replication. Two case studies are examined with relation to the cell theory. In the first case, the variation in volume of concrete poured per day for slab in tunnel is considered and the number of quality issues during the duration of pour is examined while in the second case the effect of embedded design is examined and how it has assisted in delivering quality output for a building construction company.

2. Biological Cell Theory

The following description of the biological cell succinctly captures the essence of the cell and further reflection on it lays the foundation of the premise this study intends to explore.

> ***Cells** are the structural and functional units of all living organisms. Some organisms, such as bacteria, are **unicellular**, consisting of a single cell. Other organisms, such as humans, are **multicellular**, or have many cells—an estimated 100,000,000,000,000 cells! Each cell is an amazing world unto itself: it can take in nutrients, convert these nutrients into energy, carry out specialized functions, and reproduce as necessary. Even more amazing is that each cell stores its own set of instructions for carrying out each of these activities (http://www.ncbi.nlm.nih.gov/About/primer/genetics_cell.html)*

Implied in this quote is the functional efficiency of the cell not only to be self-sustaining, but the ability to replicate itself to develop into fully functional multi cellular and complex unit. To be able to evolve successfully into multi cellular entity, it appears that the basic building block, the cell, needs to be defined perfectly for it to function with instructions ingrained within the system for it to sustain and replicate, while maintaining the ability to faithfully transmit the instructions. This can be considered as an example of efficient process manageability to ensure successful repeatability based on well-defined cell to achieve a complex multi cellular pattern as if following an embedded design. This reminds of the call by Hinks et al. (1997) for construction industry to achieve repeatability and hence manageability.

2.1 DNA as Embedded Design in Cell

A cell can be considered as basic unit of life (Gerald 2010). Cells follow a programmed death but before that it will grow and replicate and in case of multicellular organism it replicates to produce a functioning unit. This self-elimination of cell is a result of an internal program that causes cells no longer needed or cells that pose risk of becoming cancerous to be eliminated. In construction, a cell can be considered as a basic unit for replication which will grow by drawing upon the resources and stop growing once it has reached its logical conclusion. However, to carry out such function there has to be a design and in case of cell this **design is embedded** within the nucleus of the cell in the form of (Deoxyribonucleic acid) DNA with chromosomes identified as the carrier of the genetic information (Gerald 2010).

Every cell of any living being interprets the DNA strand allocated in its nucleus to produce the proteins needed for the survival of the organism (Sanchez & Tyrell, 1998). Thus the manufactured proteins based on the deciphered instructions of DNA can be considered as basic life sustaining compound. According to Alberts (2012) these instruction are analogous to the blueprints that builder uses to construct the house. However in the case of cells with well-defined nucleus housing the DNA the blueprints themselves needs to be duplicated along with the cell before it divides so each daughter cell can retain the instructions required for its own replication and these instructions constitute the cell’s heredity (Alberts 2012)..

2.2 Embedded Design and Replication Efficiency in Cell

Worth noting is the analogy of builder using blue prints to explain the working of the cell because the DNA contains the design according to which the life sustaining proteins are manufactured in the cell. It is complex operation which requires decoding the design, calling for assembling the right building blocks of protein and ensuring error free operation repeatedly. The order and consistency in handling such complexity has to be immense. Gerald (2010) has expressed that more complex a structure the greater the number of parts that must be in their place and, more regulation and control must be exerted to maintain the system to have less tolerance of errors in the nature and interaction of the parts.

The cell efficiency can be realised when we consider the rate of error in DNA duplication is of the order of less than one mistake every ten million nucleotide incorporated, and most of the errors are quickly corrected by an elaborate repair system that recognizes the defect

(Gerald 2010). The aim of six-sigma to achieve defect rate of 3.4 defects per million, or 99.99966% perfect according to Bounds et al (1994) appears inconsequential when compared with defect rate of one mistake every ten million achieved by the biological cell.

