THE MODEL IN CODED DIGITAL DESIGN PROCESS – *DIGITAL CHAIN* CASE

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ABSTRACT

The process of design and realization in emerging architecture is seen as digitally connected and interfaced. *Digital Chain* is the central principle we adopted in this research. It is an uninterruptible digital process consisting of design (idea, coding, geometry finding-modelling) from construction (structure, junction, prototyping) to production (fabrication) with every step as a programmed entity connected by CAAD/CAM interfaces. The term *Digital Chain* was originally coined by the CAAD Chair at ETHZ.

The traditional design process in architecture is cognitive operation, which associates thought to hand based on requests, standards and creativity. This operation is verified by drawings, 3D models and mock-ups regulated by manual variations. The digital design process has the same starting point and in its core is the code representing the synthesis of data – parameters or variables acquired from design assignments analyses. The code models the design process, enables the designer to easily change different parameters and effectively make and check numerous solutions. The code also includes machine parameters and allows direct production of the outputs as products of CNC machines. The present paper examines the role of the code as the digital architectural model that connects the design process and the architectural manufacturing by CNC machines.

DIGITAL MODEL IN ARCHITECTURE

You think philosophy is difficult enough, but I tell you it is nothing to the difficulty of being a good architect.

Ludwig Wittgenstein

The greatest enemy of knowledge is not ignorance, it is the illusion of knowledge.

Stephen Hawking

The relationship between architecture and digital technologies, generally speaking, is developing from the first generation of computer-aided (CAD) systems, which offered only limited computer software for visualization and documentation, focused on a two-dimensional representation of three-dimensional objects. The systems developed later were given the option of designing a model of a complex geometry, with access to three-dimensional geometric modelling and possible structural and dimensional analysis thereof, as well as to export coded design requirement in the finalized architectural product connected to computer numerically controlled (CNC) machines.
Digital design represents the transformation of traditional design activity by introducing the entire combined group of structural engineering technology, new materials, manufacturing and construction processes that the computer discovers, permits, conditions and supports in the beginning; while later, with a large number of experimental processes and products, the entire process has become reversible.

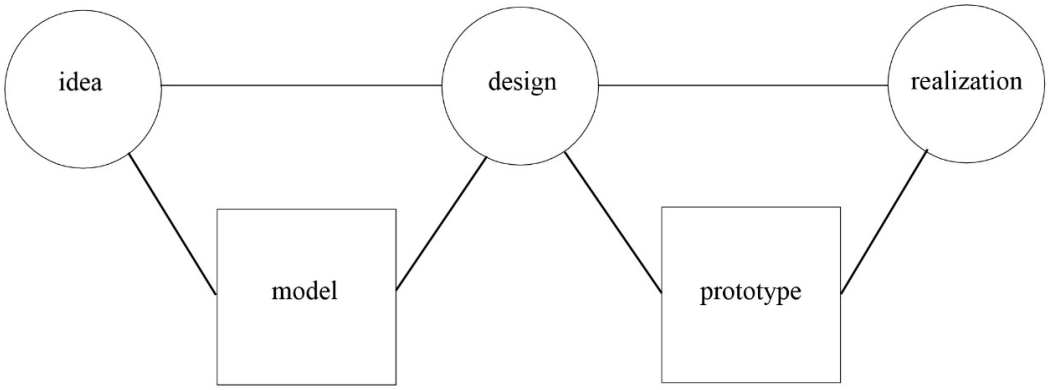

Figure 1. Digital model in design and realization in emerging architecture

The traditional design is based on documentation. However, digital design is based on digital modelling, as a cognitive architectural process with requested data and a relationship between them, produced as computer code through the work of a computer. We are involved in a continuous process founded on one code used in design and manufacturing. The digital model created in this way is flexible and changeable by parameters and a real connector of design and fabrication. The direction of the design process is not feedforward progression from sketches, toward scripts that drive machines, and resulting in the final product. Instead, a dynamic interaction between all components creates a specific system, in which the interaction of geometrical, material and machine parameters creates a unique product. Formally, the final results of the process are series of commands that drive machines. The traditional architectural model loses its traditional role and becomes a link in the *Digital Chain,* which helps to identify how machines realize design decisions.

