PARADIGMATIC FRAMEWORK FOR CONSTRUCTION INFORMATION TECHNOLOGY

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ABSTRACT: The problems that we are dealing with in construction IT were known in the sixties, and are, 30 years later, still not solved. The hypothesis is that the reasons are: (1) the scientific base for construction IT, its paradigmatic framework, is not explicit and (2) that the framework, as implicitly present through research practice, is an incomplete one and that (3) a paradigm shift is needed.

In the paper the author introduces the concept of paradigmatic frameworks for sciences. Such a framework includes axiology (values), ontology (what exists), epistemology (where is knowledge) and methodology (rules of inquiry). Current research practices of construction IT is examined in the frames of these categories, as well as the possible alternatives as suggested by Heidegger, Schoen and Kuhn.

In addition to objective, measurable progress, efficiency, integration, the axiology needs to consider worker satisfaction, sustainability etc. as important values and goals as well. Ontology should address human work as the most important item that exists and should be studied, not products or processes that can result in limiting, blinding models. Epistemology should confess that the knowledge is in the doing and in thinking about what is being done. Methodology should, because of the problems in the scientific method, consider the use of the Socratic method more often.

KEYWORDS: construction information technology, axiology, ontology, epistemology, methodology.

1. INTRODUCTION

Problems that remain in the core of research and development in the field of construction information technology were set a third of a century ago, for example by Champion (1967):

> *"One of the problems which is important in relation to the use of computers generally in the building industry is that of finding a satisfactory coding system for information. Whereas individual firms can quite easily devise their own coding systems, the use of computer techniques throughout the industry as a whole will depend to a large extent on all parties agreeing on one generally accepted coding system. One of the difficulties is that different sections of the industry may require different forms of coding; ... "*

Information exchange in the fragmented profession remains to be in the highlight of numerous research projects. A standardised product model - "coding system for information" - is still believed to be the key technology to solve it. After 30 years of research and development, particularly intensive in the last 15 years, the practice changed very little in this area. Is the wrong problem being addressed? Can the problem setting be changed? Are the current scientific methods appropriate?

In the paper, the author reflects on the topic "construction information technology" and the attributes that do or do not constitute it as a science.

2. THE SCIENCE OF CONSTRUCTION INFORMATION TECHNOLOGY

An important attribute of any scientific discipline are its framework, vocabulary, methodology, paradigms and structure - as Kuhn (1962) calls them, the *"conceptual boxes ... into which the scientists, by a rather a strenuous and devoted attempt to force nature into"*. Periodic table of elements provides such a structure for chemistry as a whole; tree of species has similar function in biology. Attributes, such as spatial and time dimensions, theory of elasticity or plasticity, number of degrees of freedom, model of material etc. provide it to structural mechanics. In this paper, the paradigmatic framework for information technology in construction is proposed.

For the last 15 years, information technology in civil engineering has been developing into a research discipline in its own right. It is getting a share in the curriculum of undergraduate and graduate programmes. However, IT in civil engineering has many attributes of an immature science. It is a subject of influence from the technology push of computer science and the technology pull of core civil engineering disciplines and therefore lacking a clear identity of its own.

Historically construction IT emerged form "computing in civil engineering" but since every civil engineering discipline started to use computers, only two sets of topics remained affiliated with construction IT:

- Technology oriented topics that span over several civil engineering disciplines (e.g. product modeling, integration, concurrent engineering, distance working and learning).
- IT support for engineering topics that span several disciplines or life cycle phases, such as construction documentation, management and economics.

This defines the topic in the context of the profession, but according to Seni and Hodges (1997), a field of science is actually defined with the following attributes:

- **Axiology** defines a value system in the field.
- **Ontology** defines "what exists" and (formally) specifies the conceptualisation of the field.
- **Epistemology** specifies what constitutes appropriate knowledge in the field, where is it and how it can be represented and transferred.
- **Methodology** specifies the appropriate rules of inquiry.

In the next four sections, these four attributes of construction information technology will be observed.