The cells are able to handle complexity effortlessly. The integrity the replication of process indicates the near perfection in the communication of the system, processes and procedures which are set out to accomplish this complex manoeuvre. For construction industry there is a likely lesson here in not only having a system to deliver the product but also the ease and effectiveness of communicating this system across the project team to replicate or produce the output as per the design.

2.3 Exploring Rate of Cell Proliferation

For a cell, growth by division during its life is the sole reason for its existence. This cell division process has been modelled mathematically establishing the rate of this process.(Bell 1967). Such mathematical models indicate that the cell growth rate can be determined. Koch (1962) has postulated that each cell grows with exactly the same growth rate constant as that of every other cell which has been justified based on the statistic of cell division for bacteria. Banks et al. (2011) have refined existing models depicting cell proliferation to compute average rates of proliferation in terms of the number of divisions undergone. This refined model has consistently estimated the average rates of proliferation (Banks et al. 2011). Mathematical models and application of statistics to understand cell division process highlights that the rate of cell growth can be determined, however it leads to question of the impact of changes in this rate, which is considered next.

The cell proliferation rate is at a **constant rate** 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 et al. 1990). Further, Martin et al. (1990) clarifies that increased cell division may imply increase in 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. It continues 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 (Lax & Thomas 2002). It seems any deviation from the established rate of cell proliferation is considered abnormal and out of control leading to problem with faster rate leading to lack of repairs to DNA as per (Alberts) 2012 and slower rate leading to degenerative diseases and atrophy (Simon 1996).

Thus abnormal cell proliferation rate leading to harmful consequences can be considered as lack of the regulatory mechanism of cell. While there are quality control and repair system in place for the cell to ensure defect free replication and these are used to address the quality risk where the cell is most vulnerable, any uncontrolled changes in growth rate has harmful effect on organism.

2.4 Synthesised concepts

The above discussion leads to two concepts, viz. constant rate of cell proliferation, and embedded design. These two concepts form the basis for further examination in a construction setting.

3. Methodology

Construction operations are in many ways repetitive in nature as noted earlier. Hypothetically it can be broken down into basic repetitive units or 'cells' which undergo replication to constitute the 'whole' – a process biological cells handle with remarkable efficiency and accuracy when replicating cells to produce functional multicellular organs. In contrast, however, the replication and proliferation process in repetitive construction is error ridden when compared with processes adopted in a biological context where cells replicate to produce functional organs with abnormally low error rates.

An extensive study of the biological cell theory revealed a number of interesting concepts but only two concepts are examined in this study, namely, 'constant rate for cell replication and proliferation' and the use of an 'embedded design' – two concepts that seem to result in an abnormally low error rate when biological cells replicate and proliferate to produce multicellular functional units. Are such concepts used in construction? What implications do such concepts have for construction? How could such concepts be used in construction? These are some of the questions that this study attempts to answer in an attempt to develop new insights on how quality can be managed in a construction setting involving repetitive work. It was thought relevant that the case study methodology be used to explore answers to these questions.

A number of discussions were held with senior managers to elicit specific examples or case studies of practice which lead to the discovery of two interesting case studies with one involving the construction of concrete slabs in a tunnel project and the other involving the use of a set sequence for completing finishing work for a multi-story apartment complex. Details of these case studies are discussed in the next section with specific relevance to the two synthesised concepts.

4. Case studies

As mentioned, two cases are considered with first case relating to construction of slab. The production rate and associated quality issues are recorded and examined to determine impact of variation in production on quality. The second case considers how the concept of embedded design is used by a construction company in New Zealand for construction of apartment.

4.1 Case 1 Quality issues with slab construction and rate of work

This case examines the construction of slab in tunnel in Australia. During the construction of repetitive concrete slab there were 76 non-conformances recorded in terms of quality issues of which 73 were product related and three were system related. The product non-conformances refer to issues like thickness of slab or finish which were out of specified tolerance and required corrective action, while system non-conformances refer to breach of documented procedures. Given that most of quality issues are not due to system issues, it seems to indicate it is production rate change that has led to quality problems

Please refer Figure 1 depicting the variation in the rate of concrete placed per pour during the project and the number of quality issues as measured in the recorded non-conformances related to slab production. The total volume of concrete placed was 3200m^3 over 86 pours with an average pour volume of 37m^3 per concrete pour.

