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# MY PURSUIT OF TRUTH IN BUILDING MATERIALS ENGINEERING

**L. CZARNECKI**[1]

The paper presents pursuits of the truth in building materials engineering. Some definitions of "what truth is" were presented. Partial truths were specified: the truth of scientific reasoning, the truth of scientific assessment, the truth of development directions and the splendour of scientific truth. All categories are addressed to the building materials engineering. In the chapter "Load capacity and stability vs entropy" definitions of entropy and exergy were presented followed by their influence on building construction, illustrated by the "Seneca cliff" and "Energy pyramid". Chapter 3 presents the truth of scientific reasoning was presented. Three partial truths were indicated: the truth of experimental fact, the truth of scientific reasoning and the truth of scientific presentation. In the chapter "Truth of scientific assessment" two main assessment methods were presented: peer review and a bibliometric parametric assessment as well as their impact on the results and authors. The risks associated with the sole parametric assessment were shown as the two basic factors of a parametric assessment – citation number and Hirsch index – need time to "mature". Additionally, the influence of digitalisation of the assessment of a scientist and a scientific unit on the commoditisation and dehumanisation of science was outlined. In the chapter "Truth of development directions: defined past – fuzzy future" the megatrends observed in technology in the last few decades years were indicated along with new possible trends. Milestones in the development of C-PCs (Concrete-Polymer Composites) were presented. The new paradigm for the new development cycle was proposed.

*Keywords*: Building Material Engineering, Fundamental Requirements, Entropy, Exergy, Science Digitalization, Development hysteresis

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# 1. INTRODUCTION

I did not study the philosophy of truth, and when I was a student the field of building materials engineering did not exist. Only the possessive pronoun "my" in the title of my presentation seems to raise no doubt and it enables a certain freedom of expression or even making "my error"; however, when pursuing the truth one should avoid error.

I vowed the following twice: *pursue **truth,** convey it and reveal it through my behaviour* – academic oath, and *to multiply science not for the common benefit or vain glory, but to disseminate **truth** on which the future and happiness of humankind depend* – doctoral oath.

It has always been nurturing me. I made a vow and what has it resulted in? In 2015, I published a paper (co-authored by J.J. Sokołowska, Ph.D.) called "Material model and revealing the truth" [1] with the abovementioned oath as the motto. I did not manage to resist the temptation to add a cynical comment by procurator Pilate: ‘What is truth?’

There is only one truth and nothing but the truth. Nonetheless, it seems legitimate to ask a question about what the truth of building materials engineering is. I understand truth in the context of statement [2] in a fairly tautological sense: to write sentences which are true, i.e. according to reality. Furthermore, the academic oath mentions ‘pursuing the truth’ and not discovering the already revealed truth. The issue becomes even more serious when we read the Preamble to the Constitution of the Republic of Poland [3], where truth is mentioned – next to justice, goodness and beauty – as a universal value originating from God or *originating from other sources for those who do not share this belief.*

Science can be defined as commitment to truth; the objective and ethos of science are captured in truth [4]. Truth as a universal value should not be described with adjectives but it can refer to an object: the truth of whom or what – my truth of building materials engineering. What if the new findings undermine the previous ones accepted as truth? It seems that progress in science does not always take a straight path to the truth. We often only answer a question if a model describing a phenomenon is true **enough**. I am fully aware that I am not the only one deliberating on the issue, neither in modern times nor over the centuries:

*All men by nature desire to know* [Aristotle, *Metaphysics*, 1.1], the truth is the proper object of this desire.

*No one is really satisfied with the knowledge that may or may not be true; only confidence that knowledge is true brings peace* [John Paul II, *Fides et ratio*].

*I have met many people who would like to deceive but I have never met anybody who would like to be deceived* [St Augustine, *Confessions*, X, 23, 33, CCL 27–73].

The truth of building materials engineering does not only have value but also substantial weight. In paper [5] published this year, called ‘Sustainable test methods for constructing materials and elements’ together with co-authors, E. Szewczak, Ph.D. and A. Winkler-Skalna, Ph.D. we demonstrate that the "trueness" of the measurement method can determine a structure’s safety but it also affects its cost significantly. In another paper (co-authored by Prof. P. Woyciechowski et al.) [6], we conclude that a model closer to the truth poses a higher risk of an engineering error. This applies to the assessment of carbonation and structure durability. Summing up, I would like to emphasise that the presented deliberations are my examination of conscience rather than my credo. In my search, I was not able to formulate one universal truth concerning building materials engineering. Let me then quote a series of partial truths in the following order:

– the truth of scientific reasoning
– the truth of scientific assessment
– the truth of development directions
– the splendour of scientific truth

Let me begin with outlining the area of my deliberations, which I perceive as existing in the material–structure relationship, which remains in feedback and is accompanied by a certain tension. I used to begin my lectures saying that *everything is made of something and all building structures are made of building materials.*

## 2. LOAD CAPACITY AND STABILITY VS ENTROPY

The basic requirements for a building structure sound very mechanistic, almost Newtonian. The mechanistic approach used to dominate, starting from the Code of Hammurabi (c. 18th c. B.C.) through to the ‘Ten Books on Architecture’ by Vitruvius (1st c. B.C.) and the European Directive published in 1989 ((EPD 89/106/EEC). Only the latest, sixth revision, of the Directive requires energy saving. In 2011, a new version of the Basic Requirements (CPR 305/20) was developed, including an additional (seventh!) requirement, which applies to the sustainable use of natural resources, also by ensuring the durability of building structures, and the reuse and recycling of components. It refers to the first law of thermodynamics – the law of conservation of energy; the total energy of a system is constant. Neither in the modern collection of Basic Requirements nor in the history of the building codes can a reference to the second law of thermodynamics – the law of entropy – be found.

