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Artificial Intelligence in Construction Management – a Perspective

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Abstract

Efficient organization of construction services seems to be a complex task, limited by the capabilities of human intelligence. During the seventies based on e.g. the development of fuzzy technologies by Zadeh, the rise of expert systems gave new hope to innovative approaches to solving complex situations in project management. As history teaches, since then no real advance could be observed regarding this concept. Nowadays construction and real estate projects have become larger, thus more complex and risky, time schedules have become tighter as have the available budgets. With this the need of support of the organizational challenge has increased significantly. In this context and supported by the presently available computing power as well as on the basis of a presumably complete model of the building including the construction process with an Building Information Model (BIM), the idea of support by Artificial Intelligence has gained importance again and new hopes as well as fears have come to life.

Prior to explicit attempts to construct tools for construction management, an investigation of the principal needs of organizational support as well as the possibilities provided by Artificial Intelligence is required in order to prepare the ground for future development.

In this paper the principle understanding of complexity based on locality developing into emergent behaviour of the organization of construction projects is presented and mirrored to the expectance towards artificial intelligence operating on a Building Information Model (BIM). This investigation makes use of the theory of systems to model the behaviour of complex systems as well as of commonly used approaches offered by artificial intelligence concepts, e.g. neuronal networks, machine learning algorithms and rule-based decisions within a complex context. On this background the feasibility of improvement in gaining efficiency in construction management organization is elaborated and reviewed.

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1. Introduction

The term Artificial Intelligence (AI) is used since the 50ties of the last century. Again and again the upcoming equality of natural and artificial intelligence has been predicted and postponed. Concepts of AI have been developed according to the understanding of natural intelligence, and received great acknowledgement but again and again human mind has been understood a little bit further and therewith artificial attempts failed to keep up. With the upcoming rise of available computing-power ancient principles have been revitalized and are now reaching heights which truly seem to be able to compete with the human brain. Not much of the fundamental concepts has changed, but the complexity of the outcome reveals astonishing heights.

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During the upcoming of computer sciences, the idea of the complex task of managing unique projects with the support of computers was established. Soon, algorithms on the basis of Theory of Graphs allowed computing CPM, MPM and PERT networks. Still resting on strict definitions of situations, solutions were not achievable in many cases due to the often contradictory character of bivalent restrictions or to causal loops inhibiting determined procedures. As a consequence, fuzzy variables were introduced first on PERT diagrams [14, 23], where durations were determined by BETA-distributions, not on the solid ground of measured probabilities, but on estimations given by experienced managers. Later, Zadeh [26] introduced the concept of fuzzy-sets in order to model vaguely determined parameters as well as equivalently vague interactions, provided by a vast range of expert-knowledge. The main problem occurred to be not the well-working maths but on the one hand the procedure of obtaining sufficiently general and numerous situations to derive fundamental knowledge from and on the other hand the applicability of equivalently vague resulting instructions and targets for the final execution.

2. Construction Management as Complex Task

Artificial Intelligence seems to be a promising approach to solve problems, which overchallenge a human mind, be it due to the sheer volume of data, of processes or, in particular, the given complexity. Issues concerning the volume of a task are understood as predestined for computer applications while the term of complexity is different. Definitions of complexity are given e.g. in [8, 13, 19, 24]. They are mainly referring to behaviour of a system, which can not be described by the local properties or next neighbour interactions but by the total interacting system. Such behaviour is in contrast to locality understood as being emergent. In former times, as long as the volumes of construction projects have been limited, and due to a fairly strict separation of contractual work into trades, this task was manageable, however with some effort and not always successfully. Meanwhile, Construction and Real Estate projects are becoming much more voluminous, as are budgetary and temporal margins becoming tighter, e.g. with large turnkey-ready buildings. With this development and clearly indicated by the observation of an increasing number of publicly known disastrous projects, Construction Management on this scale is possibly in fact beyond the scope of a limited human mind [11]. Construction Management is just the efficient organization of a large number of participating people or groups as well as an equally large number of technical construction elements or, more abstractly, virtual units like activities, services and cost, including their vast set of nonlinear relationships [22]. Clearly, the behaviour of a system “Construction Project” is emergent [4] and the task of Construction Management would be to lead it nonetheless with high certainty within a very narrow corridor to a very tight goal in terms of time and cost [5]. If this is beyond capabilities of man, will it be within the scope of Artificial Intelligence?