According to Richard Maccormac (Lawson and Doorst 2009), the design process is a journey, "an episodic journey towards a destination which you don't know about, which is what life is and what writing and all arts are like." The same statement relates today to the development process of creating architecture influenced by technology, which again should be reviewed and redefined. With the above mentioned, the overview of the architectural process from different points of view and different process definitions leads to the fact that some kind of *chain* architecture is constantly emerging, whether we are talking about common use or digital approach.
Relying on Peters (Peters and Peters 2013), we conclude that the focus is not only on the idea that the designer is introduced to the program, but also on the ability to express this idea through its use in the development of programs. The new role of the architect in the strategy of the architecture and his positioning is that the architect creates the process and returns to the realization indirectly - knowing the parameters of machines and materials needed for encoding the idea - and directly - in terms of control product. It suggests the great role of the architect in the development of application programs, which are necessary for the development and realization of the idea.
Coding/programming is a research design. Different styles of programming differently control the flow of obtaining the products that is directed by the architect. It enables architects to easily move between logic and intuition, and the division between software developer and designer is almost non-existent. The idea is not only to use the existing tools, but, in relation to the necessary criteria, to make one's own tool for work.
Fear has been expressed generally toward the control of the design by the coding. There are different types of control where coding generates a positive effect on the aesthetics, the design process and especially the performance of the design. The approach taken in most modelling tools is that the designer directly and intuitively interacts with the model as a sculptor would do with a piece of material. However, the programming requires very explicit rules from the designers and is influenced by a large body of information, but instead of forming an obstacle, this could be a creative and explorative approach. Programming design solves the problem, what is the basis in a conventional design. The process depends primarily on the way of thinking, which means that the tool is less important, while more important is the logic of problem solving and the architect's intention. The point is in abstract design, finding rules for generating space and form, and in the surprise that the program can offer. This research experience is the strongest aspect of digital coding.

EXPLANATION OF CODED MODEL IN *DIGITAL CHAIN*

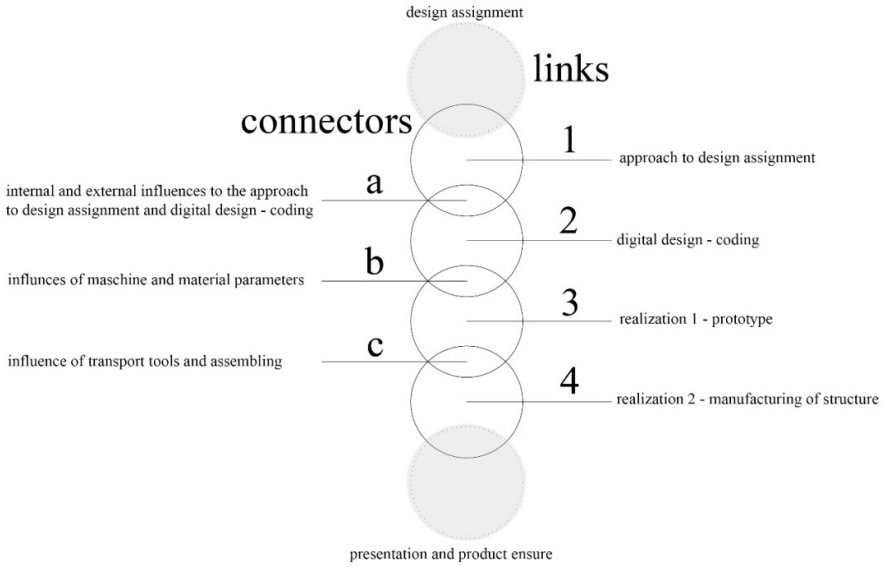

Figure 2. The *Digital Chain* structure

The *Digital Chain* is a continuous process in which the architectural intention is directly materialized by employing digital tools (Figure 2). The *Digital Chain* is a metaphor for an uninterruptible digital process, consisting of design (idea, coding - geometry finding), construction (structure, junction, prototyping) and production (use of CNC fabrication or manufacture). Every step is a programmed