Entropy is the measure of the thermodynamic probability of a system, which is approached as a measure of the system's randomness. The second law of thermodynamics determines the direction and irreversibility of spontaneous processes. A system spontaneously aims to the state of maximum thermodynamic probability – an increase in entropy. A. Einstein, who won the Nobel Prize in 1926, claimed that ***entropy is the supreme law of all sciences*** [7]. Another Nobel Prize winner (1969) M. Gell-Mann, an authority in elementary particles and their interactions, stated that *entropy is a synonym for ignorance* [8]. I. Prigogine, a physician and chemist, Nobel Prize winner for his contribution to the development of thermodynamics (1977), demonstrated in 1994 [9] that the *perception of entropy as ignorance cannot be maintained.* The issue is difficult and complex [10]. As a warning, it should be kept in mind that the creator of the notion of entropy, Ludwig Boltzman, was not understood by his contemporaries and committed suicide in 1906 [11]. Nonetheless, these controversies among distinguished scientists were not the reason why the laws of thermodynamics are so poorly represented in the Basic Requirements.

When I was dealing with the durability of structures, in particular in relation to the protection and repair of concrete structures, I did not manage to garner common support for the thermodynamically justified concept of the inevitability of structure destruction with time [12, 13]. It is interesting because the laws of mechanics and thermodynamics have always existed, regardless of the moment they were formulated and accepted. Newton's laws of mechanics (1686) were formulated 350 years ago. The second law of thermodynamics was described much later (1865) but 150 years have already passed since it was announced by R. Clausius. A significant, or perhaps the crucial difference lies in the time scale.

Violation of the laws of mechanics usually ends rapidly and in a spectacular way – with a disaster. Entropy increases creeping in, and its effects are delayed. Nonetheless, the end result can also be dramatic, especially for pre-stressed structures [14]. The disaster of the Morandi Bridge in Genoa in 2019 makes a good example. It is said to have been caused by the breaking of the corroded steel rods after 50 years of use. In this context, the Seneca cliff [15] or Seneca effect [16] is brought to mind as a model: *it could be some consolation for the feebleness of our selves and our works if all things should perish as slowly as they come into being; but as it is, increases are of sluggish growth but the way to ruin is rapid* (Seneca, *Moral Letters to Lucillius*). Seneca's concept is illustrated by a diagram (Fig. 1) used in some models of system dynamics [17]. The Seneca cliff diagram, in reference to building structures, will take a slightly different waveform (Fig. 2.) with regard to the durability of use typical of the structures.

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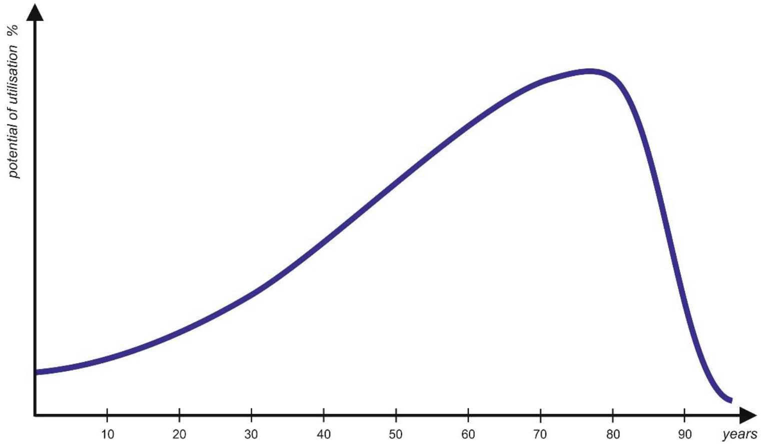


Fig 1. Illustration of Seneca effect developed according to U. Bardi [17]

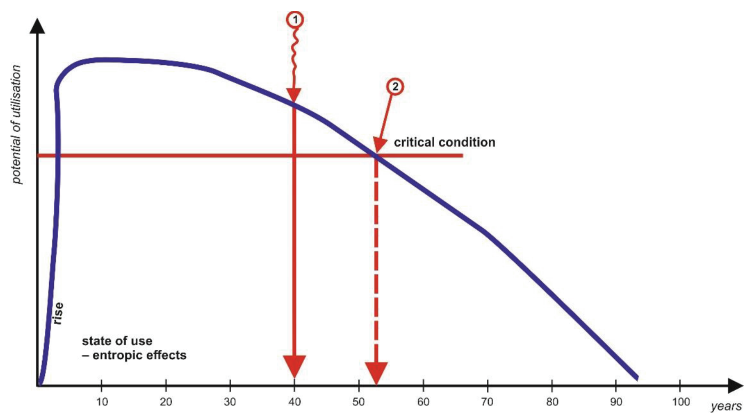


Fig 2. Seneca cliff in reference to a building structure; two moments of the structure withdrawal from use are marked; exceeding the critical condition: 1 – as a result of entropic effects; 2 – as a result of entropic effects and impact of an external factor

According to the first law of thermodynamics energy is neither generated nor vanishes; it can only change its form. We are not able to transform one form of energy into another, and real processes are always accompanied by a rise in entropy (Fig. 3); energy is dissipated as heat and only waste products are generated. Only some energy can be utilised usefully, which corresponds to useful energy – exergy.

The term "exergy" was coined by Slovenian physicist Zoran Rant in 1955. Efforts are made for exergy to be approached as a measure of environmental impact sustainability [18, 19]. An isolated system in a state of equilibrium aims to achieve maximum entropy. The interaction between a system and its environment can be analysed based on energy exchange (e.g. for heat) and mass transport (flow). Natural resources, including non-renewable fossil fuels, are a source of energy. The terrestrial system is supplied with solar energy. Owing to solar radiation, the ecosystem gains its renewable characteristics.

All living organisms take part in the flow of energy and mass; they get energy and mass with low entropy and are themselves a source of high entropy. In the case of coal used for heating, we get coal with high exergy (low entropy) from the deposit, while ash with low energy and high entropy is returned to the environment, as a waste product. The situation changes radically when fly ash from a cogeneration plant is used in concrete. It is important to select a process in such a way that it absorbs maximum exergy and generates as low entropy as possible. In the real world, there are no inexhaustible sources. Utilisation of resources and waste generation always affect the environment.