3. AXIOLOGY

The actual values of the persons practising science and, to an extent, the society surrounding them, determine the course of scientific development. Science is considered objective, the truths its discovers independent of the good, bad, right or wrong. In the scientific world, the highest on the scale of values is "scientific truth", more precisely, uncovering the "truth" from Mother Nature. Another value of science is the "objectiveness" and apparent independence of a value system - however, these two are values as well.

Some of these values have been occasionally disputed, for example in the discussions about the moral issues related to the invention of the atomic bomb or in the recent controversies related to genetic engineering. During history, some sciences have been forced into accepting value systems from theology, Marxism or liberalism.

Applied sciences, like the construction IT, are in the service of humanity who wants to create shareholder value, produce more, at lower costs, with higher profits etc. "User requirements" are ranking high in the value system. Concerns about ecological or sustainable development are not shaping the core of scientific development.

Construction IT is not a science with big ethical dilemmas. The values that derive the requirements for construction IT research are:

- organisation,
- progress,
- profit, productivity,
- efficiency,
- integration,
- quality,
- client satisfaction,
- researcher satisfaction.

Construction IT research should develop technologies that would make the above attributes more true for the construction process. Less exposed values are:

- improvisation,
- conservation and tradition,
- sustainability,
- worker satisfaction.

Some of the above attributes (if not all, if in conflict with the previous list) are considered a value, not by business owners, but by the workers in the construction business. It has been argued, that the really successful technologies enable improvisation (practised a lot in construction), don't revolutionise the way of working (improve them slowly and gradualy) and leave the workers with the creative and satisfying works.

4. ONTOLOGY

In philosophy, ontology deals with "what exists". In computer science ontology gets more formal and was defined as "a specification of conceptualisation" (Gruber, 1993) and should formally describe concepts and relationships among them, that *can* exist. Based on such an ontology, product, process and other kind of models, could be built. Guarino et al. (1997) suggest that standard models, such as STEP and IFCs, should be based on an explicitly defined ontology.

Models that are being developed in the field of construction are supposed to be models of reality. Ontology defines what exists in that reality in how can it be conceptualised. Underlying an construction related ontology is a theory of construction business. Candidate theories about construction view it as:

- A system
- An input processing output mechanism
- Hierarchy of roles, functions, powers, responsibilities
- A man machine system
- A social and learning system

- A quality system.
- A socio-technical system.

Kuhn (1962) writes that *"the notion of a match between the ontology of a theory and its "real" counterpart in nature seems ... illusive in principle"*. Therefore, a construction related ontology should be defined within the realm of human operations - it is the human activities and interpretations that provide the meaning to the defined concepts - regardless of the complexity and completeness of an ontology.

4.1 Theories of construction

There are three different theories that define what is human work is and can provide the fundamentals for construction-specific ontology:

- Work is processing. In the 1920s Taylor defined work as processing. In the assembly lines, workers got inputs, such as parts, performed some operations, and produced some outputs. Construction is seen as a flow or transformation process in which raw materials and components are transformed into construction products.
- Fulfilment of commitments. Winograd and Flores (1980) claimed that work is asking for, negotiating, accepting and fulfilling commitments. Construction is a social network of people sharing a common goal of building.
- Schoen (1983), in his observation of architects and managers found that design and management are research processes with strong social components.

The author believes that construction should be modelled as a socio-technical system (Figure 1) and should focus on human work (Turk and Lundgren, 1999).