This case will highlight the impact of variation of production rate when compared with uniform rate, which according to cell theory is an indication of activity which is out of control and has detrimental effect.

4.1.1 Analysis and Discussion-Slab construction

The figure 1 below captures the variation in production rate and recorded quality issues during the construction of slab in case study 1. The impact of variation in concrete pour rate is considered on the quality, keeping in mind the concept from cell theory in section 2.3 where variation in rate of proliferation of cells above a constant rate is considered an abnormality with activity outside the control of cellular mechanism and has detrimental effect.

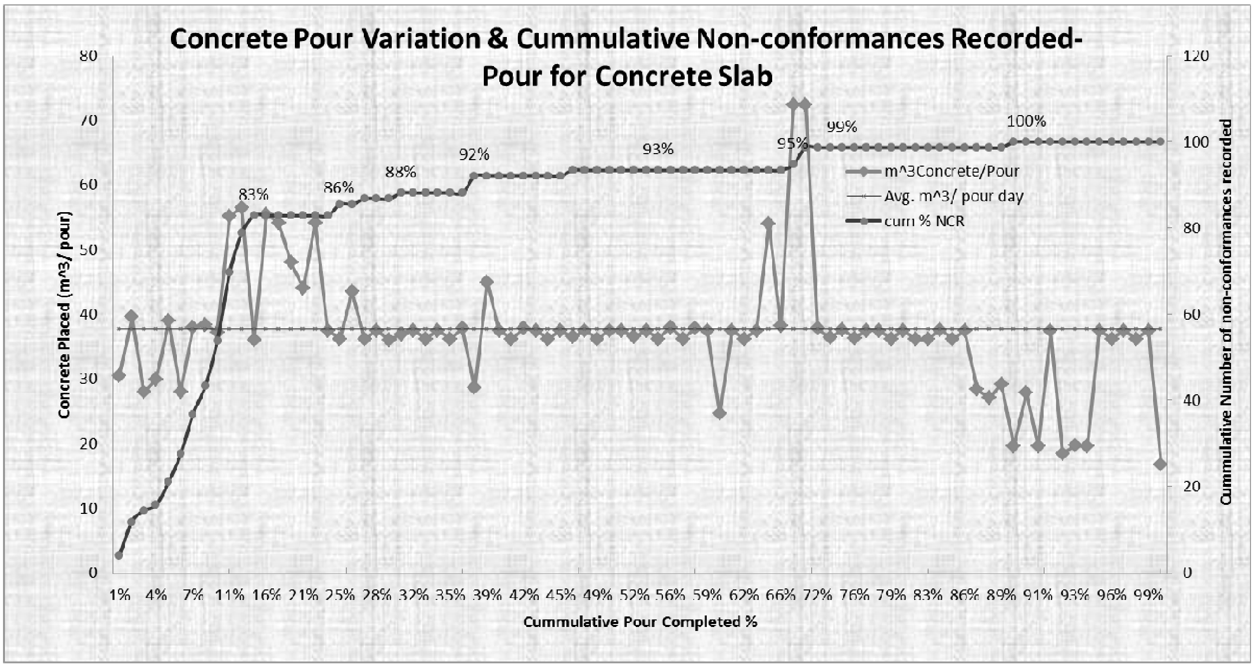

Figure 1: Variation in concrete poured per day and quality issues recorded

Depiction of variation in concrete pour volume and the quality issues recorded for the corresponding pour is presented below in Table 1.

