Research and Graduate College
Research Institute for Design Manufacture and Marketing
University of Salford

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Hinks J, Aouad G, Cooper R, Sheath DM, Kagioglou M & Sexton M

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The Research Unit, University of Salford, The Centenary Building, Peru Street, Salford, UK, M3 6EQ.
Tel: 0161 295 6146
Fax: 0161 295 6174
Email: rachel.cooper@ucsalf.ac.uk

IT AND THE DESIGN AND CONSTRUCTION PROCESS: A CONCEPTUAL MODEL OF CO-MATURATION

John Hinks[1], Ghassan Aouad[1], Rachel Cooper[2], Darryl Sheath[1], Mike Kagioglou[1], Martin Sexton[1].

1 The Research Centre for The Built and Human Environment,
2 The Design, Manufacturing, and Marketing Research Institute,

The University of Salford, Salford, M7 9NU.

ABSTRACT

This paper considers the maturation of organisational capability, specifically in relation to construction industry organisations involved in the process of designing and constructing buildings. It discusses how the maturation of construction information technology, and its application, co-exists and co-operates with process capability maturation. The result is a co-maturation of organisations and their processes. A new model to explain the integration of IT and the design and construction process is proposed.

A model for a multiplier phenomenon occurring at the interface between Process maturation and (information) technological capability maturation is presented. The model adopts the Capability Maturity Model (CMM), developed at Carnegie Mellon University, in order to describe a co-maturation phenomenon involving (a) the design and construction process for new building work and (b) the use and development of information technology to support this activity. The paper builds on the CMM approach and adapts it for developing scenarios of the design and construction process and supporting use of information technologies.

The major contributions of this paper are to define a potential synchronisation mechanism for *IT* and *Process* and to present it as a vehicle for discussion. This can firstly help orientate individual organizations and the entire construction industry (in terms of capability maturity). Secondly, the paper describes the scope for strategically planning the evolution of individual organisations and the broader Construction Industry via the managed harmonisation of capability maturity of *IT* and *Process*. The authors also outline how the capability maturation modelling approach could be developed as a strategic tool for planned organisational capability maturation facilitated by IT and based on a philosophy of continuous improvement.

KEYWORDS: Capability Maturation, Capability Maturity, Co-Maturation, Modelling, Construction, Design, Construction Industry, Process, IT, Change Management.

INTRODUCTION

The UK Construction Industry remains in the state of self-examination which was initially catalysed by the effects of the prolonged UK recession and the 1994 Latham Report (Latham 1994). The collective mindset of the industry appears to lack confidence in many of the key aspects of its current perceived *way of working*, and there is a widespread industry acceptance of the need for profound change.

At the rhetorical level, this industry-wide receptiveness to improving the industry is being expressed publicly as a desire for a multi-dimensional phase change rather than gradual improvement. A whole industry solution is being sought for a whole industry problem, but with the emphasis on achieving a *changed* industry rather than a *changing* industry – a goal-oriented rather than journey-oriented approach.

Within the collective desire for whole-industry change lies a multitude of inter- and intra-professional sub-agendas and, of course, the localised desire for competitive advantage to be derived from the re-positioning of the industry. Entwined with this dynamic is the very powerful external pressure from the client as emergent expert in construction procurement.

Concerning the UK Construction Industry and the change process *per se*, there is a diversity of opinion about what the changes should be. This is being expressed in terms of how the *changed* industry should look. There is also debate about wherein the priority for change lies, and also how the necessary changes should be catalysed.

It is the view of the authors that at the heart of achieving any of the debated priorities sits the issue of strategically-driving change, which in turn hinges upon an understanding of the architecture of process-change *per se*. These facets of change are currently insufficiently understood by the Construction Industry to support a concerted change process. This compounds the problem of an industry pre-occupation with a *changed* industry rather than a *changing* industry.

For many in the Construction Industry, uncertainty also surrounds how change occurs in the individual organisation and its processes. Clearly the micro and macro issues of Process change are inter-related, and it is the authors' premise in this paper that macro change (whole-industry) and micro change (individual organisations) are inter-dependent.

It is this central issue of a *changing process* which the paper addresses in the context of two inter-related facets of industry change which have been clearly identified by industry lead bodies as priorities - the Design and Construction Process (hereafter the Process), and Information Technology for Design and Construction (hereafter Construction IT).

This issue of process and IT maturation and their inter-dependency has been the subject of investigation in other industries such as defence, manufacturing and software engineering (Karandikar et al (1992)). This paper addresses this problem within the context of construction organisations' capability maturity. The work is primarily based on the initial findings of an UK EPSRC Innovative Manufacturing Initiative funded project.

POSITION STATEMENT ON PROCESS AND CONSTRUCTION IT

This section of the paper discusses a position statement on the design and construction process and IT in the construction industry. It highlights the main problems associated with the inter-dependency between this Process and the supporting IT. The co-maturation and co-stagnation phenomena are discussed.

Co-Dependency and the Scope for Co-Maturation: Many key facets of the Construction Industry's modus operandi are currently the subject of self-examination, including the nature of the relationships within the industry and between the industry and its clientele ; the process of design and construction itself; and the perception of an historically poor uptake and application of Information Technology. These are all inter-related to the industry stagnation, so will have to be inter-related to its re-generation and changing capability maturity.

Process: A new Process appears unattainable without a supporting change in attitudes and operational arrangements, a change which is required to foster the necessary changes in that Process and render them sustainable. Conversely, an altered attitude to relationships within the industry (and between the industry and its clientele) requires changes in those contractual arrangements which sustain adversarialism within the current Design and Construction Process.

Adversarial attitudes and adversarial protocols are currently co-sustaining. Trust, or rather the lack of it within the industry and between the industry and its clientele, continues to be a chronic and major inhibitor of change. The paradox for strategic change management is that these are inter dependent ... pre-requisites for process change, and appear to have a macro-industry momentum which the individual (micro) organisation cannot influence, only react to.

Construction IT: Information Technology can assist the attainment and maintenance of a new Process operating within new relational parameters if the incoming new Process and the mechanism of change are sufficiently prescribed and detailed to allow industry-specific Information Systems and Information Technology applications to be designed and applied.

Conversely, the diversity of emergent IT is what helps stimulate change in existing practices. So here also there appears to be an inter dependent ... pre-requisite paradox for maturation, in the context of Construction IT application.

The authors believe that without the expansion of Construction IT into a genuinely industry-wide supporting tool for change, the existing fragmentation between sub-sectors and/or levels in the Industry may be compounded, which will also be self-defeating for a whole-industry re-generation. Indeed, the collective and concerted application of Construction IT may provide one consistent feature in construction practices (and hence one coincidence of micro and macro mechanisms for change) which supports the development of a changed and changing construction industry. Herein may lie a potential agent of change, if developments in IT and Process can be synchronised.

From this superficial analysis, there appear to be a complex set of inter dependent ... pre requisites operating in an currently undefined manner. This leaves progression in Construction IT application both as a pre-requisite and a dependent of the Process change dilemma outlined above. It is the authors' opinion that from such co-dependencies arise either co-stagnation or co-maturation. The issue for strategic change management is changing from a viscious stagnated cycle into a vicarious maturing cycle, moreover achieving this coincidentally at the micro and macro industry levels to remove fragmentation.