The energy situation shown in Fig. 3, which changes along the time axis covers – in cosmological categories – the period from the Big Bang to the absolute Maximum Entropy Production (MEP). A peculiar point is when entropy equals exergy, followed by the permanently increasing advantage of entropy over exergy. In reference to the selected systems (local and momentary situations), it can be interpreted as an occurrence of a thermodynamic barrier. For instance, one could try to make the point that the crisis in the coal industry does not result from coal deficits in the deposits but from such mining conditions in which the entropy related to the process exceeds the exergy of the mined coal.
In 1886, L. Boltzman highlighted [20] that the magnitude of entropy related to the acquisition of fossil fuels, rather than their deficit, would become an existential problem. H. Jonas' imperative of responsibility should apply here [21]: *avoiding a disaster which is unpredictable but avoidable when a risk is not taken.*

In general terms, a recommendation resulting from the "energy pyramid" can be applied to the period before the thermodynamic barrier: energy saving (reasonable use of energy, heat insulation), prioritisation of the use of renewable energy sources, and limited use of energy from fossil fuels in order to create methods of energy acquisition from renewable sources. There is only one Earth, which is subject to the law of conservation of energy and the law of increasing entropy, and not just to the law of gravitation.

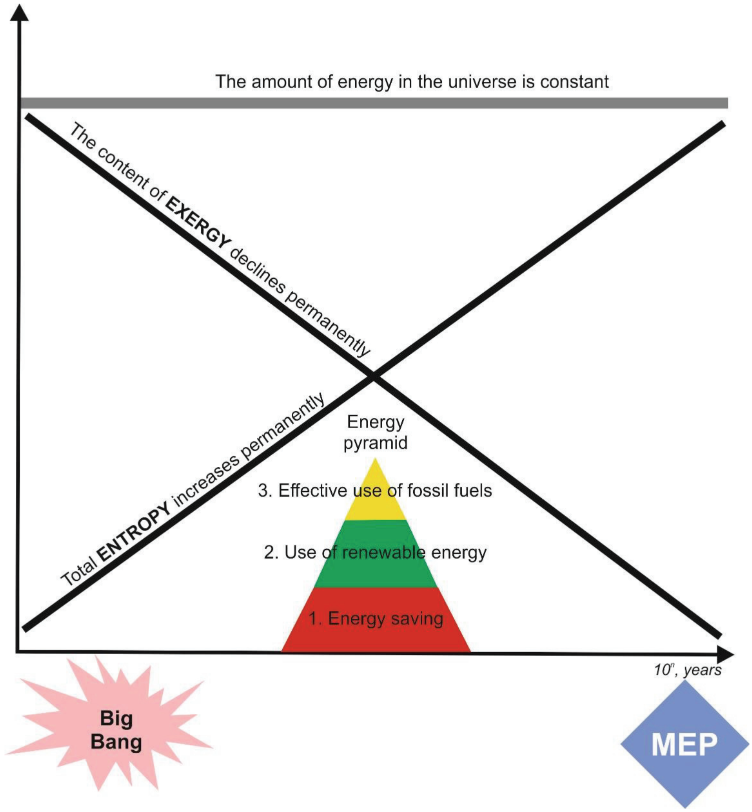


Fig 3. Energy in cosmological categories along the time axis: "energy pyramid' [19]

When I was searching for artistic expressions for the presented deliberations, I looked through an album called "Rauch Architektur" [22]. I would like to draw your attention to two sketches, though I suppose the author's intention was different. Fig. 4 can be attributed to a hazard caused by the entropy of waste from constructing and using a building, while the picture in Fig. 5 could well illustrate the turbulences preceding the reaching of the macro-MEP state.

Fig. 4. Creeping anisotropy accompanying the creation and use of buildings [22] Copyright: Hans-Georg Rauch

Fig. 5. Turbulences which precede the reaching of macro-MEP [22] Copyright: Hans-Georg Rauch

## 3. TRUTH OF SCIENTIFIC REASONING

At the beginning of this part I would like to recall the pronoun "my" used in the title, which means that this reasoning will still be "mine", i.e. incomplete and imperfect. In my opinion, the scientific discipline of "construction" refers to absolute more than other disciplines:

stands – does not stand

meets the basic requirements – does not meet the requirements

loads lower or higher than acceptable

structure or a pile of debris

The responsibility for the effects and a certain harshness of the job leave no room for subtleties. Aristotelian categorical imperative "true – false" offers the comfort of making a decision, though it always happens in reference to an adopted model and assumptions. The closer to the material issues we are, the more often the statement "yes, but …" is used. The issues related to the assessment of building structure durability, especially in terms of residual durability estimation, are not so unambiguous [23] – we refer to degree and probability. When evaluating a building structure's degree of sustainability, we officially use the term *nearly zero-energy building* [24].

The truth in building materials engineering is usually the truth of a degree and not a dichotomous truth; it is closer to Plato than to Aristotle. "Don't lie – tell the truth" is a categorical imperative: either – or. It assumes that the adversary knows the truth and either does not tell it or lies. In science, which involves cognition – discovering the truth – we approximate the truth. The "seniority" of mechanics over technology can be seen in this stratification. References (often indirect) to the logics of fuzzy sets are often used in building materials engineering. A great populariser of fuzzy logic, Prof. Bart Kosko [25], from the University of South California, Los Angeles, claims that *everything is a matter of degree*. Prof. William Kahan, from the University of South California, Berkeley, states in turn that fuzzy *logic is the cocaine of science* [25]. Referring to St Augustine (*Confessions)*, it can be added that *any exaggeration is sin*.

When analysing scientific reasoning, the following can be distinguished:

– the truth of experimental fact;
– the truth of scientific reasoning;
– the truth of scientific presentation.

In each of the subsets there is a series of partial truths. The truth of a single measurement seems "the truest" in the researcher's opinion. In reference to macro-non-homogeneous composite materials, such as building materials, it contains too little information to be useful. Representativeness of a single result for the non-homogeneity of a studied structure is low. We increase the number of measurements and "determine the accuracy" in reference to the set [26], using the term "precision" as the measure of dispersion, and "correctness" as the measure of position (Fig. 6.); the differences between the sets are assessed by means of statistical significance tests.