From Table 1 it is clear that with variation in production rate there is associated quality issues related. However, when the pour rate is greater than the average rate, there are higher numbers of quality issues recorded as there are 49% of such total pour which account for 51% of quality issues. Comparing with 45% of pour where the rate is lower than the average rate which have 36% of quality issues recoded is indicating that production rates with variation higher than average rate is more susceptible to quality problems. Remarkably, for 6% of pour which are at an average rate have recorded 13% of quality issues, which is the minimum for the project.

Table 1: Variation in Pour rate & Corresponding QA issues for slab construction

Variation in Pour Rate compared with Average Pour Rate	Number of pour as % of total number of pour for slab construction	No of QA Issues as % of total QA issues for slab construction	Remarks
Pour rate of less than average rate of $37m^3$ per day	45%	36%	With variation from average pour rate (or constant pour rate) on the lower side there are 36% quality issues recorded
Pour rate equal to average rate of $37m^3$ per day	6%	13%	With nil variation in the pour rate there is drastic reduction in quality issues recorded at 13%
Pour rate greater than average pour rate of $37m^{3/}$ per day	49%	51%	With variation in the pour rate on the higher side of average pour rate this is highest rate of quality issues recorded at 51%
Total	100%	100%	

Depiction of total number of pour and number of quality issues recorded during the project on progressive basis is presented in Table 2.

Table 2: Progressive Completion of job and quality issues recorded.

% Completion of job	Number of concrete pours	Number of Quality Issues or Non conformance	% QA Issues
First 25% of total concrete poured	19	65	86%
Between 26% and 50% of total concrete poured	22	6	8%
Between 51% and 74% of total concrete poured	19	4	5%
Final 26% of total concrete pour	26	1	1%
Total (3200 m^3 concrete)	86	76	100%

The Table 2 depicts how at the start the process is unstable with bulk of quality issues recorded during the first 25% of the job and progressively diminishing. 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.

The cell theory has established any variation either higher or lower than uniform rate is abnormal with activities beyond cellular control, similarly for construction the same can be concluded based on Table 1 as production variation has adverse effect on quality, indicating some out of control activity leading to such quality issues. 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.

4.2 Case Study 2: Embedded Design for construction of apartment

One of the top tier contractors in New Zealand with construction portfolio which includes apartment building has developed what can be considered an example of building a construction cell based on what resembles an embedded methodology for construction of apartment. There is a methodology and planning, based on lesson learnt from past construction projects which has the sequence of activities and checkpoints before proceeding to next stage. One striking feature of this plan is requirement to construct a mock-up apartment 100% complete in every detail which is approved and meets the accepted quality level. This constructed cell is then used to make template which are used for each apartment construction to ensure consistency and uniformity.

This plan is strictly adhered to and relevant personnel involved informed about this. Those involved in critical areas of project undergo class room like training where the method and sequencing of job is reviewed in detail. Daily morning briefings are held to ensure all those involved know what they are doing, who else will be working in the same area and if any material delivery is scheduled. There are checkpoints and regular inspections carried out to ensure compliance as each trade progresses.

The company's manager in personal communication with one of the authors has confirmed that after various sequences the company has been able to identify an optimum sequence of work which is now embedded in the company's way of working. However, further work needs to be undertaken about its design, its impact and the implications reflecting further on the cell analogy described herein.

4.2.1 Discussion-Embedded Design and Construction

The approach this company has adopted is similar to the cell behaviour in many ways. Each cell has an embedded design in the form of DNA which is communicated in an error free way to ensure accurate replication. Further, according to Gerald (2010) the cells are evolving in response to the environment and this is an on-going process that continues to modify the properties of cells that will be present in organism that have yet to appear.

The construction company has refined their design and processes based on past experiences and refined the methodology of delivering the building project, so much so that the company has been able to identify, what it considers an optimum sequence of work. This is an example of evolving and preparing for projects that will be delivered in future. Importantly, it addressing the lament by Kransdorff (2006) regarding the lack of use of organisational memory to improve poor decision making by imbibing past lessons learnt, as this company has used the lessons from past experiences and made it part of its ‘DNA’ for delivering the projects.