It is the authors' opinion that the states of industry stagnation and industry fragmentation are currently entwined, and that synchronisation of the solution is an additional pre-requisite for sustainable and industry wide (and industry deep) change. The consequence of an alternative, continuing patchy micro maturation will amplify the chronic fragmentation of the industry and impose a limit on the whole industry maturation capability. In the authors' opinion, it is precisely this scenario which the industry finds itself in currently, and which uncoordinated IT applications offers more of.

Co-Stagnation in Process and IT Capability: Stagnation in the Process may occur (in part) because of stagnation in Construction IT capability and application. Conversely, stagnation in Construction IT application and/ or use may emerge from a stagnated Process/ practices. Furthermore, additional stagnation pressures may originate in the mismatch between Process maturity and/ or Construction IT capability that occur between the different organisations which require to temporarily cooperate to undertake the Design and Construction Process for a project. Hence, macro-stagnation of the industry is probably due in part to misalignment in Construction IT application and use, with and as well as inherent Process difficulties and inconsistencies at the micro level.

Co-Maturation in Process and IT Capability: If a realistic opportunity for change is to be created, this will require both issues (Construction IT and Process) to be addressed in concert. They will require to be addressed from the coincident perspectives of individual organisations and whole-industry. It is this complexity of dynamics which has defeated a whole-industry solution to date, and will probably continue to do so unless this complex problem is addressed with a sufficiently complex whole-industry strategy.

Analysed as such, co-maturation appears to be the only tenable premise for industry progression, and perhaps the only mechanism for achieving the multi-dimensional phase change which is publicly desired by the industry. The authors do not believe that a phase change can occur in a single step however. It will come from a continual improvement process, a process to date undefined and unmodelled.

CURRENT VIEWS ON CONSTRUCTION INDUSTRY CHANGE

Maps and Journeys: The lead bodies for change in the UK Construction Industry[1] have been calling for *roadmaps* for the purposes of alignment and identifying the direction for change.

Such roadmaps have been called for in terms of Process and Construction IT[2]. The authors have contributed maps for Construction IT and for a Generic Design and Construction Process Protocol[3], the latter of which has been adopted by the UK industry-wide strategy panel, CRISP, and looks likely to be central to the creation of a collective lead vision for industry change and embodying the currently abstract but publicised desire for *a new way of working*[4].

Clearly, any such visions need to encompass how change operates and can be strategically driven, as well as the concept of a 'final' changed state for at least two reasons.

Firstly, seeking a collective and single-step phase change may be akin to seeking the pot of gold at the end of a rainbow, with the attendant possible consequences of an over-emphasis on the goal rather than the journey. It also blurs the issues of micro and macro change creation and sustainment.

Second, the process of change towards a goal depends on where you start from, and in terms of current capability maturity this is profoundly variable across the micro industry It is also profoundly unknown at either micro or macro level.

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[1] Included in this are CRISP, the Construction Research and Innovation Strategy Panel; CPN, Construction Productivity Network, a initiative developed out of the Latham Report recommendations; and Construct IT, the lead implementation body for the DoE (Department of the Environment) on Construction Information Technology.

[2] The approach of using roadmaps is not exclusive to the Construction Industry. In particular, this concept has been exploited in the context of concurrent engineering and process maturity. See for example Karandikar, H.M., Wood, R.T., and Byrd, J. Jr., 1993.

[3] This project is financed under the UK Innovative Manufacturing Initiative, and involves funding from the EPSRC (Engineering and Physical Sciences Research Council) in a two year £818k project due for completion in August 1997. The industrial collaborators with the University of Salford are Alfred McAlpine (Special Projects), BAA, BT, Engineering Technology, Watermans, EDM Architects, and Boulton and Paul. The stated objective of the project is the creation of a generic process protocol for the Design and Construction Process. A central feature of the research is the comparative analysis of manufacturing processes in the New Product Development sector. The interim findings of the project are reported elsewhere, further details of which are available from the authors.

[4] The concept of *a new way of working* was a central conference theme of the UK CIC in January 1996, and has become an emergent theme for UK Construction Industry change.

Hence the limitation of generic maps and their use currently appears to lie in the over-emphasis on where the Construction Industry wants to get from, with profound uncertainty remaining over where it wishes to get to or, indeed, the way forward. Notably, the journey and goal are also being framed in terms of current capabilities, rather than needs.

The emphasis on a changed industry rather than a changing industry is creating pressure for a singular and immediate solution. To extend the metaphor, the industry position on the roadmap is not clear or uniform at micro or macro industry levels, and the metaphorical route options (in terms of existing capacity) are being contemplated before identifying the destination. More profoundly, the metaphorical analogy of destination is not necessarily appropriate in a process-based industry. It may be more realistic to consider how a journey is to be made.

The Relevance of Whole-Industry Dynamics: For whole industry process maturation to occur, sustainable continuous improvement must be a feature of all the co-operating organisations in the design and construction process. Only then can the virtual companies[1] which operate on particular projects be able to continuously improve their collective, industry-wide, operating maturity. The authors argue that the alternative to this is the reinforcement of the traditional contractually-driven fragmentation of the industry via a new technological and process maturity fragmentation phenomenon.

Such a development may produce localised short term gains for certain elements of the industry, but since the whole industry currently operates via (contractualised) co-operation, there is a need for the entire sector to develop together and by mutual agreement. What has been termed the two-tier industry would actually be a multi-tier industry which is nonetheless interdependent for its capability growth. Such a scenario would represent no fundamental change other than a consolidation of the problematic mechanisms of the present. The greater the variance and diversity of capabilities and process maturity, the more embedded becomes the stagnation of Process improvement. Convergency rather than divergence is the key to process maturation, and construction IT harmonisation.

There is an additional risk that too much is expected too soon in the construction sector as a whole, and that an exclusively goal-oriented philosophy will defeat the establishment of the sustainable, continuous improvement which has characterised the success and inter-cooperability of other industrial sectors and key foreign competitors in construction.

STATE OF IT AND THE UK CONSTRUCTION INDUSTRY

Modern design and construction operations have become increasingly infiltrated by Information Technology, however this has been led by the availability of IT (hereafter supply-led IT), and therefore relatively uncoordinated in terms of provisions for the various operations and activities constituting the design and construction process. This has also meant that the co-ordination of these variable support tools, and most importantly the nature of their co-ordination with existing processes, has also been sporadic. Therefore, the level of sophistication of knowledge support and process agency provided by construction Information Systems has been patchy and fallen short of its potential.

[1] This point refers to the novel membership, structure and operation of construction teams, which involve the creation, operation and dissolution of short-term virtual companies, and which strategic or term partnering may assist in terms of collective ownership and cultural alignment.

In terms of progression of Process sophistication within individual organisations, this has largely occurred on a local, fragmented, and technology-push basis, with Process maturation occurring within organisations on the basis of localised uptake and exploitation. IT developed for other industries or in relative isolation from the Processes which the Construction Industry attempts to use it to support, means that the construction IT is often a solution looking for a problem. There is usually a requirement to adjust the existing Process-related activities to match the IT capability, or to customise the Construction IT to suit the local Process. This causes knock-on effects such as communication-compatibility problems. In most cases, the operational protocols of the organisation appears to determine the nature of uptake and subsequent operational practice which has contributed in part to the patchy uptake of complex IT support tools. A viscious circular phenomenon occurs, wherein the knock-on effects contribute to a stagnation in Process and Construction IT maturation at the level of the individual organisation, which in turn explains in part the apparent lack of uptake of IT in the Construction Industry. The greater the shortfall in existing Process activities to use the emergent Construction IT, the more fragmentary the uptake and industry capability becomes. In an industry such as construction, where the Process maturity is low, the result is typified by profound problems with IT uptake. Indeed, the IT compounds the problem through over-complicating or over-stressing unstructured and immature Process systems.