entity and they are connected by universal interfaces. The computer is no more a passive digital drawing board, but an active design-controlled work tool.
The *Digital Chain* is a complex continuous tool for troubleshooting. Today, it is also an instrument for obtaining and using code. A code without execution on computer is only text that means nothing. However, by simply manipulating coding, we obtain the different types of necessary drawings, i.e. interpretation of the idea or performance of solutions. The computer facilitates the prediction of architecture by means of conceptual structures - presenting it simultaneously in various mental modalities, in accordance with the architectural thought, material and machine, and not against it. The digital approach to the design and realization is the streamlined approach, where digital technology as a tool participates in the process and the creation of architecture. The process is developing from the relationship between digital technology and the design process in architecture in terms of solutions to the problems of feasibility and implementation, caused by complex conditions, needs, ideas and digital techniques. Coding is a synthesis of data derived from a detailed analysis of idea and design requirements, while obtaining one or more solutions through a set of parameters, which are then verified through a prototype realization.
The setting-up and controlling of all the design parameters, as well as completed and connected process of design and realization of the architectural product, through realization of prototype, are performed by the architect. In the *Digital Chain,* the architect creates both a process and a product. It means that the creation of the design process in new architecture and control of each of its units is impossible without a clearly positioned architectural influence.
Another important factor underlying the digital design is making of the model through prototyping and the incorporation of machinery and materials as required by what is created. This is what Bob Sheil (2012) calls a production of the contracted model based on the module and custom creation.
If we consider the context in digital architectural terms, it represents an artificial environment, i.e. an environment of digital design - coding, where the selected parameters assume the role of factors and determine it in the form of an artificial environment (Markovic 2013).
The *Digital Chain* evolves from the relationship between digital technology and the design process in architecture in terms of solving the problem of feasibility and realization, due to complex conditions, needs, ideas and digital techniques. This complex information, the requests that *Digital Chain* be an interruptible process interlinked by digital design-coding, most intensively affects the conventional process of design and converts into realization-production as the continuous extension. Coding is a synthesis of data derived from detailed analysis of idea and design requirement in order to produce one or more solutions with the given parameters, which are then verified through the realization of a prototype.
The product becomes the materialization of the program options that shapes it in many cases, and the computer tools are rarely used to improve the design solutions in a complex construction program and a limited budget. The settings of the conceptual approaches out of the theory of computer practice require grounding on the analysis of the relation tool - a conceptual model (prototype) and finally – the materializing. An integral part is the careful introduction of computer design tools for delivering solutions that exceed human capacity thanks to the interconnections in the code. The next necessary step is setting of controlled creativity of architects in certain parts of the architectural process.

DESIGN APPLICATION MANUALS – CONDITIONS OR LIMITATION OF CODED MODEL?

The integration of process methods for analytical procedures and finding the generative form is closely linked to the conditions set by architects or engineers. Each optimization, either structural or contextual, yields the result only in the reality of an abstract computer model, not a final solution for the real world, nor an indication of change in the concept of the design.
When the architect writes software for troubleshooting, the algorithm becomes part of design, and can then be researched and creatively explored. However, as Fabian Schreuer (2013) explains, algorithms represent simultaneously the description of the problem and the solution. They define the solution space and are built around the definition of the problem. Schreuer claims that the design is everything related with the decisions, and that they are delegated, always following a predefined path. Frequent use of existing tools leads to existing solutions. Through the creation of new tools, new ways of thinking and new solutions can be found.
Algorithmic thinking implies taking an interpretive role to understand the results produced with the generated code and to modify the code in order to explore new options and speculations about further potentials of design. As architects, we are under the influence of tools and techniques that enable us to understand our vision. It is claimed that the tools are setting the limits to art. The use of