Not only is there an embedded design which is evolving and communicated for proper execution, there is also a cell of acceptable quality created in the form of mock apartment, which is then replicated. This mock apartment is similar to cell behaviour where a cell is replicated in an error free manner with its design or DNA intact, ever evolving to meet the future challenges.

5. Cell-Theory and Quality in Construction

With lessons learnt from cell theory it is likely adverse quality issues can be avoided if there is a perfect cell developed for replication based on an embedded design in construction. Further, any unplanned change in rate of production is like a red flag which is indicating activities which are out of control and have the potential to cause quality issues. Changing the rate of production is quiet often the norm in construction as the crashing of activities with an associated increased cost is an accepted fact given the inherent relationship between the time and cost (Sears, Sears & Clough 2008). Thus increase in rate of production especially those on the critical path to shorten the project duration is a planned activity and may require additional resources for proper execution. But the cell theory clearly points out that any unplanned variation in production rate either on higher or lower side of the uniform rate is an indication of abnormal or uncontrolled activity, with potential to impact adversely the quality.

According to (Abeyesekera 1997) many projects are being planned with uniform rate of build with allocation of resources to create flow of work to achieve uniform rate of build. If this uniformity is not maintained and there if there is an acceleration of the work (i.e. the flow of work) or variation in production, particularly with the same resources, the cell theory clearly indicates the need to be alert as such variation in production rate has the potential to have impact on quality.

The implication of cell theory is that only planned variation in rate of build with appropriate allocation of resources are likely not to contribute adversely to quality. To further enhance quality of replication which is error free, the cell theory has suggested that embedded design which is evolving has the potential to deliver projects with an optimum sequencing of activities. While the focus of tools like six-sigma is to control variations to achieve quality consistently (Bounds et al. 1994), the cell theory has not only focussed on the variation as quality control too, but suggested an approach based on embedded design as one of the ways likely way to address such variations and the resulting quality issues.

The quality system of the cell allows for suspension of activities to fix the defect. In construction industry with the pressure to complete the job once started, the suspension of works for quality issues is rare. The general tendency is to complete the work and fix it later. It seems the defect liability period and retention mechanism to ensure quality issues are addressed later is a testimony to this fact and acceptance of such practice as normal in construction. By contrast, cell theory has indicated fixing the problem before proceeding to next step to ensure quality. This could be because the cost of failure of quality in cell replication can jeopardize the survival of the organism, and with life as the basic property of cell according to Gerald (2010) the cell has system to ensure high levels of accuracy of the order of less than one mistake in 10 million nucleotides incorporated. While in construction the penalty is in terms of cost of time and money, and sometimes the loss of reputation which the construction company has to endure in case of quality failures.

Achieving of quality in construction is indeed challenging which is characterized by its chaotic nature (Bertelsen Oct 2004). While Womack and Jones (2003) recommend implementation of Lean Principles to minimize waste to improve quality, Spear (2004) has warned that implementing Lean principles without proper understanding will only provide short term gains. Keeping this in mind, it is clear that for the construction industry a proper approach is the need of the time and the cell based approach to achieve quality is one of the promising and a refreshing ways as articulated in this study.

6. Conclusion

The cell behaviour indicates that unplanned variation in rate of production is abnormal and is an indication of out of control activities which has the potential to impact the quality. Such variations of production in construction can act as red flag for the project control team to be alert for any out of control activities, as uncontrolled activities is one of the least desired in construction, which are likely to have negative impact on quality.

There is potential in the concept of embedded design which holds promise for the construction industry. There is positive outcome in terms of quality when a perfect cell is constructed based on embedded design and then used for replication, however this needs further exploration in construction.

Two cases discussed here resonate with the findings from the cell behaviour but further research and validation of this approach is required. Meanwhile, it cannot be denied that such an approach is likely to lead to better understanding of the process to achieve quality and enhance the planning to control the variation of flow of work to achieve quality. This new approach to achieving quality holds promise and requires further investigation.

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