Currently the following technologies are in use (or considered for use):

- *Established used systems and technologies*: Office automated tools, computer aided planning, estimating, purchasing, etc.
- *Existing systems and technologies* with little influence: knowledge-based systems, neural networks, case based technologies, etc.
- *Emerging systems and technologies* still considered as research tools: Virtual reality, 3D Modelling, CASE tools, etc.
- *Future technologies*: Robotics, automated tools, etc.
- *Communication and standards systems and technologies*: STEP (Standard for the exchange of product data), IAI (International Alliance for Interoperability), EDI (Electronic Data Interchange), CORBA (Common Object Request Broker Application), VRML (Virtual reality modelling language), and Internet communication protocols.

These technologies, when integrated, could provide a mechanism for a technology push of the process. However, it has to be said that the emerging and existing Information Technologies will need to have a wider acceptance and a more profound application to the operational activities of the industry before a major impact on the process can be realised. Taken in conjunction with an appropriate development approach, these technologies could result in an improved interface process which would, in turn, take further advantage of the technology and the new ways of performing businesses – a vicarious circular phenomenon. The overall (contemporary) picture of such a scenario is shown diagrammatically in Figure 1:

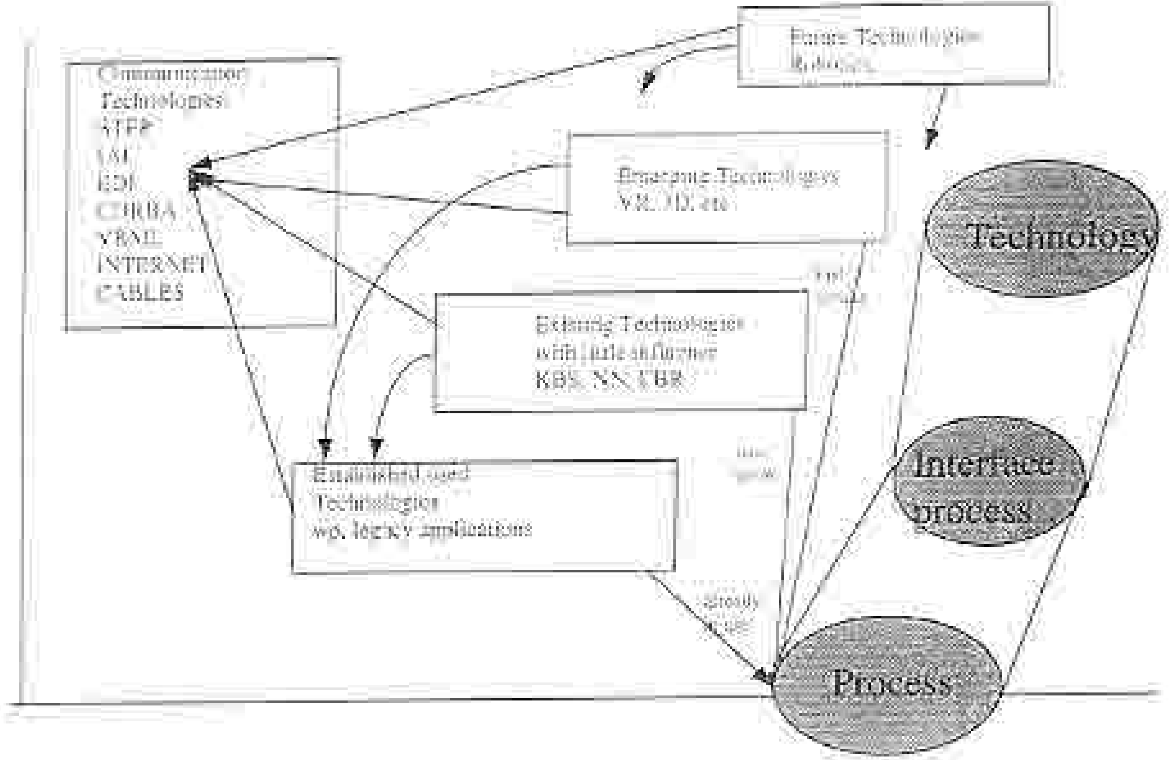

Figure 1: Schematic model of the relationship between IT and process at the interface.

THE DYNAMICS OF IT AND PROCESS MISMATCH AND CHANGE.

The nature of match or mismatch can be modelled in more detail. Action research studies in the context of maintenance management, and to examine the effect of Process and IT incompatibility, indicate that a rigid, or brittle Process character requires a rigid and complementary Information System for successful IT agency to occur without over-stressing the existing system. In such circumstances, co-maturation is difficult where the IT and the Process are both rigid and brittle. However, where a system is flexible, and the incoming IT is rigid and brittle (the normal scenario), or where the IT is flexible and the Process is rigid and brittle, the consequent mismatch leads to failure in co-operation between Process and IT, with negative consequences for process efficiency. In some cases there may be a break down of the process dynamics by the very IT which was incorrectly expected/ specified to support it.

Adaptation: Such scenarios lead in the short term to localised stagnation of Process and IT application. At the individual level, customisation of IT and/or alteration of practices may lead to a co-maturation via an emergent co-capability. Essentially this is a from of symbiotic co-adaptation. Where the organisation is a reflective and learning organisation, in other words institutionally adaptive, this localised adaptation in the Process may be strategically extended to a shift in the Process for the organisation as a whole. This represents a maturation of the process. It is distinct from an increased capability, since the adapted Process/ IT hybrid may actually be less efficient or less effective than the arrangements that it replaced. In such cases the adaptive nature of the industry will ensure that the change is re-modified or rejected since the individual or organisation concerned will be uncompetitive. Where the individual or organisation has an enhanced competitiveness, the practice may spread. This spread can occur via the spread of the adapted IT, which may be directly via the IT creators being part of the adaptation process (the re-issuing of new versions, for instance under a update agreement). It can also occur via the modification of Process practices, which may develop to the extent that a whole-sector or whole-industry change in Process occurs. Hence in the medium term there may be a co-maturation stimulated by the flexibility of Construction IT applications and the Process activities which they support or infringe upon.

The Co-Maturation Dynamic: This scenario of co-maturation relies on a metaphorical arena or forum for development, wherein practitioners apply IT as a support tool for existing Processes, or as a change agent for emergent practices. For this to occur in most cases of application, the maturity of the IT and the existing Process need to be adjacent. That is, a level three process activity may be stimulated to advancement in the particular context of an IT application by a level 4 IT capability. The technology pulls the Process capability. However, for the application to extend beyond the individual who is customising the Process and/ or the IT there requires to be a process push, that is the supporting or facilitating change in Process to adapt to the potential (or shortfallings) of the Construction IT.