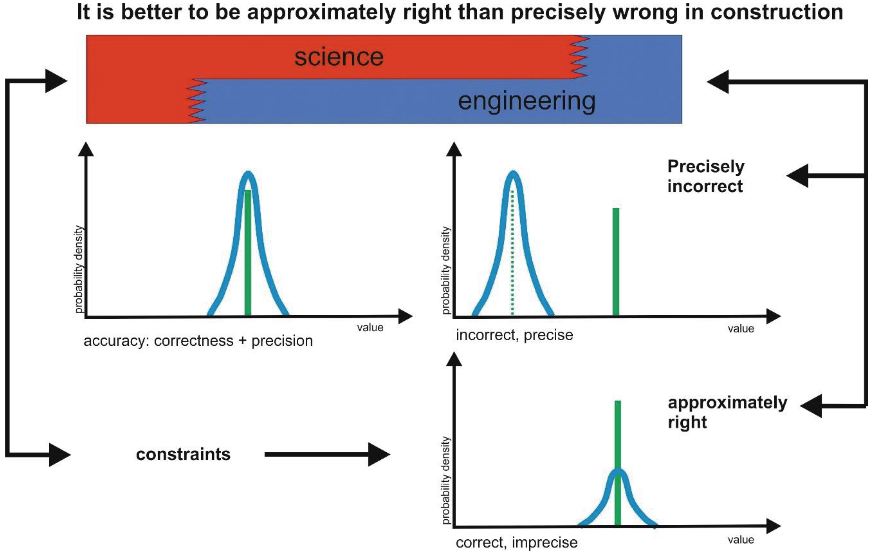


Fig. 6. Paraphrase of J.M. Keynes' concept (1924) in reference to construction, following PN-ISO 5725-1 [26]

If we want to learn the causes and mechanism of the phenomenon, we have to ask how and why. In reference to building products, taking into account the responsibility of their use, we make every effort in order to ensure that the characteristics are fulfilled for the expected intended use (Fig. 7.) – this is what validation and verification are for [27, 28].

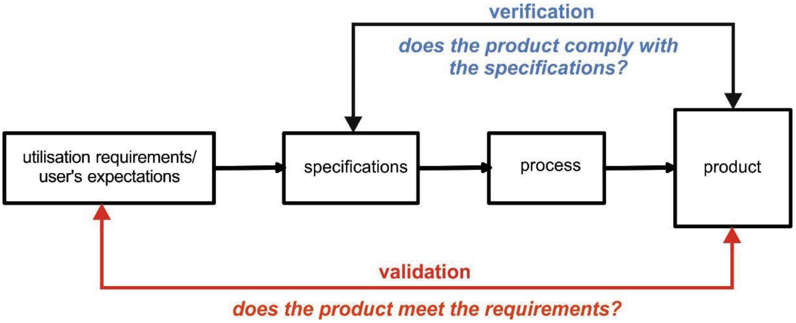


Fig. 7. Precautions in reference to the characteristics ensuring usability of construction products [27, 28]

We attempt to organise the measurement points for different variables – seeking to achieve a surface of response and creating a model of the phenomenon. We are farther away from the truth of a single measurement, "the price in truth", which we pay for generalisation of cognition, and which we identify by means of statistical measures of relationship. For an investigator, it means a task aimed at maintaining balance between the challenge to sort out the essence of the phenomenon in the clutter of the test results and to demonstrate its significance. It happens that we misleadingly assign the cause-and-effect agency to the changing time.

Considering the truth of scientific presentation, it is easier to mention the traps than to enumerate good practices. An apparently minor change in the scale step value suddenly reveals a "significant" relationship, which cannot be observed in a "normal" scale. Accurately running the line through all points, apparently "close to the truth", does not reveal the truth but misleadingly suggests non-continuity (the first derivative passes through the zero value) and, consequently, constant changes in the phenomenon (Fig. 8a). Describing the data of a regression function in the form of a power (Fig. 8.b) or in a logarithmic form (Fig. 8.c) in the same set provides good correlation and determination in both cases ($R^2$>0.95). For a power function, the values of the ordinate axis seem to increase faster and with no asymptotic constraints, contrary to a logarithmic model, while an unlimited increase makes no physical sense in the analysed case.

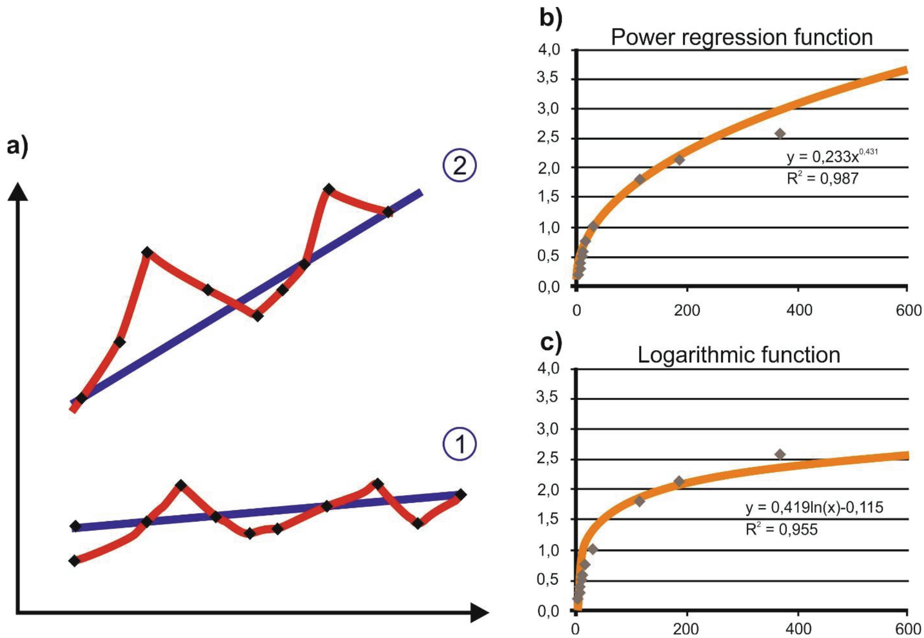


Fig. 8. a) Change in the step of coordinate scale (3x) versus visualisation of a straight line arrangement (dark blue). Running the lines exactly through the points (red lines); a suggestion of numerous discontinuities and a multiple change in the phenomenon mechanism; b) Relationship described with a power regression function - a permanently increasing function; c) The same experimental data (as in b) described with a logarithmic function - a sense of aiming at an asymptotic value.