3. Technical Approaches to Model Artificial Intelligence

Since nevertheless “artificial” implies the creation of this “intelligence” by the human mind, first, the principle methods and algorithms need to be laid out:

3.1. The Principle of Industriousness: Procedural Formulation

With procedural respectively imperative formulation of tasks [27], a set of rules is elaborated in a way that a complex task is treated correctly and the correct results are provided. These rules and instructions, developing from a well-defined state to a next also well-defined state, are processed for huge volumes of data or a long time, possibly repeatedly or iterative. The resulting behaviour looks like “AI”, but all the “I” is pre-programmed including all foreseeable particular and specific situations. This is applied with classical software programming processes and, thus, poses the problem of formulating in short, but absolutely strict, the rules and instructions which represent the complete and complex behaviour. In Construction Management this concept is made use of, e.g. within a costing software, where values of single items are precisely assigned to a node within an unambiguous structure and locally treated there according to very clear rules. Only the application of the repeated instructions of where to receive the values from, how to process and in particular where to cumulate allows for an overall correct result of costing [22].

Comment and evaluation for Construction Management: This approach is widely used in Construction Management but still based purely on human intelligence: Any not precisely understood development of a system cannot be brought down to instructions and therefore never be actively modelled. Therefore, this offers no progress on tackling complexity beyond human capabilities.

3.2. Virtual Intelligent Behaviour: Object-Oriented Formulation

In contrast to imperative formulations where the creative mind is located outside the system, object oriented design facilitates intrinsic behaviour [27]. A large number of local rules connecting objects to determine properties of a destination object are set up as being valid and correct. Due to their strictly local character their validity can easily be proven. Applying these to a large set of data, i.e. objects with their properties, recursively or iteratively, represents the behaviour of the system [2]. The interaction of the local rules and the un-predetermined type and structure of the data-set leads to emergent behaviour. This again is true as long as the set of rules is locally true and complete. The emergent behaviour reflects the correct situation and looks intelligent. However, a system like this produces “intelligent” behaviour, as long as simply emergent behaviour is intelligent and not just complex. It is in fact just unintelligible. If the local rules are well-determined, i.e. the system perfectly well-known, then the resulting character is in fact reflecting the reality to be expected (besides some artefacts due to the imperfect modelling and execution of the local rules). This is the fundamental approach to simulation, mainly used with iterative processing.

Remark: If otherwise the behaviour to be modelled is known and the local rules to achieve this are to be developed, things become more difficult. This would be the case with object-oriented programming, which is only applicable if the behaviour is clearly assignable to a limited number of local rules [2].

The challenge of intelligence modelled on the basis of interacting objects is that in particular correctness and completeness of the set-up are fairly difficult to ensure but nonetheless inevitable. In Construction Engineering this concept is used e.g. for all sorts of Finite Element methods, in Construction Management as the basis of the Ford-Algorithm for positioning activities on the time-axis, simulation of processes [27], or for clash detection within a Building Information Model (BIM) [3].

Remark: This approach poses a specific problem: Trying to create such systems leads to making the users as well as the constructors slaves to it, even if the complex behaviour is found not to match the observed or required reality. This is mainly because there are no ways to track an error back to a single rule to be modified. Observing the emergent behaviour, in particular the not matching part of it, allows only to test-wise introduce additional rules and observe the hopefully improved result again. The connection between result and input is a very strict one-way road.

Comment from the view of Construction Management: This approach is also widely used in Construction Management. In particular, where all the local information is given, clearly complexity is only the emergent behaviour of the total system controlled by nothing else [28]. However, completeness of the primary description of the system is essential to this understanding since complexity implies the characteristic of irreducibility, i.e. missing a single element or interaction may change the whole picture to an incalculable degree.

3.3. Neuronal Networks

A completely different approach is maintained by the concept of neuronal networks. This is an attempt to fight a way back from observed emergent behaviour to local rules. Intelligent behaviour can be observed in the real world, e.g. based on intelligent decisions of clever individuals. Methods like neuronal networks construct weighted sets of rules, capable to reproduce these decisions and extrapolate this behaviour to proximate situations. This is an attempt mimicking the learning process of a human brain. However, a fundamental model needs to be constructed, utilizing a set of parameters which are to be optimized for a proper representation of correct implications. This procedure implies that the pre-constructed model is correct or at least sufficiently general to cover the given issues. With neuronal networks the underlying model is a multi-layered linear combination of possibly nonlinear triggering elements. Such a pre-set is already restricting the possible output, nevertheless promising. The Neuronal Network approach is

particularly successful with optical and acoustical pattern recognition tasks. However, the developing processes require a huge set of information to learn from, in particular somewhat orthogonal rules in order to cover a given space of situations. Due to the requirement of comparability of solution spaces, the resulting intelligence is limited to answers already experienced by the learning material, never reaching beyond these.