Incompatibility in Capability: In instances of IT and Process which are distant in terms of capability, the step from the lower capability to the higher may not be immediately possible. Hence emergent and highly specific research tools for IT may be too eclectic to allow their immediate application within the existing system of Processes. Some adaptation of the IT is necessary - this is usually termed an increase in user-friendliness. In essence it is the attunement of the IT to the more generic process practices. However, this adjustment is probably going to be accompanied by an adaptation in the Process as well. So in the example of expert systems, the early expert system emergencies gave an IT agency which was more sophisticated than the heuristic understanding of the processes which expert systems could have supported. The result was a stagnation in uptake of IKBS whilst a few adaptive issues were explored for heuristics (eg, medicine). As expert systems emerged, the technology of case-based reasoning also emerged, as did case-based tools operating as a hybrid which took data and effectively assisted in the identification of heuristics produced the scope for co-maturation of processes via hybridised IT. It is important to recognise in such instances that an advanced IT tool which is essentially a research tool with poor current applicability may be of high potential use but is of low applicability, and therefore requires to mature in the sense of applicability in order to harmonise with the changing process which it supports.

From User to Organisation: The above adjustment process, as IT and Process become more coincident in terms of capability maturity and co-mature as a consequence, limits the pace of growth. This limitation occurs in the context of the changes in process within an individual organisation, also between organisations. Since individual organisations will tend to use a specific application of IT to suit their specific process practices, there will also be a period of increased misalignment and temporary hardening of individual organisational IT or sector-based IT. This may mean that cross-sector or cross-organisational communications based on IT are temporarily frustrated as localised advances to occur. Once the localised changes become more widespread the intra-sector problems of communication tend to reduce. Problems of communication compatibility alignment of IT based processes between sectors or professions which require to cooperate for the purposes of construction may take longer.

CAD as an Example: Consider the example of CAD-based operations. These were initially not generally communicable and hence led to CAD use being restricted in practice to a marketing tool. This was followed by a patchy uptake and translation/ re-keying problems, through to the emergence of industry standard IT tools (e.g. AutoCad). Within this phenomenon lies the harmonising adaptation of design process practices and the evolution of AutoCad to become specifically applicable to construction CAD applications. What started as a research tool with minimal real-use application in the 1970s has evolved together with the Process that it supports to become a IT-based process capable of supporting information interchange and shared working. In some cases other professions are able to attach their data and processes to the same packages and gain a shared (and matured) element of the process via communication.

Outwith the individual organisation, the phenomenon of isolation and difficulty in communication has also occurred, especially where localised adoption (and/or customisation) of non-industry-standard software has created practical exchange data.

MODELLING THE DYNAMICS OF CAPABILITY MATURITY, PROCESS AND IT

This section describes the maturation of Process and Construction IT within a construction context. The model adopted for developing and describing both phenomenon is based on the capability maturity model described later in this section.

Maturation Proposal: Capability maturation does not appear to be a causal phenomenon which can be stimulated in a single phase jump, nor is it something which is likely to occur homogeneously without strategic coordination either. Rather, maturation of process capability appears to be a localised, organisationally-initiated and organisationally-driven phenomenon - this is symptomatic of the historic whole industry dynamic.

Furthermore, whole-industry maturation is led by a complex interaction between industry lead organisations, an interactivity which has been and can continue to be stimulated and facilitated by the introduction and application of relevant Information Technology.

Organisational maturation appears to be the product of interaction between the Process and the mechanisms of that Process, an interaction which involves interdependent technology-push, technology-pull, process-push, and process-pull. With positive capability and management, a vicarious circle of Process and IT capability maturity may be generated and sustained. Without coordination, there may continue to be localised spontaneous improvement, but residual stagnation is also likely.

Capability Maturation Defined: The Capability Maturity Model (hereafter CMM) was developed by the Software Engineering Institute at Carnegie Mellon University in order to manage the development of software for the US government, particularly that which was to be used by the Department of Defence (Paulk (1993), Humphrey (1987, 1991), and Johnson & Brodman (1997)). Its application here is in terms of an analogy to software production capability maturity. The CMM model is also currently being used at the University of Sussex in developing benchmarks for process positions across various industries (Groak 1997).

The US Department of Defence identified that in order to produce a systemic software provision using a variety of producers, and to achieve the quality of process necessary to yield and extend a quality software network, some coordination of supplier quality and capability maturity was necessary. The response was to inaugurate the CMM as a means of auditing capability maturity, and to create a tool for the systematic improvement in quality required to achieve a reliable and more homogenous quality in the industry. The CMM has been considered in the context of other concurrent processes outwith the software sector.

The CMM is a five-level model of process maturity, comprising (1) ad hoc, (2) repeatable, (3) defined, (4) managed, and (5) optimised stages of process evolution. Each development stage, or *maturity level* distinguishes an organisation's process capability, and is defined in terms of a number of parameters which are construed as characterising a particular level of capability maturity.

Ad Hoc Process Capability Maturity: The *ad hoc* capability level is recognisable by chaotic teams which do not operate or co-operate effectively. There is inconsistency in Process operations, probably a lack of reflective practice, and generally ill-defined protocols for the operation or use of process support tools (including IT) (Karandikar et al (1992)[1].

Repeatable Process Capability Maturity: A *repeatable* process is definable as a process or set of sub-operations and practices which are sufficiently developed to be repeatable, and are recognisably repeated within organisational practices. In an industry as diverse and fragmented as the UK Construction Industry, the question arises about the extent of pervasion that a process or tool requires in order to be categorised as repeatable or repeated.

In this particular context, it is noteworthy that the categorisation of process capability maturity as *repeatable* is a reasonable analysis from one perspective of the macro-industry - a sketchy collective process can be outlined which describes what the industry as a whole does. However, closer inspection at both the macro and micro levels reveals a lack of repeated or repeatable design and construction process. This issue of focal range needs to be considered in all analyses of capability maturity.

Note the distinction between repeatable and repeated. The Construction Industry tends to adapt its activities and processes according to specific projects. Inconsistency, or a lack of repetition in operational protocols appears, for example, in the design sub-process, the procurement sub-process, the scope of construction operations and technologies, also management. It also occurs in the use of the building. Indeed, in almost all activities which the Construction Industry partakes there is profound diversity in practice. Repeatability and repetition may appear locally within an individual organisation whilst across the industry the repeatability is not apparent.

This raises the importance of perspective in defining repeatability as a Construction Industry Capability goal. In terms of goals, should an industry structured traditionally around a diversity of products seek repeatability in process or practice? One approach has been to attempt to standardise the components and products of the industry to create a repeatable and repeated process. In other industries this approach has created profound stability and subsequent extensions of capability maturity in areas where there is product stability and predictability (eg. automotive). However this would be inappropriate for an industry involved in producing a diversity of products ... Should the Construction Industry seek repeatability via seeking repetition in process, practice, or is it more a matter of achieving a sustainable repeatable and repeated *way* than an exacted series of practices that is needed to improve the industry? The distinction between repetition and repeatability lies in capability of the industry to adapt repeatability

[1] These definitions of CMM levels are based upon the interpretation of the CMM made by Karandikar, H.M., Wood, R.T., and Byrd, J. Jr.

without sacrificing flexibility to repetition. What is needed is a standardised, repeatable way of working rather than a singular standard practice. IT may be part of the solution to this.

Notably, other industries with more regularised products and processes are alert to the potential benefits of this lack of repetition at a macro level, especially in terms of flexibility and adaptiveness of the industry players to variations in circumstance and change. Whilst the authors are not presenting this diversity and lack of repeatability in the way of working as a fault in its own right, the issue does highlight the problems inherent in seeking a singular protocol for the macro-industry. Moreover, whilst repeatability is a founding feature of a changing capability maturity, an industry founded upon repetition could have simply moved from one state of stagnation to another. Clearly, how the UK construction industry approaches change is once again highlighted as being critical as well as what it wishes to change to.