A change in the coordinate system contradicts the definition of a square (Fig. 9) in spite of the fact that the same truth is presented in all diagrams – it is a square. We have a sense of "dishonest truth" here [1]. The transformation of a pig into a bison (Fig. 10) raises no doubts – it is manipulation! [1, 29]. A conflict between the suggestiveness of the visualisation and the suggested truth occurs here.

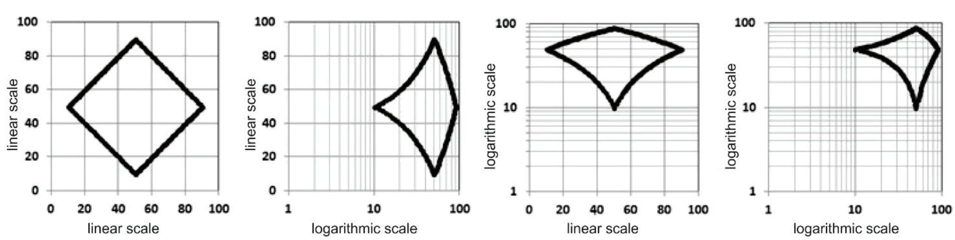


Fig. 9. A change in the coordinate system deforms the square

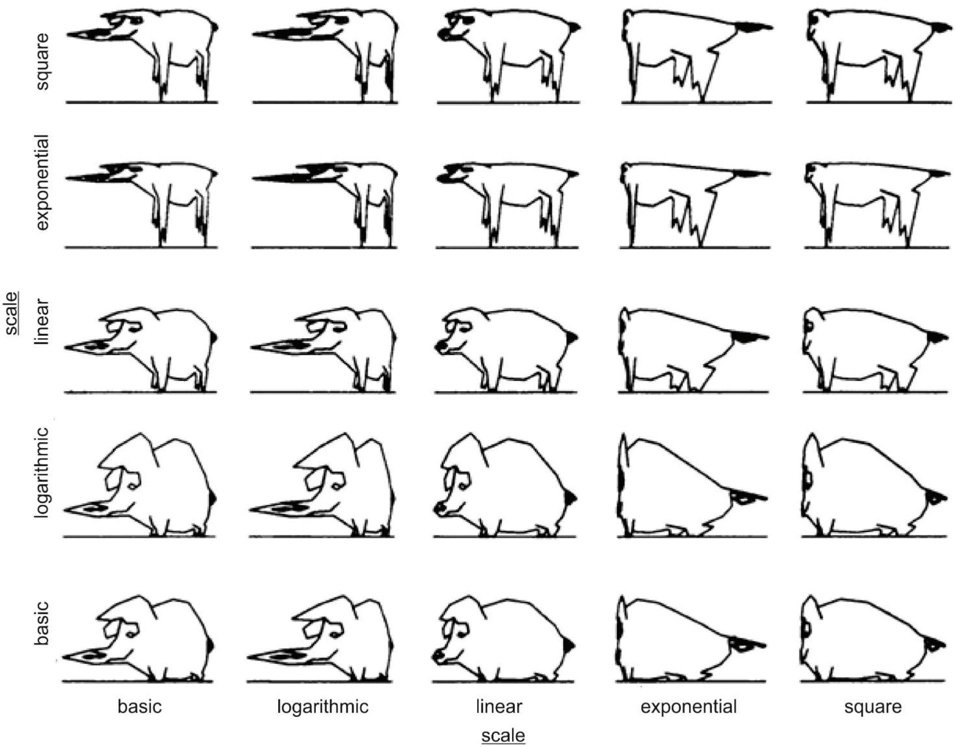


Fig. 10. A change in the coordinate system turns a pig into a bison [29]

The American philosopher R.A. Wilson (1932–2007) claims that due to our experiences each of us sees the world differently and that the "truth is in the eyes of the beholder" [30]. You can look at the ambiguous caricature (Fig. 12) drawn by W.E. Hill (1915) and never decide whether an elegant woman or a witch is the incarnation of truth. I could also gaze for hours at the clutter of aramid fibres broken as a result of extrusion (Fig. 11) and, without my studies, I would never know that buckling is the mechanism responsible for the damage and that the distance between the damage points is constant and amounts to 100 μm. This paper was published 40 years ago (co-authored by Prof. J.L. White) [31] and has been quoted ever since – 268 times so far[2] (according to Google Scholar). This experience made me an ardent advocate of the statement made by L.E. Boltzman that *there is nothing*

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*more practical than a good theory.* In my opinion, an idea should precede every project and every research programme. That is why when I was organising a conference devoted to the new challenges of civil engineering [33], I made every effort to precede it with a publication authored by ten Polish scientists, entitled 'The Ideas Shaping […] the Development Directions' [34] and '[…] in search for the construction development paradigm' [35].

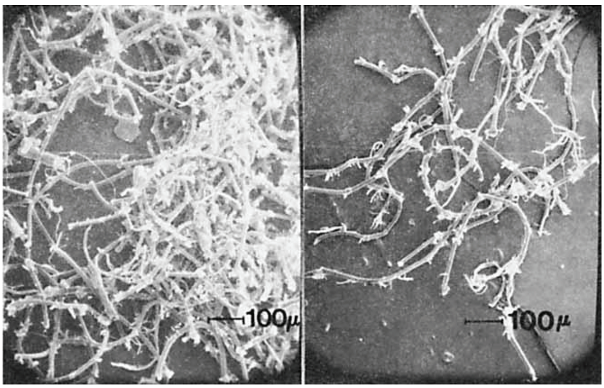


Fig. 11. Cluttered aramide fibres after mastification [31]

Fig.12. A beauty or a witch? [32]

Truth is beautiful as such and it should be accompanied by adequate presentation, which will enable communicating as much information as possible with moderate measures. The most important problems include the art of simplification [36], significant on all levels of building materials engineering (Fig. 13): how to reduce complexity, facilitate access to knowledge and add practical usefulness to the conclusions. Maintaining the balance between **accuracy and simplicity** is the boundary condition. One should remember that due to the uncertainty level, which occurs both in reference to the technical characteristics of non-homogeneous (!) building materials, as well as in reference to the material load in the structure, there is a regular trend to develop probabilistic methods – reasoning in statistical categories. The uncertainty applies in particular to building structures intended for repair [37, 38]. Consequently, non-destructive tests are regularly developed.