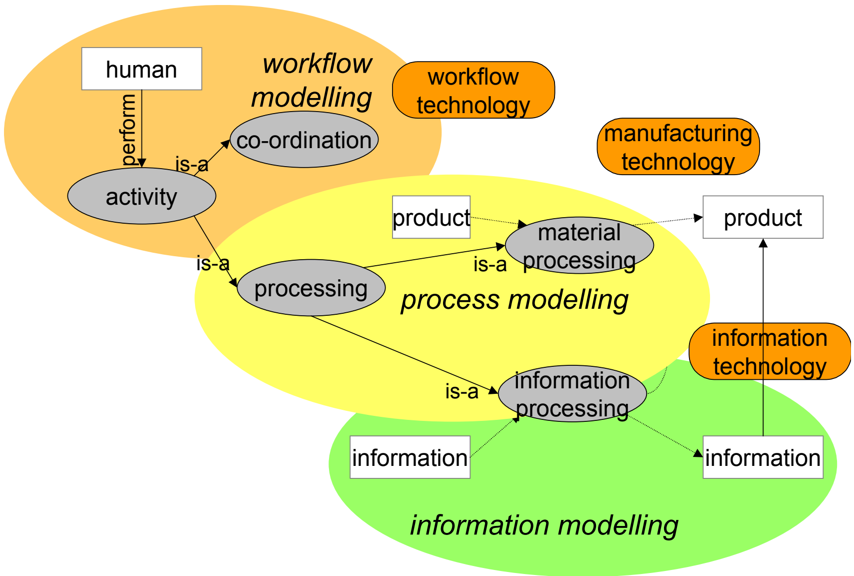

Figure 1: Semantic network of key concepts in construction.

5. EPISTEMOLOGY

Epistemology attempts to identify where can the appropriate knowledge if the field be found and/or created. The candidate sources include:

- Knowledge is achieved by applying the fundamental truth of the hard sciences into the applied sciences (mainstream positivistic view).
- Knowledge is achieved through reflection-in-action (Schoen).

- Knowledge is in-action, including common sense knowledge and intuition, reflection comes after breakdowns. (Heidegger).

5.1 Traditional epistemology

Traditional science believes that the source of knowledge are the scientific theories and techniques (Figure 2). In that view, professional activity is instrumental problem solving made rigorous by the application of scientific theory and technique. Attributes of a knowledge base for any profession (e.g. construction IT) is supposed to be:

- specialised,
- firmly bounded,
- scientific,
- standardised.

Work is the instantiation of models and application of scientific theories to day-to-day practice. This view had a profound effect on education - professional education (e.g. of engineers) should be the education in sciences, not in the professions. This view is based on positivism. Positivism is a branch of philosophy that flourished particularly in the late 19th and early 20th century and influenced by the rapid technical development of that time. It was during this time, when in fact the skeletons of the university curricula were shaped. The three principle doctrines of positivism are:

- Empirical science is the only source of knowledge.
- Minds should be cleansed of intuition, mysticism, pseudo-knowledge ...
- Scientific knowledge and technical control should be extended to society (and socio technical systems, such as some types of computer software).

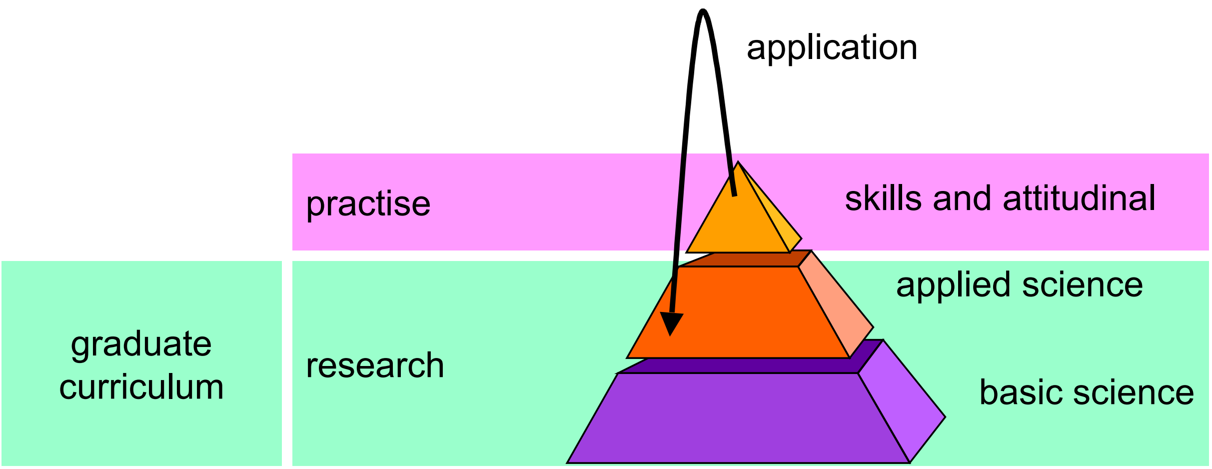

Figure 2: Application of science to practice; traditional view.