real instruments for the thing that somebody creates is the both - a profound connection between the use of the tool and its formal results. It determines the potential of what could be achieved by computing and the possibilities what it could be made, become much larger.
The emerging design of today's architectural reality includes a wide range of different types of architectural products, created in parallel processes of design and realization of conventional, digital or combined tools. In response to a complex context and today's requirements, emerging architecture itself is the already-mentioned experimental process, based on a digital approach to constant rehearsals and changes, which is a necessary passing phase of the prototype, but in most cases also testing of the design and realization, materials and machines.
Emerging architecture sets in front of the architects a large number of requirements that are now digital, interrelated and conditioned by various more or less acceptable results. Architecture as a science and art of design is forming the space determined by the context.
Functionality includes compliance of architecture with the requirements of purposes, as well as with the standards of design and dimensions corresponding to user. On the other hand, the economic unsustainability of a single function, and the complex activities of man introduce, as the basic requirement, the multi-functionality. This results in flexibility of space are particularly reflected through the parameter of utility of major projects with predicting and understanding the different functional programs to support the sustainability of architecture (house).
Generative design takes the idea one step further. Instead of centralized programming, it benefits from schemes and set of rules that show what is happening and how the shape is developing by time. It requires a different way of thinking, a different kind of imagination and a different type of an architect. The resulting objects are far more complex than can be object designed by the traditional drawing tools. The generative design easily describes repeated and half-periodic structures. Hierarchical structures composed of smaller substructures may also be described. For this reason, generative design offers high efficiency to the designer during the designing schemes that are complex and composed of many small parts. By programming, the designer predicts the conditions to which the object will need to fit, and thus form a coding that will be changed due to changes in conditions.
Several applications have been developed to support generative design. Grasshopper, Dynamo and GenerativeComponents are visual programming languages, meaning that the designer does not need to write the code but is using visual objects and relations to create procedures. The basic modelling instances that these applications support are geometry entities like points, plains, translations and all other entities like lines, surfaces, solids are represented as functions dependent on basic entities or other higher-level objects. Essentially applications are focused on generative geometry design and the connection to the fabrication process depends on exporting the model by applying the most common geometric data formats. Since all applications support the development of procedures by means of scripts or general programming languages, it is possible to develop any kind of computer program that will support fabrication parameters inside the application.

FABRICATION MANUALS – PARAMETER OF MACHINE

In architecture, in order to explain the new approach, we increasingly rely on philosophy of technology, which was created considering the technology in terms of understanding of design practice and created artefacts. This includes the emergence of processes and systems, as well as understanding of the nature of the product created in the continuity of the philosophy of science and philosophy of action and decision-making.
The aim of the process is to establish an efficient, complex, specific and defined design on the basis of various materials, which leads to a continuous series of limited automated realization of architecture, with a creative and controlled contribution to the architectural profession in every part of the chain.
Complex modern machines require an entire library of written technical manuals with the collected information, which are continuously increased and improved by their designers, builders, and people in charge of their maintenance. To make them easier to manipulate, there is infrastructure of less complex tools, techniques, skills, processes and practices that support the function of the system.
The essence of this process is the direct guidance by the architect, who controls the design in terms of realization of creative and controlled solutions, production of knowledge and creation of new tools. Architects design the behaviour and responsibility of the machine itself (Gramazio et al. 2014). Positioning architects in the process of architecture is current, flexibly and depends on the process itself and the relationship of architecture and technology.

Programming does not represent the centre of the digital practice of architects, neither does it represent trust in the programs. It provides an opportunity for the designer to participate with his desires and creative solutions in the entire program through the setting parameters that can be variable or automatic. The user of the tool – designer is now becoming also the maker of tools - the designer of the program. Users of the program are improving it through the subprograms.
Programming was previously the task of specialists and no part of the education of architects. Today, many architects are confident in the potential of creative programming and convinced that the change is necessary as part of education in emerging architectures. The change has not yet been clearly defined and strictly implemented in the basic education of architects, but it is more left to individual cases according to personal motivation.
It is desirable that architects be familiar with the mode of scripted code in order to better organize code and overall design, as part of their cultural and theoretical knowledge. However, information complexity and the interconnections form a product - the architecture (the house), but the explanation remains the challenge of contemporary computer processes. The integration of process methods of analytical procedures, as well as the invention of tools, which can meet the necessary requirements in terms of context, structure and aesthetics are closely linked to the conditions set by architects or engineers.
The present and future architectural practice should cultivate a critical awareness of such restrictions, but also awareness of the superiority of ideas over the process, to make the development of process tools the basis for the successful development of future strategies. Digital resources are desirable in innovation, with architect's responsibility for the product and the profession during the process and the consequences they initiated.
The development of techniques promoting greater creativity is mainly based on the combined use e.g. of parametric modelling and linear communication through 3D models, in dialogue with the location context. The idea is, for example, to reduce additional elements of design and to include surface geometry to obtain a valuable concept that is not the result of an uncompromising architecture, but helps to reduce the invested time and price of the structure, as it is evidenced by the Spen design of architects Matias del Campo and Sandra Manninger (Gengnagel et al. 2011).