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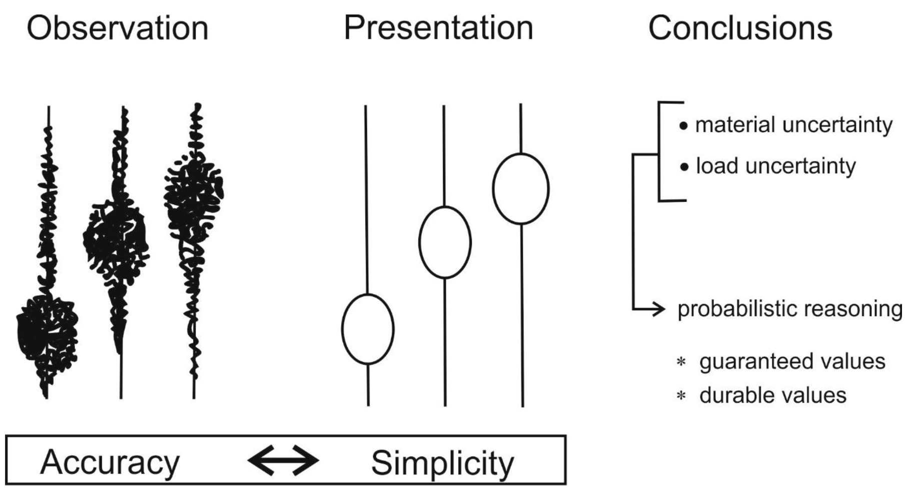


Fig. 13. Illustration of "the art of simplification" in building materials engineering [39]

## 4. TRUTH OF SCIENTIFIC ASSESSMENT

The right to evaluate the achievements of another author (work or promotion application) is too high a privilege not to be used with moderation. It should be added that not every opinion, even expressed by a scientist, is true. There are two competitive assessment methods: *peer review* (interestingly enough there is no Polish term for it [40]) and a bibliometric parametric assessment. I have already expressed my conviction [41, 42] about the inevitability of the contribution of parametric indicators to a scientific assessment, though only in a limited scope, as necessary supplementation. In this study, I focused on the need for such limitation because in my opinion too much parametrisation guides us away from the truth of the assessment.

Parametrisation is a useful tool for objectivisation and for making ranking lists. It becomes a special case when it refers to groups of humans, especially teams of exceptional personalities, and applies to their career ambitions. In the case of civil engineering (and transport), it applies to a group of specialists involved in the scientific fundamentals of design, construction technology, maintenance, repair and recycling of building structures [43]. In practice, this kind of activity consumes huge amounts of matter (mass and energy) – over 40% of global consumption.

Science and knowledge of technology intermingle in engineering sciences. Therefore, those who develop the scientific fundamentals of these activities carry special responsibility; thus, certain "conservatism" is understandable, reflected in their expression, and it determines the discipline's operation [42]. When we describe a scientist's achievements with a number, we lose the richness of their personality. Parametrisation is also an expression of a certain conformism, as it is much easier to indicate the greater of two numbers than to develop a professional assessment where adjectives have to be critically contrasted with facts.

Digitalisation of the assessment of a scientist and a scientific unit leads to the commoditisation and dehumanisation of science, but conversely it does not result in such transfers of professors as those which take place in the sports world.

The important aspects of a parametric assessment include the number of publications and their citations, which means the number of citations and the related Hirsch index (h). It is hard to say that a particular work had made a contribution to science, if its author has not been cited. Nonetheless, it cannot be denied that two great personalities – Socrates and Christ – who exerted enormous influence on the development of civilisation did not leave a single written word, except from a few words that Christ wrote on sand with a stick.

The more the assessment is limited to a number in aggregate, the easier it is for decision makers to direct the financial streams (usually quite limited) towards specific disciplines and scientific units. The two basic factors of a parametric assessment – citation number and Hirsch index – need to "mature". In the area of civil engineering, a work becomes "noticeable" for its citation number within 3–6 years from its publication. Hence, an assessment of a promotion application would be shifted back in time only on such a basis. "A true assessment" by its nature should include an expert forecasting component.

Assessment digitalisation also has a number of effects for a scientific workshop. The author's temper and personality are reflected in the style of expression. My opinion may be considered biased but I attribute a decay or lack of individual style to the drive towards increasing the number of papers. The truth of the presentation is lost due to lack of expression accuracy. Intentional inaccuracy (lack of knowledge) leads to hypocrisy, either resulting from the inability to define notions or use different terms interchangeably or lack of discipline in syntax. A conflict occurs between the intention of a statement and the ambiguity of its interpretation.

A side effect of parametrisation, which is considered to be positive in technical sciences, is an increased tendency towards multi-author publications. The number of single-author publications decreased to less than 10% of the total number of publications, while the average number of authors of a paper increased to over five [45–42]. In technical science, it is often a necessary ability to cooperate in research. It often contradicts a conservative conformism of promotion application reviewers, who have to evaluate the candidate's individual contribution. This is similar to Infeld-Einstein's dilemma: did Infeld lose because he was only the "co-author" or did he win "by co-authoring with Einstein" when the two scientists published together "The Evolution of Physics" in 1938?

In evaluating scientific activity, the Pareto principle is contradicted, which states than 'roughly 80% of scientific achievements stem from no more than 20% of scientists in a team'. It denies the leader's role in science and reduces them from mentors to "game masters" in a peculiar "game for a score". It should be confirmed in a self-critical manner that if somebody makes a decision to co-author a publication, they do not analyse what role they will fulfil among the 14 possible roles [44] in the team of authors.