Comment from the view of Construction Management: This approach is fairly close to the historical attempts tackling Construction Management during the 1980s [18]. That time it suffered from both the lack of sufficient data to learn from as well as the computing capacities to process this volume accordingly. Both seems to have increased largely by now. So, speaking of AI to cover Construction Management issues focusses solely on the neuronal network approach.

4. Fundamental Approach to AI

Artificial Intelligence is expected to decide better as or equal to a human being exposed to the same situation and parameters, i.e. based on an identical level of existing information. On the background of the second law of thermodynamics within a closed system the total entropy S will only increase. Understood as a measure of information according to Shannon [21] we have $S = \ln_2(I)$ and therewith the main law of Informatics stating that information can only be lost, i.e. destroyed, never generated. In particular, this allows AI principally not to generate knowledge, which is not primarily existing, but only to process existing information into decisions based on mechanistic rules.

Remark: The technical approaches to AI discussed previously take account of this principle.

In contrast to this, an intelligent (human) mind might be able to contradict this principle. Szilard [25] approached a comparable situation investigating the existence and entropic situation of the Maxwell Demon. Taking into account the requirement of entropy to accomplish the measurements a decision is based on, the gained entropy exactly balances the spent entropy and thus proves the validity of the Second Law of Thermodynamics even for the action of an intelligent mind. However, this applies only for deterministic reasoning where rules and information are given and all the decisions are purely based on these. So far, this again comes down to pure industriousness. Bringing in the creative mind, where we assume decisions to be made on the background of taste and fantasy, such consideration might not apply. In particular, Ebeling et al [7] investigated generating information of different types by e.g. an intelligent mind, a creative being and finally self-organizing mechanisms. Considering intelligent and creative beings, this may happen on the entropy cost of the existence of themselves, but self-organisation presents itself as revealing information which was just hidden within the system and had no opportunity to establish visibly. Artificial Intelligence therefore is understood to operate within a closed system where only causal reasoning is possible, even if mechanisms of self-organisation are taken into account. As soon as external knowledge, i.e. information, is required, possibly in the form of creativity (of an external mind), the system is no more a closed one.

Remark: The Turing Test, which is agreed on to be the fundamental test for an Artificial Intelligence, simply compares the machine to the human mind conducting a lengthy discussion. Besides simple characteristics like response time, which comes down to computing-power, it is merely the capability to answer questions in a way a human being considers an equal counterpart. It is not a competition and can principally not state superiority over the human mind.

5. The Construction Management Situation

On this background the question arises, to which degree the operation of construction processes, i.e. construction management, is bound and completely determined by available rules and information [16]. With scheduling, all boundary conditions, as there are activities, relationships and fixed dates are given. The task remains to find an optimal solution to the minimizing problem of the construction time while obeying all the predefined conditions, which is just an ordinary well-understood task [14, 22, 23]. So far, the problem can be separated into two independent segments. First, the situation needs to be described completely and accurately before, secondly, any mechanism may approach the optimization problem. The later is certainly – difficult or simple – a matter of causal reasoning, probably minimizing losses including soft facts like fuzzy variables or probabilities, and thus may be subjected to artificial or human intelligence without violating major principles as the generation of entropy. However, the major task would be

to describe the situation accordingly. Mathematical completeness is not feasible, so it comes down to judging the relevant issues to be modelled. This again may be subjected to causal reasoning as well, but on the background of individual large and complex projects seems not possible and therefore again becomes decidedly a matter of a creative mind.

5.1. Database

One of the most popular applications of Artificial Intelligence is the IBM-Watson portal. The functionality of Watson [23] describes very well the capability of AI, based on neuronal networks. In principle, the “Watson” – intelligence rests on a vast variety of unstructured data, available by the internet, as are reports, tweets, messages and other entries. The main capability is to operate on this raw data via less tight semantic analysis processes, in contrast to the exact investigation of a classical search algorithm bound to logical strictness. Therefore, a huge amount of internet data of all sorts can be made use of. The same semantic approach applies for the questions to be asked and the provided answers to additionally learn from. However, there is a point made, that internet data are not necessarily correct or relevant. To repair this, the help of a human operator is still required when acquiring data to manually sort out erroneous or insignificant information.