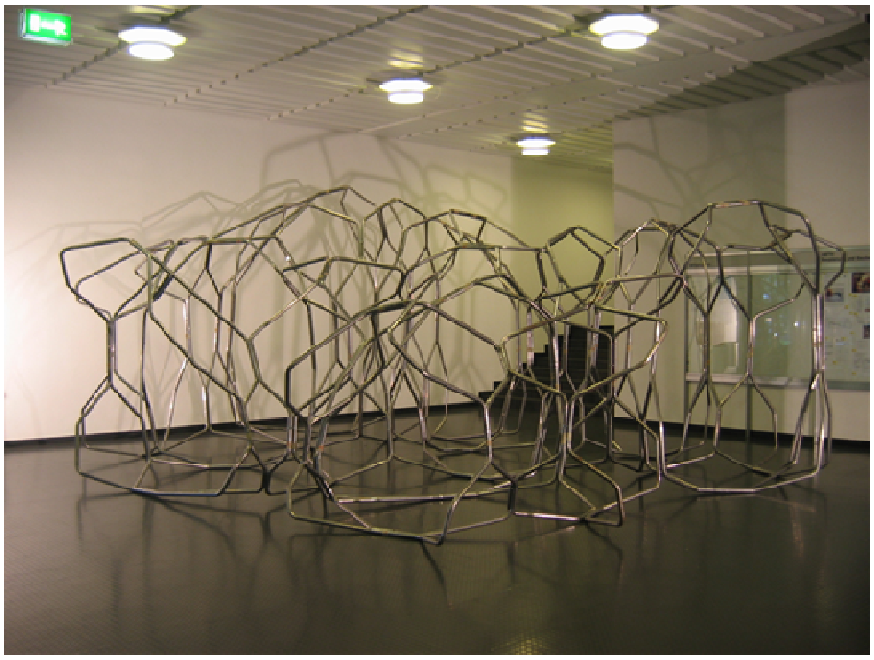

Figure 3. The structure designed in *Digital Chain* principle (Source: http://wiki.arch.ethz.ch/twiki/bin/view/MAS0506stu)

The CAD/CAM platform basically consists of three components: 1) the digital interactive design and analytical environment for making geometrical object's models, which would eventually be produced (CAD system), 2) CAM programs, where the user specifies how the real design would be produced

and creates a serial of digital instruction for CNC machines and one or more computer-numerical machines and similar tools, which these instructions translate in real machine's operation, to produce an object. One of the most detailed examples showing the wholeness of the CAD/CAM procedure on the principle of *Digital Chain* is the Group Master thesis of CAAD ETHZ course 2005/2006 (Figure 3) (MAS05-06 2007).

Every year the Master course at the CAAD Chair accomplishes a group thesis, which represents everything that is taught and learned there. The group thesis is a product designed in the way of the *Digital Chain*. The process contains the following components: 1) Approach to Design assignment, 2) Digital design: coding, 3) Production 1: prototype, 4) Production 2: production of structure. The process relies on connections with direct experiment relation. ie. internal and external influences to the approach to design assignment and to digital design-coding, machine parameter influence, fabrication influence of transport tools and assembling (Markovic 2009).

The task of the group thesis was to make a pavilion by means of a digital process. The pavilion was to be created from a complex system of information and requirements that was then resolved with computer programs. The result of the structure aimed to represent the computer program‵s capacity to organize and resolve a multifaceted problem. The objective of this final project, as defined by the Chair, was a work that resolves a straightforward problem. The work should be bigger in scale and more complex than individual projects. The output of the work is an exhibition and presentation of the work, which needs to be insured afterwards.

The essence of coding in order to obtain the *Digital Chain* of design and realization with the database of identifying variables requires the following of the design. It establishes a hierarchy of linked parameters and their linking in a logical relationship to the concept of geometry such as the structure and physical model. Together they form a complex, long chain and definition of their suitable behaviour, i.e. performances and dimensions that lead to designing solutions. Necessary adjustment of parameters and connections is achieved through a comprehensive model that serves to observe the changes relatied to the most appropriate solution, and also the changes of the geometry and logical dependence on the research purpose and alternatives. A combination of techniques is required to acheive better solutions. The important fact in the application of CNC machines is their control in the CAM environment, as Schodek (2015) stated: "The purpose of the controller is to manage information by translating and converting one binary language to another so that language understood easily by humans may be easily understood by machines tool are specific to each tool."