I find it hard to accept many of the recommendations for evaluation criteria described as truth. Axioms described as "prestige inheritance rule" raise obvious doubts [45]. *The publication reflects the journal's quality, and the book reflects the publishing house's quality.* We do not ask if a paper was clever but where it was published. Therefore, a doubt appears whether things will improve if scientists prove to be rational and limit themselves to h-effective activity?

In my deliberations, I tried to present a proposal of "kind restraint" as – in my opinion – the closest to the truth of scientific assessment. Some could argue that kind restraint, when evaluating a publication, leads to approval or even to an increase in the number of average or even marginal papers. I would rather not formulate this allegation explicitly, because in science development it sometimes happens [46, 47] that some marginal results can turn out to be precursors of a new stage of development (Fig. 14) – a change in the paradigm. **In the population of scientists who accept only excellent results, the probability of such transformations is very low.**

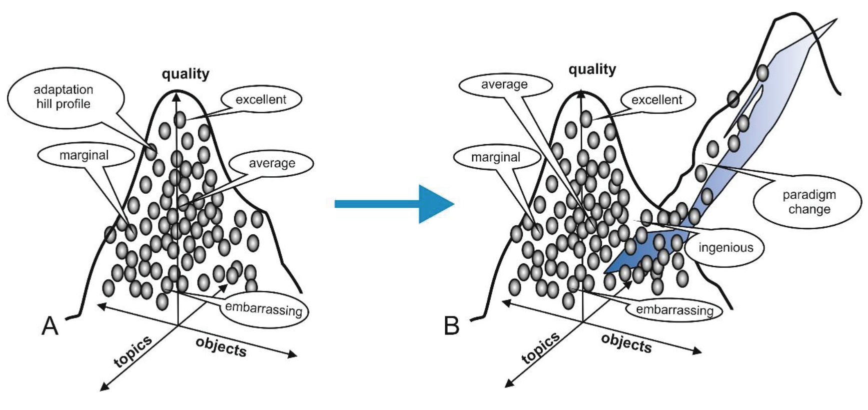


Fig. 14. Illustrative presentation of scientific research dynamics [47]; A – mature phase, B – breakthrough; marginal results turn out to be ingenious and trigger a new development phase

The indication of "kind restraint" in reference to construction also entails special responsibility, which I would call "semantic", of the reviewer in the area. Some may associate construction, which has been recently implemented as the official name of a scientific discipline, more with craftsmanship than with science. In this respect, the situation is even worse in India, which is intensively extending its infrastructure and where construction as a discipline is called "brick and mortars engineering" [48]. In civil engineering and transport, which is the current name of the discipline, science and engineering strongly intermingle; hence, it is often difficult to separate scientific issues and there is a sense of low potential of dissertability.

The problem occurs not only in Poland or India. The question *How much science is there*? [49] is also asked in other countries. M. Nehdi announced a crisis of civil engineering in the era of IT in North America; F.P. Torgal [50] in Portugal and A. Lawless [51] in Africa share the same opinion. It is up to us, however, whether those who build using atoms and molecules will enjoy equal appreciation to those who build using bytes. The world around us – whether created by nature or by humans – is composed of atoms and molecules. Civil engineering outcomes are permanent elements of our surroundings and their lives tend to be measured by the multiplexed life of their creator–engineer. There is no other discipline like this – only the Colosseum in ancient Rome and Homer's works can be called immortal.

M. Porter, professor in the University of California, in the closing part of his "Trust in Numbers" [52] claims that the meaning of a number – parametrisation – becomes more important, the weaker the elites turn out to be. It can be perceived as the reason for the disquietude and emotions raised by the implementation of parametrisation in science. A. Einstein said that ‘most people say that it is the intellect which makes a great scientist. They are wrong: it's character’. This attribute is not included in science parametrisation and unfortunately it is rarely reflected in the reviews of promotion applications.

## 5. TRUTH OF DEVELOPMENT DIRECTIONS: DEFINED PAST – FUZZY FUTURE

The past has already happened, so it is deterministic; the future is becoming, so it is probabilistic; the forecast is fulfilled only to a certain extent, so it is fuzzy. Forecasts that do not come true are not necessarily false. The truth of a forecast is bona fide – it lies in its honest preparation. I am convinced that ideas should precede research programmes (see Chapter 3). If so, studies on basic development directions (megatrends) and on the expected paradigms of small and medium research workshops are necessary. This is a difficult issue because there are no logical premises to anticipate the future based on past experiences. S. Lem claimed that the fact that *the past in the past was similar to the past does not mean that it will be so in the future* [53].

Induction as an attempt to transform information from partial to full, is not fully substantiated in information theory. Not knowing the objective, we are not able to use the forces which drive the change for our own development. According to Seneca the Older ‘you must know for which harbour you are headed, if you are to catch the right wind to take you there’. One should remember that the moment of creating a forecast – reading the emerging "technological wave" – is determined by the equilibrium between the uncertainty and risk of the message and the arrogance of the concept presentation. The megatrends observed in technology for the past several dozen years or so include the technology of integrated circuits initiated in the 1950s, biotechnology in the 1970s and nanotechnology in the 1990s (Fig. 15a). Nowadays, we could expect digital technology to emerge as a macrotrend. All these trends were meant to intensify the method. A reorientation and focusing on the objective could be expected – adopting the necessary survival option: protection of well-being and its future and not unlimited progress (Fig. 15b). This is supported by deliberations on the entropy barrier (Chapter 2), as well as H. Jonas' rule of caution [21]: *new solutions implemented after gaining unambiguous knowledge that no irreversible consequences will come as a result.* Let me highlight that I am writing this paper in a very special time. We experience the horror of the Covid-19 pandemic and the world is increasingly distressed. Since 1980, there has been a growing number of articles devoted to existential threats and the risk of a global disaster. The percentage of papers dealing with this topic in 2017 exceeded 15% of all scientific publications [54]. Conversely, in reference to the previously quoted *arrogance of the manner of concept presentation*, it can be mentioned that according to the forecast published in 1997 in "Nature" [55], starting from 7 February 2020 *all science will be novel*. The authors – S.H. Friedman and J.O.H. Karlson – used the data from the twenty-year period between 1975 and 1995 to extrapolate the exponential share of publications including the words "novel" and "novelty" in their titles to reach such conclusions. At the beginning of this section, I emphasised that induction meant as transformation of partial to full information is not justified.