5.2 Knowledge in the doing

The theory of reflection-in-action was invented by Schoen (1983). Although he does not reference earlier works of Heidegger (1962), there are several parallels in the works of the two.

According to Heidegger, the basis for our everyday action is the ability to act pre-reflectively when "thrown" into a situation. We know before we think! Contrary to the tradition, which considers reflective analysis of a detached observer as the basic intelligent behaviour, he claims that reflective thought about objects and properties is derived from pre-conscious experience of them as "ready-to-hand". The essence of intelligence is "throwness", not reflection. To hammer a nail, he argues, we do not require conscious reflective knowledge about the physical properties of a hammer. The tool is ready-to-hand and we just hammer the nail into the wall. Similar pre-reflective actions can also explain the so-called "intuition", "insight" or plain "common sense" that are sometimes used by the designers or engineers to explain their creative process. The very instant we begin to think reflectively about a situation and analyse it in terms of object and properties we disconnect ourselves from the being-in-the-world, we try not to be thrown into a situation. We limit our view of the problem to the one that can be expressed by the objects and properties we have adopted, and create blindness for all other possible solutions. Heidegger claims that we do reflect on situations, but only after breakdowns or problems.

Schoen agrees that the key part of the knowledge lies in "doing" something and that this knowledge is difficult to make explicit. Professionals like architects, engineers, psychotherapists, scientists, managers exhibit substantial knowledge while doing their jobs, knowledge, which they cannot make explicit and knowledge, which is not an application of scientific truths learned in school.

Schoen does not acknowledge the limitations of reflection, if done in action and claims that this is how professionals work - they reflect in and on they work. Such understanding changes research and education agenda, as well as software development priorities.

He observed architectural design. According to Simon (1972), design is “a process of changing existing situations into preferred ones”. We know each design case is unique, uncertain, non-standard. The difference between a good designer and an average one is first's capability of re-framing, re-setting of the problem in a way in which the designer *feels* she can solve. Master designer has developed and uses a repertoire of past cases, sees new case as a version, or metaphor of an old case ...

Schoen claims that professionals are very similar to scientists because reflection-in-action includes experiments such as:

- exploration ... see what follows
- move testing ... deliberate action with an end in mind
- hypothesis testing ... discrimination against competing hypotheses

However, it is not scientific in the sense, that scientific research is about finding new general truths while reflection-in-action is about transforming one current situation into a “preferred one” and not more.

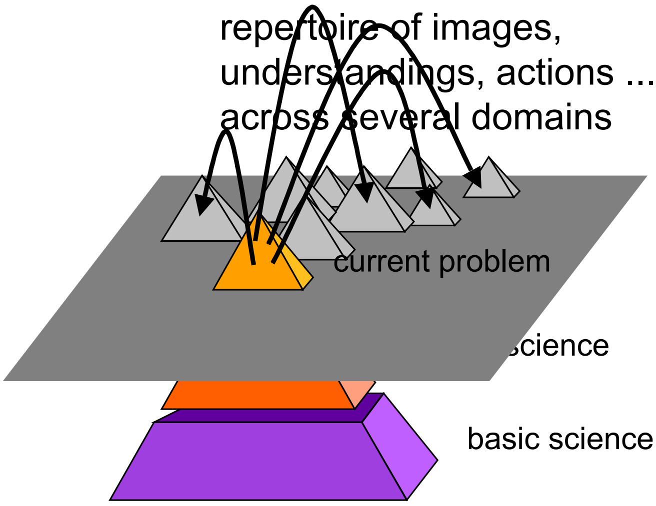

Figure 3: Science and practise - alternative view. The professional mostly uses his repertoire, not science.

6. METHODOLOGY

Methodology defines the rules of inquiry. Two methods are known:

- Scientific method: Use conceptual models as hypotheses: an abstract structure that admits inference of its consequences (i.e. a theory), and an interpretation of its terms into the things of interest in the enterprise to which they are intended to refer.
- Socratic method: Perform a thought experiment, a case that conforms to the theory but clearly fails to exemplify it. Intellectually argue *against* proposed model.