For Construction Management, first of all, the Building Information Model (BIM) as a presumably complete representation of the building to be erected is available [3]. The model is created as a highly sophisticated form of planning, i.e. in three dimensions, as physical objects including all of their physical and logical interactions. This is, by the way, treated and assumed to be a strict and logical model, which needs to be failure-free and complete. As soon as Construction Management comes into play, these physical elements are to be realized and processed on a time axis, optimizing project duration and cost without giving up the quality defined as perfect match to the contracts. Yet, since projects are unique, there are no criteria available whether these procedures will be or have been carried out with optimal efficiency or not. The knowledge of performing well in this respect is obviously not that strict, as present projects are teaching. Otherwise, classical algorithms like CPM, Ford etc., would be solving the given task on a mathematical basis fairly well [8, 22]. Explicitly, the particular elements of a model representing managerial issues, like detailed contracts, sub-target dates etc., as well as their organisational interaction are subject to *in-situ* coordination and therefore principally not available. The laborious and extensive task of coordination itself is defined as a costly service to be delivered during the execution of the project and therefore an element of the model which principally cannot be determined *a priori*. Thus, exactly the badly required part of the construction management model is not available within the BIM [9].

5.2. Information

The database for this fuzzy knowledge seems to suffer from some difficulties. Absolutely no significant information, neither regarding positive nor negative experience, is publicly available on the net. Knowledge of this kind (experience) is treated as specific asset (Know-how) of the companies and therefore deliberately never published. Thus, the existing knowledge is available only within the companies and therefore principally limited in volume. Furthermore, management knowledge is sourced basically on finished projects of the company and on people, i.e. on their specific education. This again is derived from abstract experience, i.e. academic examples, and structured knowledge as of how to treat situations in a more abstract way via methodical approaches. Both these sources of knowledge are not documented but bound to the respective persons as Human Capital. Thus, none of this is principally accessible for analysis by a neuronal network.

Remark: Beyond this well-reasoned situation, further experience worsening the situation is observed and reported by many participants: According to numerous investigations for expertise requests, even the experienced knowledge taken from closed projects is obviously not documented, neither in a structured way nor as unstructured data. Otherwise, according to principles of knowledge management rules the respective projects would not have been running into problems, where an expertise is required. Furthermore, people with this type of knowledge are in particular project

managers and construction supervisors, who are to solve the actual problems with higher priority than to secure the knowledge for later projects. However, the coordination part of project management is mainly acting quickly on upcoming situations, leading in many cases to more intuitive reactions and not so much to data-based decision-making. Finally, the failure–culture plays a significant role. The knowledge needs to be derived from well-handled projects as well as from well understood failures.

In order to investigate the emergent behaviour via a neuronal network we observe a statistical problem: There are no two projects similar enough to form a database, where emergent behaviour can be investigated from. Statistical considerations [30] are strictly limiting the exploitability of data with no exception to neuronal networks. Significance is measured in multiples of the standard deviation which needs to be increased by factors according to sample-size based on the Student-t-distribution. Therefrom, a minimum sample-size of the order of 10^2 is required for reliable conclusions. Since the sample-size refers to projects or situations of comparable type, the number of indistinguishable classes needs to be fairly low. However, since parameters of construction management are legion, merely no two projects are really to be judged comparable. For a virtual set of e.g. 10 parameters, which are far too few, with 5 options (also far too low) each, the number of incomparable situations would already rise to more than $5^{10} = 10^7$. Thus, extracting reliable information from raw data of closed projects would require millions of projects in any case, which are available under no circumstances.