BEHAVIOR OF CODE ON THE PATH DESIGN – REALIZATION

Intellectual design challenges related to idea and logic of the digital design constitute an additional motivation for thinking about this topic in this era. Programming is a new creative force and a part of computer design in the research field, but not its essence. The conventional design is still the main approach to creative and critical participation in learning, while programming is merely an option.

Conditionality of the new approach is based in the technological sense on interactive design and realization of architectures that require, in the sociological sense, interactivity of actors in the architectural process within the idea, external and internal influences, modelling and implementation of a prototype in the final product – architecture (Markovic et al. 2017). The essence of this process is the production in terms of implementation of creative solutions to the problems.

The core objective of the architecture remains the same, but the process changes significantly. The necessity of critical thinking and action of architects is obvious, but the position of necessity of the architects is not specified or defined (Markovic 2016).

Digital technology moves the existing parameters and the fixed order of design from the established process, which does not have to lead to irregularity and complexity of forms, to the interconnectedness of design and fabrication. The obligated part of the architectural knowledge is design thinking through the computer models, which is at the same time part of the design and realization based on a research-oriented design. Architectural engineering is the medium between the architects and civil engineers, which facilitates new approaches to the logic of generated computer systems that integrate the material, shape and performance of the machines in the process of design that provides the ways of processing. In the emerging digital architecture, each new design is also a new experiment, and the *Digital Chain* does not serve to create the universality of the product, but rather serves as an attempt towards a universal approach, while the design and product are specific, though simple at first sight.

Redefinition of architectural practice induced by the development of digital tools that create opportunities for the design process, fabrication and construction is not based on the concept of computerization, but instead on the performance of computing and simulation, fabrication and construction, as well as on an integrated art form that complements the ability of architects to solve complex situations. A significant part of the redefinition is the computer design thinking with the computer system approach that comprises coding - programming and programming skills with possible parametric and generative guidelines. Digital design involves information processing and communications between the elements that create a specific environment. The maximum connection with the design and the designer is through the major computing application in the realization of the products created by internal and external characteristics.

Architecture today must provide effective solutions to a wide range of complex issues and requires an interdisciplinary solution for which numerous technological tools are developed. The only instrument to achieve that is the architect. The relation, role and intention of the architect and design and realization of architecture are unbreakable, and that relationship is timeless and mutually dependent.

The position of architects in the digital approach to design and realization in the emerging architecture based on CAD/CAM technology is often undefined due to the complex demands and contemporary conditions, and in such cases often it is lacking. On the one hand, technological tools resolve the divide between design and realization of architecture, which is the product of disconnectedness of thinking complexity and development of the industry, and excommunicate, on the other hand, the presence of architectural knowledge and experience (Markovic 2016). The digital model received in this way relates to the complexity of the criteria guiding the contemporary design process. In addition to the usual conditions that define the characteristics of the space (size, function, brightness, multi-functional requirements, connection to the interior/exterior, construction and interior design elements, the change of seasons, change the time of the day), the effects of computer numerically controlled machines are included - CNC in manufacturing (type of material, mode of forming, flexibility and material processing, machine parameters) on the characteristics of individual architectural elements (ornament acquires functional determinants and the third dimension), as well as the position and influence of accompanying (additional) effects (e.g. light and colour).

The establishment of the split positions of the design and realization in architecture and solution of the problem, as well as the positions of inconsistencies and the formation of uncontrolled architecture by operation of digital tools leads to the examination of the advantages and disadvantages of the process of digitization of design and realization. The evidence of the necessity of existence of digitization is reduced to an evident role and conditioning of all phases of digital approach in the process of design and realization in emerging architecture by architects.

CONCLUSION

The general characteristics of the digital model that would fully support the fabrication process are still undecided. Obviously, for the fabrication process to be fully simulated using a computer, it is necessary to include a digital model of the machine and fabrication process in a potential computer application. In this way, the process would be freed from the necessity of having a specific machine for fabrication and numerous experiments that are necessary to establish a concrete relationship between the machine used and the materials. Also, the existence of a machine and material models would allow for each experiment in the field of fabrication to be represented in the form of a computer model that would hinder the process of learning and development of this technology. This owes to the fact that today all results are available only in the form of case studies that are difficult to reconstruct in the absence of the complete technology adopted in that case.

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