6.1 Scientific method

Scientific method (Dye, 1999) has the following steps:

1. Wonder. Pose a question.
2. Hypothesis. Suggest a plausible answer (a theory) from which some empirically testable hypothetical propositions can be deduced.
3. Testing. Construct and perform an experiment, which makes it possible to observe whether the consequences specified in one or more of those hypothetical propositions actually follow when the conditions specified in the same proposition(s) pertain. If the experiment fails, return to step 2, otherwise go to step 4.
4. Accept the hypothesis as provisionally true. Return to step 3 if there are other predictable consequences of the theory, which have not been experimentally confirmed.
5. Act accordingly.

6.2 Socratic method

The procedure of the Socratic method is (Dye, 1999):

1. Wonder. Pose a question (of the "What is X ?" form).
2. Hypothesis. Suggest a plausible answer (a definition or definiens) from which some conceptually testable hypothetical propositions can be deduced.
3. Elenchus. "testing," "refutation," or "cross-examination." Perform a thought experiment by imagining a case, which conforms to the definiens but clearly fails to exemplify the definiendum, or vice versa. Such cases, if successful, are called counterexamples. If a counterexample is generated, return to step 2, otherwise go to step 4.
4. Accept the hypothesis as provisionally true. Return to step 3 if you can conceive any other case which may show the answer to be defective.

5. Act accordingly.

6.3 Methodology of construction IT

The scientific method in construction IT is typically applied like this:

(a) follow the advances in general IT, wonder if some technology is any good in construction and find a problem it can solve; or select the technologies, which seemed appropriate for a problem in the construction industry,
(b) hypothesis: "this" is a good approach, it can be used ...
(c) model the construction industry's products, processes or whatever in a way fit for the selected technology, do system analysis and design, produce diagrams ...
(d) write the software an prove the hypothesis with a prototype.

There appear to be three major faults in this process:

Firstly, the hypothesis is not well defined, measurable and verifiable. It is vague and inprovable with methods used in natural sciences. With current approach, it is impossible to objectively prove right or wrong. Why?

Schutz (1962) distinguishes between first and second order constructs. Natural sciences concern itself with 'first order' constructs. They are not changed or influenced by observation or intellectual manipulation. The second order constructs are *"constructs of the constructs made by actors"* and are therefore influenced and changed by the observer. They are studied by social sciences. Most construction IT constructs are second, not first order.

Secondly, the value of research prototypes is doubtful. Some talk of them like of hiding mice and elephants. They prove little until implemented by a CAD vendor and actually used industrially. If this does not happen very soon after the research, it is very likely that the problem will be solved by the advances of general computing. But because most of point (c) and (as illustration) point (d) is very useful for scientific publishing, there has been a tendency of a growing complexity of models invented, rather than applying the Occam's principle.

Finally, the interpretation of the models and prototypes is done by intelligent and flexible humans. The Socratic approach of cross-examination and refutation is almost non-existent. It seems, however, very useful in discussing phenomena that do not have physical existence, in particular product and process models that model human conventions and not some physical 'first order constructs'. This is manifested by a multitude of different, correct solutions and almost zero failures. The zero failure rate, however, does not prove construction IT research successful.

7. DISCUSSION: TOWARDS A PARADIGM SHIFT

According to Kuhn, a paradigm shift in a science happens, not if the new paradigm solves problems, but if the new paradigm offers enough interesting new problems for the scientists to tackle. What are the research issues that should be in the focus if the alternative framework components would be used:

7.1 Support reflective practitioners

Research can help reflective practitioners by providing tools and technologies for frame analysis and repertoire building.

Frame analysis research should provide different ways of framing or setting problems. Provide many different modelling methods/paradigms, instead of one standard one, but find a mapping between them to enable integration.

Repertoire building research should be developing technologies that will allow for archiving on-going works with near zero overhead; develop technologies for finding, retrieving and reusing past cases on different levels of granularity and in different contexts; study case-based retrieval and matching mechanisms; develop technologies for template building.

7.2 Examine how construction is specific

We read often that construction industry is different from other engineering disciplines as follows:

- it is involved in one-of-a-kind products; buildings and other facilities are usually unique;
- they are designed, built and maintained in a one-of-a-kind processes;
- the process is carried out by a one-of-a-kind team of contractors an subcontractors;
- team members vary in size, budget and level of IT expertise and are typically small to medium enterprises (SME).