Defined process capability maturity: The process for both management and engineering activities is documented, standardised, and integrated into a standard process for the organisation. All projects use an approved, tailored version of the organisation's standard process for developing and maintaining work.

Managed Process capability maturity: Detailed measures of the process and product quality are collected. Both the process and product are quantitatively understood and controlled.

Optimised Process capability maturity: Continuous process improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies.

The key process areas for Levels 2 and 3 have been the most completely defined. Since few organisations have been assessed to be at Levels 4 or 5 (Humphrey (1991a), and Kitson (1992)), less is known about the characteristics of such organisations within the software engineering context. The problem is compounded in construction as these organisations are striving to develop measures within the first three levels of CMM. It also compounds the problem with the construction industry search for a changed industry (at a level of maturity which is currently undefinable) rather than a changing industry.

CONTEMPORARY CONSTRUCTION IT AND PROCESS CAPABILITY MATURITY.

The following diagrams attempt to position some important sub-processes and IT-based activity-support tools on a CMM-based framework. Figure 2 demonstrates the similarities between Process and IT maturation and the dynamics of both aspects. Process maturity is assumed to be in relation to multi-disciplinary individual organisation.

An emerging process or technology will go through the process of refinement/ improvement in order to reach level 5. A process can mature to a certain level when the corresponding technology is within the boundaries of that level. For instance, a rapid prototyping process can only co-exist with the enabling technologies such as VR, 3D modelling,

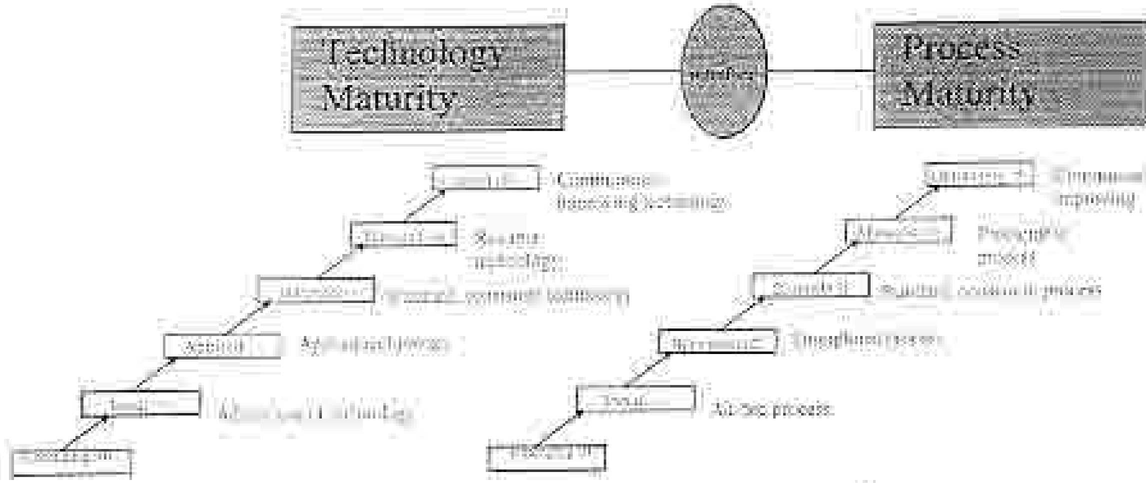

Figure 2. Comparison of IT maturity and Process maturity

Looking at the specific aspects of IT provision, analyses of the contemporary IT application within the construction sector (Riley 1997, Aouad 1996), indicate that there are a range of *emergent*, *initialised*, and *applied* technologies of increasing industry specificity and hence specialism in construction process support. See figure 3. However, and it is the authors' contention that this is a consequence of the limited capability maturity of those specialised processes which they support, the IT capability maturity does not tend to extend beyond level 3 - wherein some integrated applications are supporting, and supported by, defined process activities such as construction. See also figure 4, which shows the maturation of the overall process performed within a multi-disciplinary organisation.

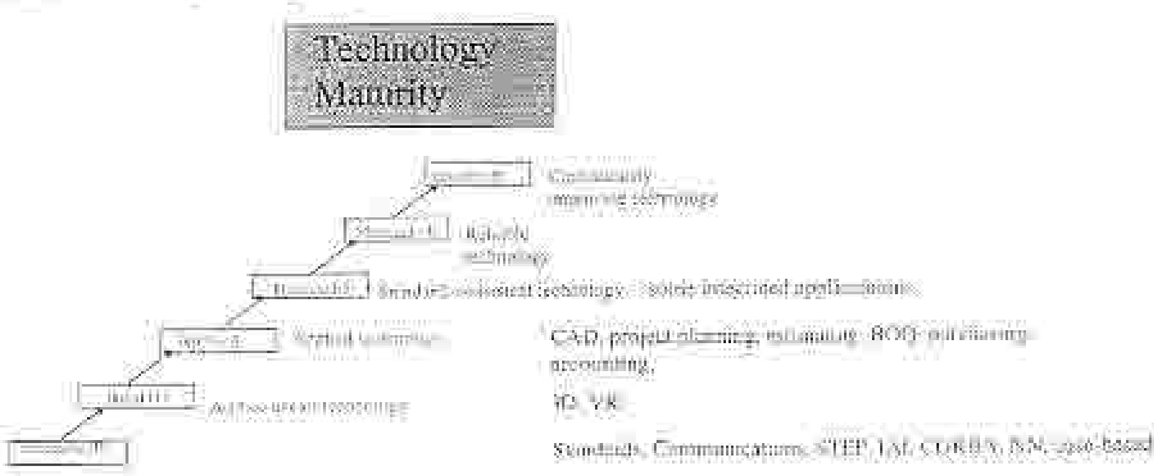

Figure 3. The technological maturation of applications within the construction sector.

Figure 4. The maturation of the overall Process performed within a multi-disciplinary organisation.

STRATEGIC MANAGEMENT OF IT AND PROCESS ALIGNMENT AND CO-MATURATION.

Creating an appropriate interface between construction IT and Process is a matter of designing the IT introduction and application to suit the existing process capability - which in turn requires a realistic perception of the relevant process capability maturity. In a multi-disciplinary organisation, the disparity in localised professional capability maturity makes this a difficult and sensitive issue in the strategic management of change. Construction IT evolution has generally followed a steeper gradient of maturation than process (if measured against a notional time line on the x-axis on these diagrams). This has frequently translated into an IT-Process capability maturity gap, behind which lies localised (micro) and whole industry (macro) variations in IT/ Process capability maturity.

A micro-level IT-Process capability maturity gap may symbolise an industry coming to terms with the changes in process maturity needed to apply and exploit relatively mature IT, which requires to become more user-friendly (that is, more guiding in terms of process requirement adjustments necessary to apply it).

Conversely, at the micro-level of lead organisations which stimulate the industry, there will be localised rapid adaptation or even Process-IT capability maturity gaps for the same IT.

In between these two extremes lies a portion of the industry which is in chronic flux as it tries to adapt IT and Process coincidentally, and where IT application and Process jostle for superior maturity. This is where the generic maturation occurs, and where application of IT translates with Process change. It is this crossover (figure 5) which requires to be strategically managed in order for co-maturation to occur.