5.3. Organization

Since it is principally not possible to derive intelligence from experience, the solution is given by breaking up complex projects exhibiting starkly emergent behaviour [12, 17, 22, 24] into a number of smaller units, which are becoming less specific and therefore more general – and less complex. Therewith, both the availability of matching samples is strongly rising as well as the applicability is increasing. However needs to be taken care of, that the concatenation of these sub-elements is kept simple and linear, and therewith does not recreate a complex system of simple sub-systems. This is elaborated in [30] on the basis of Systems Theory [1, 12, 15, 25] and leads to the demand towards expertise to break up complex systems into just complicated systems, which are solely formed by the well-known graph-theoretical tree structures or rank-sorted network plans. In particular, exactly this competency is taught to managers as the central methodical approach to solve difficult, i.e. complex (non-standardisable local) construction situations based on fundamental knowledge [10]. Setting up an organization is to develop complex behaviour into complicated behaviour, i.e. investigate separability. The German Standard DIN 89901 defines a specific organisation as a central characteristic of unique projects [6]. Creating a specific organisation precisely corresponds to breaking up complexity into a well structured, i.e. linearly concatenating set of sub-units allowing to be treated separately and thus forming a frame to solve the over-all problem. This is accomplished in two steps: First, based on separability the structure of the organisation (Organisation Planning) is created and second, exactly the so established organisation coordinates and maintains the separation in detail and on the fly (Operation of Organisation) [29, 31].

The fundamental precondition to this process is the total knowledge of complexity implying the judgement of interactions between absolutely each element including the therefrom derived consequences. This would only be accessible to AI (or other Intelligence) if the systems were described and, thus, describable down to very last detail. However, this information is principally not available *a priori*. This situation would provide the conclusion of a fundamentally non-solvable problem, if the system were therefore not *created* respectively laid down based on the understanding of separability: Since an organization is specific to a project, it can not be existing *a priori* but needs to be generated based on the specific situation, be it in advance or during the operation. Since elements and interactions are also not accessible *a priori*, they need to be developed along and on the basis of general structures. These are termed “views” since they maintain only a small section of the total system, but can be understood, i.e. “overviewed” by the (human) person creating the elements or interrelations to be attached next. The structures need therefore to be simple and clear, again solely referring to graph-theoretical trees and rank-able network plans. The total system is modelled via a possibly large number of different views, maintaining different interwoven substructures and aspects. Therefore, only understood interactions are being modelled, irrelevant interactions and elements are omitted. There is

naturally no prove for completeness existing. Thus, we have less of a task to actively separate existing complex systems into complicated systems, but of generating - compatible with the human mind - the description of a complex system on the basis of separability.

This process exactly represents the contribution of the human mind to the AI process. However, under the given circumstances in Construction Management, this human contribution seems to be the major part. After having completed the preparation, the remaining task can in fact be easily assigned to algorithmic means as are common.

6. Conclusion

From the market-situation it seems to be difficult to solve the task of an efficient organisation of construction (Service) based on human intelligence. This is apparently owed to the fact, that the behaviour of a project organisation exhibits clearly complex emergent behaviour and can therefore not be easily predicted by the definition of local rules. On this background, application of artificial intelligence over human intelligence suffers from some principle problems: The already used and well-established imperative and object-oriented approaches are covering all the areas where clear rules can be established, e.g. based on BIM including Operative BIM, where cost and time are implemented as higher dimensions. However, this is limited to the factually and contractually predetermined and fixed hard facts. The situation changes as soon as it comes to the service of organization, comprising *coordination* means to efficiently distribute information and *motivation* as in distributing incentives, e.g. via contracting [20]. In this context local valid rules are not available, leading to clear miss in applying imperative or object-oriented methods. The attempt to make use of neuronal networks to elaborate such rules in a less distinctive way suffers from the lack of widely available data as they are not published. On company-level available information is much too limited in volume to provide statistically significant results. Breaking down the complex situations to be tackled into smaller separable sub-tasks allows for increase of generality of the situations and therewith the universe increases as well. Taking furthermore into account, that those generalized situations are no more specific for a particular company and thus may be published, the database becomes serious. However, this is already done to a very far extent leading to the present situation, where no artificial intelligence is required to derive valid rules but well-parameterized information are available. Thus, the only remaining difficult task is the beforehand provision of the separated complex systems as a number of less complex subsystems, which serves as a precondition to any manual or algorithmical processing, setting up the specific organisation. However, precisely this preparatory task can principally not be handed to AI, but the methodical processes to generate these well-separated structures are taught with Construction Management as a specific competence by universities. Therefrom we conclude the general need for understanding organization as well-separated structures, answering the transformation of complex situations into just complicated tasks in order to determine the range of AI, i.e. algorithmical, support to this principally human task of understanding a situation and forming a model of it, which inherently implies the solvability.

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