Nevertheless, have we ever drawn any consequences from them? Doesn't all this say that modeling tools should be designed in such a way that they are easily adaptable for one-of-a-kind products; would not this argue for relatively minimalistic models composed of very generic items? Shouldn't we shift the focus to handling data efficiently and not insist on having every bit of data "in a formation" (in-formation!). Processing power and data mining techniques could be applied to get the right data at the right moment.

The processes are unique and typically assemble a unique set of partners. Are the approaches that were conceived for the modeling of certain bureaucratic processes in banks and administrations that are repeating millions of times, really suitable for something as chaotic as construction? What does happen in construction a million of times? The speech act theory and the communication workflow approach have not been sufficiently addressed so far.

A particular problem in the implementation of IT is the varying IT capability of the team members. The co-called state-of-the-art could be available to some best practice firms, but how about the rest of them. In particular if the goal is computer-integrated construction, the benefits come when the entire virtual enterprise can use them.

In summary, construction IT is different in the following ways:

- It should support products that cannot be described by standardized product models.
- It should encourage the transparency of the private models used in various applications more than the use of unified, standardized models (e.g. XML data exchange, publicly available EXPRESS files or component definitions).
- In "process" support it should focus on human-human communication and acknowledge improvisation as an important way of working in construction
- It should build a thin layer over a moderate technical and human-resource infrastructure. Web and browser based solutions that work with little overhead over phone lines seems the lowest common denominator.

7.3 Gap between research and practice

It has been often noted that the intake of information technology in the construction industry has been slow, slower than in other industries. Researchers seem to live under the impression that they have all these fantastic solutions and that all that is lacking is a way to make the construction industry use them. Several research projects have tackled this issue from the perspective of filling this gap bottom up - to bring the construction companies to the level of academia by educating the practitioners (e.g. SCENIC) or asking the practice what it wants (ELSEWISE).

What they should know, and what would be very useful for the researchers in the field would be, how much are they capable and have time, to learn in a given period of time. Suppose that an upgrade from Word 6 to Word 7 is a unit of technology enhancement effort (TEE). How many TEEs a year can their staff afford. How many TEEs is worth an introduction of a commercial document management system? How many TEEs is the implementation of a state of the art integrated environment created in a multimillion EU project? How much overhead can they swallow to adopt a new technology? What should be investment return rate e.g. after how much time would the time invested in installing and learning a new technology return in time savings due to using the technology? Yes, computer assisted learning can speed up the learning process but without clear answers to the above questions, we don't know by how much.

Intuitively it seems that due to the nature of the work, construction industry is very demanding in these matters. Evolutionary technologies, that would build on existing knowledge and ones that would have a clear upgrade path would have an edge over revolutionary ones. The axiologies of sciences and that of practice are divergent.

8. CONCLUSION

Construction IT has been considered an applied science and its paradigmatic framework has not been studied. In the paper, the four dimensions of this framework were discussed. Because a paradigm shift seems to be needed in this field, the possible alternatives to the mainstream were presented:

Axiology - in addition to objective, measurable progress, efficiency, integration, we need to consider worker satisfaction, sustainability etc. as important values and goals as well. Ontology should address human work as the most important item that exists and should be studied, not products or processes that can result in limiting, blinding models. Epistemology should confess that the knowledge is in doing and in thinking about what is being done. Methodology should, because of the problems in the scientific method, consider the use of the Socratic method more often.

Kuhn (1962) writes: - *"To be accepted as a paradigm, a theory must seem better than its competitors, but it need not, and in fact never does, explain all the facts with which it can be confronted, thus making research possible"*. Approaches that break problems apart and study the pieces (so typical for modelling) fit this goal better than the holistic approaches.

The research issues within the new paradigm include the study of human-human interaction, workflow, social issues of technology, frame analysis, repertoire building all taking into account the peculiarities of construction and its ability to adopt new technologies. Future directions of construction IT should focus on the human and his behaviour - the engineer, the architect, the technician - who is supposed to be assisted by the technology and who designs, engineers, learns and interacts with other humans. Research methodology should be influenced by that of the social sciences. It should be taken into account that the objects of study are a second order entities.

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