The exact position and width of crossover will depend upon the organisational form and maturity consistency; it will also reflect the relevant professional capability maturity status as a whole. Hence the alignment and positioning of a micro organisation will require careful audit of the internal and external process maturity, and the current and affordable support IT.

The steeper the gradients the greater the cost, and the wider the capability maturity gap the more difficult co-maturation will be. For a progressive co-maturation to occur, there must be a joint maturation of reasonably coincident capability maturities in IT and Process. A cyclical juxta-positioning of technology push and pull, and Process pull and push will occur. It is this which requires to be managed in order to advance this organisation's IT application and Process capability maturities. At the centre of this needs to be a journey-oriented construction process improvement philosophy.

Clearly, within such a model a dynamic and sustainable growth will occur in a *changing* organisation rather than one focusing on a *changed* status. At a macro-industry level, this is even more critical because of the need for an inter-dependent industry to co-mature in terms of Processes and IT.

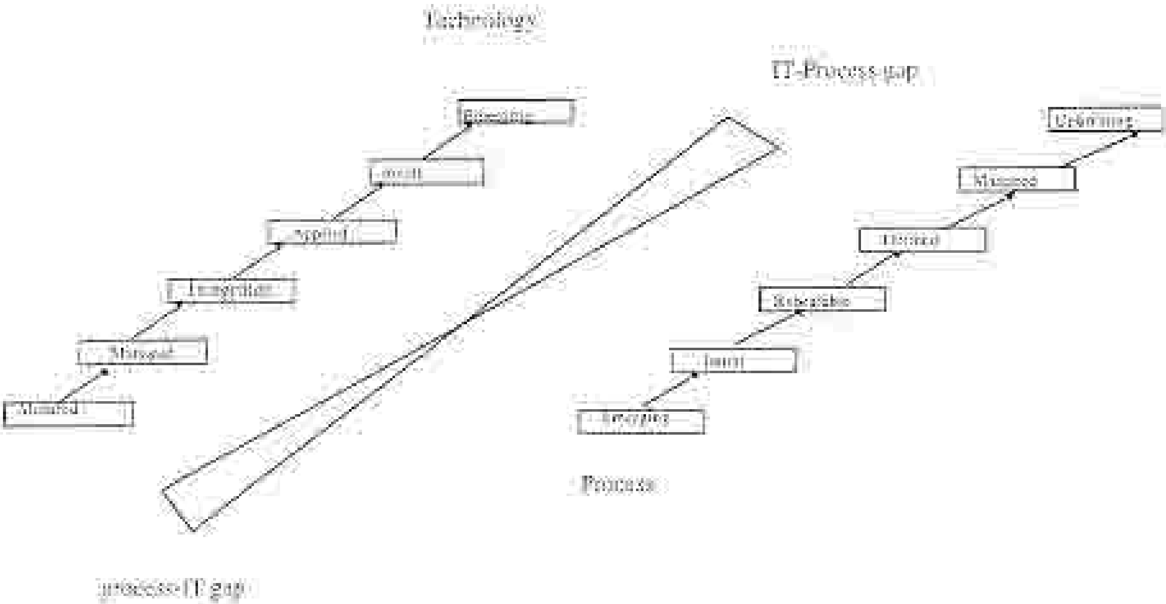

Figure 5. An appropriate interface can occur at the intersection of process and IT through the phenomenon of push/pull.

THE CO-MATURATION OF CONSTRUCTION IT AND PROCESS - AN EXAMPLE BASED UPON THE DESIGN FUNCTION.

The Construction Information Technology/ Process gap at the emergence of initial CAD systems is considered in this section. In the first generation of CAD systems, CAD was explicitly a research tool - it was not easy to use, input or interpret. At a generic level, it did not co-relate or co-respond with the existing or changing design process. There was limited technical and or graphical capability, and hence little scope in the first CAD forms to add value to architect's work or work process.

In contrast, at the time of the emergence of the first CAD tools, the vast majority of architects were designing/draughting on paper, tending

The Relevance of Contemporary Measures of Capability Maturity: At this time the RIBA plan of work was a defined and manageable process tool. The IT was highly specific, needing a great amount of training and supplementary skill (which in general were not transferable to other contemporary IT tools or other processes activities). Moreover, these IT applications and the process alterations which were created as a direct result of adaptation of activities to suit these relatively rigid IT protocols were not in widespread use throughout the design industry. Additionally, they were not in use in any other sectors of the construction industry. Exchangeable data or information products were not available, hence interactivity with the remainder of the Process did not occur.

By the 1980's, 2nd generation CAD systems had started to emerge. Emergence of more user-friendly AutoCad versions, for example, led to improved user friendliness and an applicability still not specific to the construction industry and the contemporary design and construction Process. There were increases in uptake and occasional co-operative working between users, but almost all use was within single organisations operating within a single professional sub-division of the construction industry. This constituted an ad-hoc application of the IT and an accompanying ad-hoc change in the previously defined process activities. In localised application, the co-maturation of construction IT and the design process was occurring via a maturation of the IT and a temporary immaturation of the Process in order to gain a shared higher level of co-maturity and co-capability of both IT and Process.

This is typical of how change appears to be pioneered in Process via construction IT, and is being replicated in a contemporary 1990's context with VR and 3D modelling applications which are still being uptaken on a localised and ad-hoc basis. The widespread contemporary under-use of such technologies, for instance as a marketing tool, rather than as a more capable design aid with repeatability and interactivity which defines the way of working within the design profession and between this and other professions, is a symptom of this symbiotic aligning of capability for future shared capability progression.

Returning to the emergence of CAD and growth of co-maturity in the design Process, by the mid/ late 1980's the third generation CAD systems had started to appear on the market. Now the maturation in capability was facilitated by exchangeable data, which could be achieved by DXF and IGES. This helped with the exchange of data between organisations, which in turn resulted in an improved element of the Process, but was still largely concerned with a single sector of the construction industry.

By the early nineties, fourth generation CAD systems emerged with more 3D modelling capabilities. This allowed organisations to consider seriously the process of rapid prototyping resulting in more maturation within the design and construction process - and notably the communication between different professional players and sub-elements of the construction industry and project team.

Fifth generation CAD systems, formerly research tools, which are about to appear on the markets, will be able to support the exchange of objects (design components, rather than lines), potentially resulting in a more integrated and consistent process based upon a shared consistency in application, level, and IT protocol of the construction IT supporting the disparate process activities undertaken by different functionaries

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This contemporary relevance of this issue extends also to the problems of attempting to create a changed industry which would be defined in terms of the contemporary practices and expectations, whereas a changing industry and changing process also changes its views on what is a manageable or optimal process. Hence the search for optimised process approach is a self-re-inventing exercise.

of the project team. We are now at the point as an industry, where this context of construction IT is awaiting a co-ordinated process protocol maturation, coupled with exchange protocols for information to support the process in a more defined and hence manageable manner. This represents the crossover point described in figure 5, and wherein the opportunity window for continuation of IT and Process co-maturation lies; if managed appropriately. The continued co-maturation now awaits process maturation, and the IT maturity capability maturation may be slowed whilst the process catches up to allow its full exploitation. A push-pull cycling of IT and Process superiority allows the pre-requisites ... interdependencies to be utilised rather than to stagnate the Process.

Clearly then, the maturation of IT and process can be strategically inter-twined if the capability maturity within the Process and construction IT are considered collectively. The following example models this in more detail, and suggests some audit parameters for categorising IT capability maturity.

CAPABILITY MATURITY - A COMMUNICATIONS-BASED EXAMPLE.

Level 1 - Initial or Basic IT: At the most basic of capability levels, IT is used for word-processing and assistance in supporting business activities, all of which activities are completely generic to all industries. These technologies are so entwined with educational minima and conventional societal and organisational operations that they are now taken as being the base datum for information management and information processing.

Other examples of these dumb media, which define the contemporary level 1 capability envelope include conventional use of telephones (speech & fax), calculators, and word-processing/ electronic typing.

This level of IT supports spoken or written communication and hence are useful for elements of Process which involve spoken/written communication of information/ data interactive. This practice is useful for stating position and structuring discussions at a distance.

The written support technologies tend to be slow and require repeated use. Spoken or written material may need re-preparation for each use, which may not be a particularly problematic bottleneck where information emerges sporadically, in small amounts. The level of IT capability maturity is not useful for co-operative development of work (e.g. design, except as a medium). These technologies represent closed systems in widespread use. PC-based Information Technologies typifying this level tend to be generic, closed, systems which cannot readily translate content between software systems.

Level 2 - Applied and Semi-Permeable Systems: Above the baseline technology lies the level of interactive communications. This is more advanced and applicable to specific Processes than basic closed system technology since the data is characteristically transferred in a <u>retrievable and manipulable</u> form (fax is retrievable only). It is also by implication storable and can operate interactively. Information can be transferred in and out of other software applications - hence these are part of <u>open or semi-porous</u> Information Systems. The semi-porous/ porous distinction is made because the data may need some (re-)configuration and there may be some losses which limit the immediate use by other information technologies without some conversion process or additional work. This is the evolutionary position of many of the main word-processing softwares, wherein the scope exists for exchange between particular applications produced by the same company. The broader issue of universal inter-operability lies within this capability envelope, and is the subject of IAI initiatives in the US. At present this represents one of the key bottlenecks to mutual operation and sharing of processes via technological commonality, especially in an already fragmented industry such as construction. This appears to be the widespread but not universal status of many industries. Examples include email, and interchanges of data between sub-suites of software packages, WWW, video conferencing

Level 2 IT capability tools are not exclusive to the Construction Industry only; nor are they used in the entire industry (problematic). Whilst these are typically semi-open systems, the transfer is of data only and they are not dynamically interactive at the Process level of decision-making. Level 2 Information Technologies do not add process sophistication, since they support existing communication practices only. They are not 'smart' (although mailing lists make a step forward in this context). If more specialised IT applications are converted to a compatible format, data can be communicated via this level of IT.

The key facets of the level 2 semi-permeable systems is that they facilitate global communication of basic IT-derived information, hence making the transferral between otherwise local applications possible via standard or ISDN telephone links. They are becoming known as enabling or informing technologies. There are some emergent limitations on medium capacity use related to the economics of data transfer technology rather than the technology *per se*.

Although the speed and capacity are greater, and the cost of kit and use can be greater than generic baseline, the trend is likely to be that of a reducing cost .

Level 3 - Integrated, 'Generic To The Construction Industry' Tools: This level of IT is specialised to the particular needs of an industry. There is some variability in the exact status of such IT, since true generic-to-industry software may include in the context of the Construction Industry softwares such as power project, superproject, project planner, which may be in use in another customised form in another industry. AutoCad has become generic to the design sub-sector of the Construction Industry now, defined by the widespread nature of its use, and measurable according to the likelihood of finding the same software in application in peer organisations.
Level 3, generic industry tools are designed for widespread use in a bespoke industry application or process based on the use of information. The widespread uptake necessarily follows the maturation from an initial and applied IT use to wider uptake. This also requires infusion of the Construction IT into the Process at a generic level, and in part serves to define generic industry processes. These information technologies are likely to be a component in an broader information systems, systems which are sufficiently sophisticated (mature) as to match good, normal practice and industry Processes.

Examples of IT at this level of capability maturity include SPACE[3], an industry-specific integrating tool which allows multiple users to access and use for design process purposes data originated in a multitude of otherwise closed software packages, so that professionals can co-operate using historically incompatible software. This IT actually pulls process and IT capability maturity forward by creating a proxy interchange, or integration platform to allow the true integration needs or potential of the Process to be supported. Through this support the IT can evolve, and the potential stagnation of low level IT capability (in terms of communication, not the specific functional capability) is bridged. The co-maturation of IT and process is facilitated.

[3] Further details of SPACE are available from Prof. Mustafa Alshawi, The Research Centre for The Built and Human Environment, University of Salford

Other examples include price estimating tools for use in the QS sector of the Construction Industry, which are highly specific to the industry and range from simple calculation tools requiring a normal level of pricing experience and professional intuition and interpretation, to expert systems for pricing which require the same user group to have a much more advanced level of interpretative capability. The use of such systems is self -limiting by the range of capabilities of the user group. For many users the sophisticated capability of the Construction IT may exceed their needs or current capability maturity. Levels 4 and 5 do not represent contemporary industry development.

This cross capability maturity spanning by IT within the same specific sector and application is a feature of co-evolving Construction IT and Process maturity. Here the full complement of forces operate, not necessarily within each organisation, rather across the industry as a whole. The localised competitive advantage which may be gained by the professional adaptation and interpretation of such Construction IT stagnates the collective maturation by harmonisation, nonetheless capability maturation is occurring locally and in parallel. Professionals moving between organisations, and the overall industry maturation drift will eventually spread these activities, and the authors see this as an example of the natural facilitation of the industry-wide co-maturation process. It could be accelerated (as in the automotive industry of the 1980's) by partnering, an approach through which change managers could create opportunities for co-organisation maturation in a symbiosis of IT and Process capability sharing.

IT applications at this level usually involve high cost/ high training/ and high added-value to Processes, and process information in a complex manner and of sophisticated application. There is a glass ceiling below this level which prohibits all but the largest firms from investing, training and maintaining or upgrading the necessary IT. Contemporary industry-wide examples are rare because of the mismatch between Construction IT capability and widespread Process capability.

Level 4 construction IT can communicate with other systems (usually) using traditional communication media. This is slow because in reality it is overloading the basic communications, designated on our diagrams by the distance between levels 4 and 1 (or 2). The greater the distance (difference in maturity and capability) the more the overloading that this creates, and the more normalising of the higher capability maturity by the lower. Synchronicity between the IT or Process is also important.

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had been sufficiently established in the Construction Industry, a level of Process prescription (not project prescription) will arise which will allow a sufficiently flexible Construction IT tool at level 4 or 5 capability maturity to manage the process automatically.
This is related to another function, that of change management. This is currently being operated in some design circles which are using round-the-clock working by multiple users located worldwide and a protocol of colour identification of changes in designs to allow concepts to be carried between users. Such a system could be extended in concert with a process management role to allow all discursive and decision-making processes to be controlled via an automated change filter. This change management function stimulates participants for change requirements, accepts and checks changes for consistency and re-distributes the exchanged status of decision and any accompanying process revisions according to a priority protocol for user change authority. Such an activity could operate with the legacy archive discussed earlier as a source of meta-protocol. Change management and Process management would also be the focus for the systematic co-maturation in Process and IT capability.
Such evolutionary mechanisms would operate with very advanced protocols, requiring pan-industry consistency in protocols and meta-knowledge management. They would be specific to the Construction Industry.

Level 3, generic-to-industry tools can exchange data with added value and/or contextualisation via dumb media or directly via disc exchange. In most cases this remains the predominant medium of data exchange, and is a limitation on process uptake. Enhanced exchange technology capacity will reduce this issue for the contemporary data exchange requirements at level 3, perhaps to become a bottleneck to levels 4 or 5 and so on. This still represents capability maturation..

The distinction in operation of the level 3 Construction IT tools is that they can embody value in the knowledge which is transferable (i.e. preparation of information by user 1 can be directly input and applied in parallel contexts by user 2. In a construction context, a similar phenomenon appears with level 2 semi-permeable IT, but here the knowledge may or may not be valuable to the process-specific support requirements of the Construction Industry design and construction process). Typically, such IT would not be directly useful in another industry.

In use, these systems supplement the skill/ knowledge input of the user to enhance their performance of their role in the design and construction process. A level of user skill (in IT use), a complementary or greater skill in the relevant Process practices, and knowledge of how the industry uses such information and processes are also needed.

Note the capacity for such levels of Construction IT to harmonise practices in the industry at the level of individual user and organisation. There is a clear potential for in-service CPD by the local and general co-maturation in Construction IT capability and Process capability which it serves.

Levels 4 and 5 – Specialist (Or Customised Generic To Industry (Level 3 Hybrids)) IT For Construction Industry Use, up to and including Optimised Capability Maturity: This form of Construction IT is aligned to specialised activities within the construction industry . Such applications are not necessarily local to a particular profession, there are two main forms.

Firstly, the specific use of Information Technology may relate to a high level feature of Process which requires such an application to be highly specific to one function in the design and construction Process only, and hence is not conventionally a data exchange issue. The use may require an unusual degree of information support coupled with a specialist process and IT knowledge.

The second scenario is one of an industry wide exchange or co-operation involving several professions and a high level of information, which is used by all concerned in the process. Examples may include a legacy archive, which captures and makes available for re-use information about the manner of decision making as well as the decision outcomes themselves. Also within this category of IT capability maturity is the scope for automated change and process management'.

These concepts have been developed as part of the authors' project on developing a Generic Design and Construction Process Protocol. The Process Management Function is a high level process management activity, which involves the scheduling and coordination of activities, including a manufacturing technique of stage-gate analysis for discrete phases of the Process; and within which arrangement the entire process is controlled by a single point of responsibility identified as the Process Manager. This is distinct from the Project Manager, and involves the exchange and management of information about specific project decisions, the decision-making process *per se*, and also the duty/ownership rules and [illegible] of all of the functionary participants in the Process. It is envisaged that when a generic process protocol has emerged

As IAI solutions to historically incompatible level 3 IT removes one glass ceiling to IT and Process co-maturation, and upward IT compatibility become technically stable, development will be led by user groups which have sufficient process maturity to use IT constructively. In conjunction with a process maturation protocol, the use of automated legacy archives, design libraries/VR, and object-oriented 3D modelling interacting with specialist design tools (eg, strucad) is possible... Hence the design and construction Process may approach the [illegible] of manufacturing. However, in this scenario, a new form of gap may occur, as the localised multi-disciplinary or virtual-company based synergy of high process maturity and investment, coupled with interactive development of IT, creates & self-supports a superleague of construction IT oriented firms. This separation, or tiering of the industry, may only produce short term gains, as the normalising and continued need to work as a co-operative industry remain. The outcome probably depends upon whether a critical mass of sufficiently cross-disciplinary Process and IT lead organisations create the necessary critical maturation in industry capability. Whether this can be strategically managed is another issue.

Also pressure on communications will focus the economic scope for upgrading, which may occur in a phase change, perhaps with satellite based communications for 24 hr working coupled with interactive high volume communications on level 5 'IT'...

Hence the IT roadmap is more akin to a topography. Capability maturity gaps in IT support occur not only with IT missing, but where the process needs & IT capability do not meet. The construction industry will improve most - and most rapidly and most economically where IT & Process meet in terms of capability maturity and grow together.

Where established IT is supported by Process evolution, the re-design & re-application of the IT into next generation IT is done by alignment and support of process. This is an optimised process of maturation, rather than an optimised state of maturity. The journey analogy is once again pertinent.

This approach appears to be translatable to the contemporary Construction Industry, wherein a multitude of 'suppliers' of goods and services (including project and contract management), of variable and un-audited capability maturity attempt to cooperate on a (usually) single project basis to produce a building (system). Since there is usually no explicit coordination of the sub-processes employed by each player in the resultant virtual company, nor any practical method of review and feedback to the future (as yet undefined) virtual companies, there is no learning cycle beyond the individuals concerned, and perhaps some process improvement

The CMM model offers the strategic change manager with the scope to identify the process capability traits which distinguish lesser and more mature organisational processes, lesser and more mature construction IT applications. Each process maturity level provides progressively stronger foundations for higher evolutionary stages of process maturity.

CONCLUSIONS

The model presented offers an outline concept for how the process capability and IT capability of individual construction companies, and the construction industry as a whole, can be categorised. It also offers a hypothetical mechanism to explain how these individual capabilities may mature, alone or in combination. The potential synchronisation of IT and process capability could allow mature organisations to achieve stability in their operations and strategic planning.

This paper has highlighted the potential nature of interaction between process and IT, especially in the light of current moves to improve both in the UK construction industry. Whilst further research is clearly needed to develop the model, there does appear to be the possibility for a co-maturation or co-stagnation phenomenon which the industry strategists will need to accommodate if the industry maturation is to be successfully and efficiently orchestrated.

REFERENCES

Paulk, M. et. al., 1993 Capability Maturity Model for Software, Version 1.1, Tech Report. CMU/SEI-93-TR-24, Carnegie Mellon University, Pittsburgh, 1993.

Aouad, G, Alshawi, M and Bee, S. 1997 Priority Topics For Construction IT Research, *The International Journal of Construction IT*, Winter 1997.

Aouad, G, Hinks, J, Sheath, D, Cooper, R, Kagioglou, M & Sexton, M. An It Map For A Generic Design And Construction Process Protocol. Submitted to ITcon the electronic journal.

Karandikar, H.M., Wood, R.T., and Byrd, J. Jr., 1992 Process and Technology Readiness Assessment for Implementing Concurrent Engineering CERC Technical Report Series Technical Memorandum 92 004, Concurrent Engineering Research Center, West Virginia University.

Johnson, D.L & Brodman, J.G. 1997 Tailoring The CMM For Small Businesses, Small Organisations, And Small Projects. Software process Newsletter, IEE Computer Society, no 8, Winter 1997.

Latham M, 1994 Constructing The Team, H.M.S.O.

Humphrey, W.S., 1987a Characterizing the Software Process: A Maturity Framework, Software Engineering Institute, CMU/SEI-87-TR-11, ADA182895, June 1987.

Humphrey, W.S., and Sweet, W.L. 1987b A Method for Assessing the Software Engineering Capability of Contractors, Software Engineering Institute, CMU/SEI-87-TR-23, ADA187320, September 1987.

Humphrey, W.S., Kitson, D.H., and Gale, J. 1991a A Comparison of U.S. and Japanese Software Process Maturity, Proceedings of the 13th International Conference on Software Engineering, Austin, TX, 13-17 May 1991, pp. 38-49.

Kitson, D.H., and Masters, S. 1992 An Analysis of SEI Software Process Assessment Results: 1987-1991, Software Engineering Institute, CMU/SEI-92-TR-24, July 1992.