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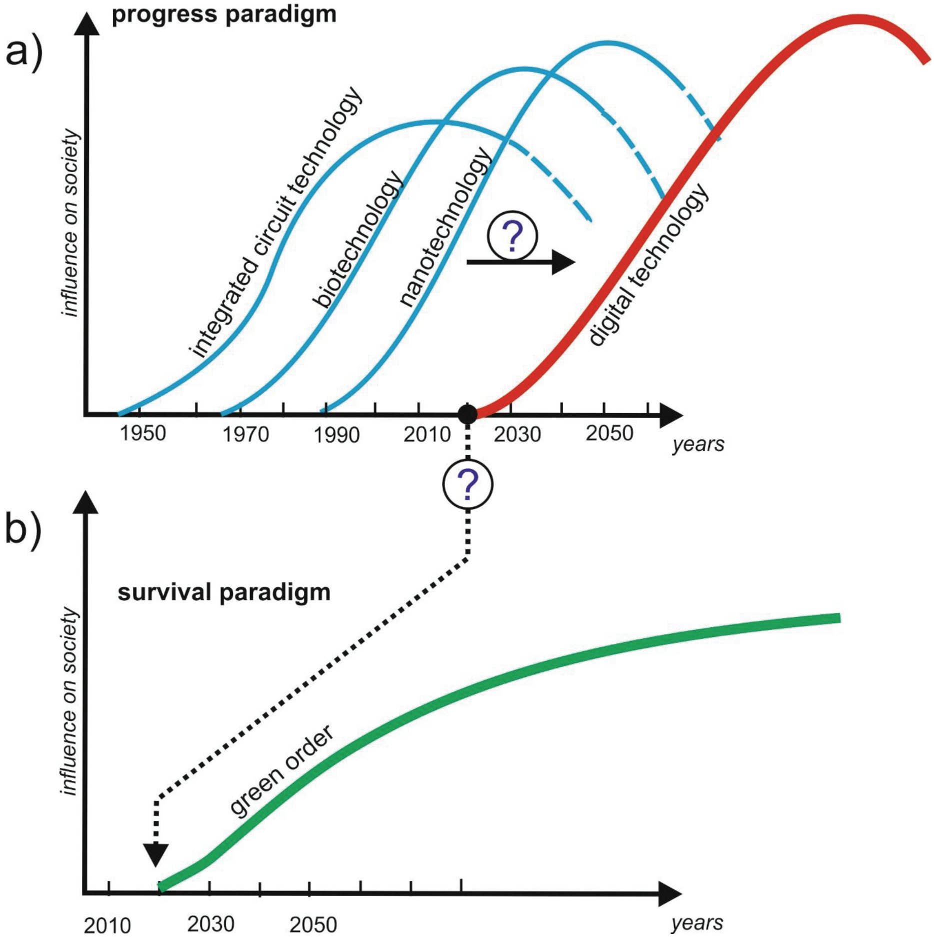


Fig. 15. Megatrends in technology development: the blue lines represent 'technology waves which affect society', published in 2013 [56], according to T.A. Volde, 1998 [57]. The green and red lines are the forecasted trends

Due to its immateriality, "an idea" often contains idealistic or "dreamy" elements in its semantic area. I used to publish, following the President of CEN TC 350 A. Ilomaki, a diagram presenting the idea of sustainable development as a "decoupling" of economic growth from the consumption of natural resources and negative environmental impact (Fig. 16), usually pointing out that it sounds utopian but necessary.

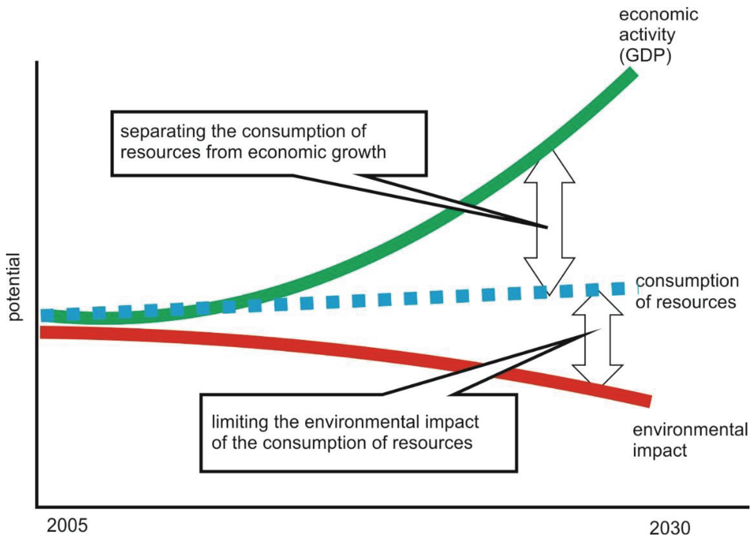


Fig. 16. Schematic presentation of the concept of sustainable development (following A. Ilomaki [58]) [59]

Nowadays, over 30 years after the UN proclamation [60] of the concept of sustainable development, it is hard to notice in global statistics [15] the separation of economic growth from the increase in energy (matter) consumption, required by many visionaries. Nonetheless, the idea can be partly expected to become true as the **circular economy** [61].

**The durability of building structures** is a spectacular example of an idea whose impact exceeds material effects. Building structures are constructed, they **last**, and deteriorate, they are demolished, and the idea of their **durability** has survived since Hammurabi's times.

The presented (Fig. 15) development trends of the dominant technologies have their characteristic shapes. Only the first, "optimistic" part of the bell-shaped curve is shown [36, 62]. So is "my" curve of concrete development (Fig. 17) – it includes only the rising part of the bell-shaped curve.

A generalised concrete development curve (Fig. 17) shows qualitative progress, represented by concrete durability development over 160 years, and quantitative development measured with concrete production increase. It also illustrates that demographic growth is the process driver. The questions which arise include: Will it be similar in the future? Will progress still be exponential and rise so steeply? Will it still be possible to describe the qualitative and quantitative growth with the same function or will the durability and production volume ordinates get separated?

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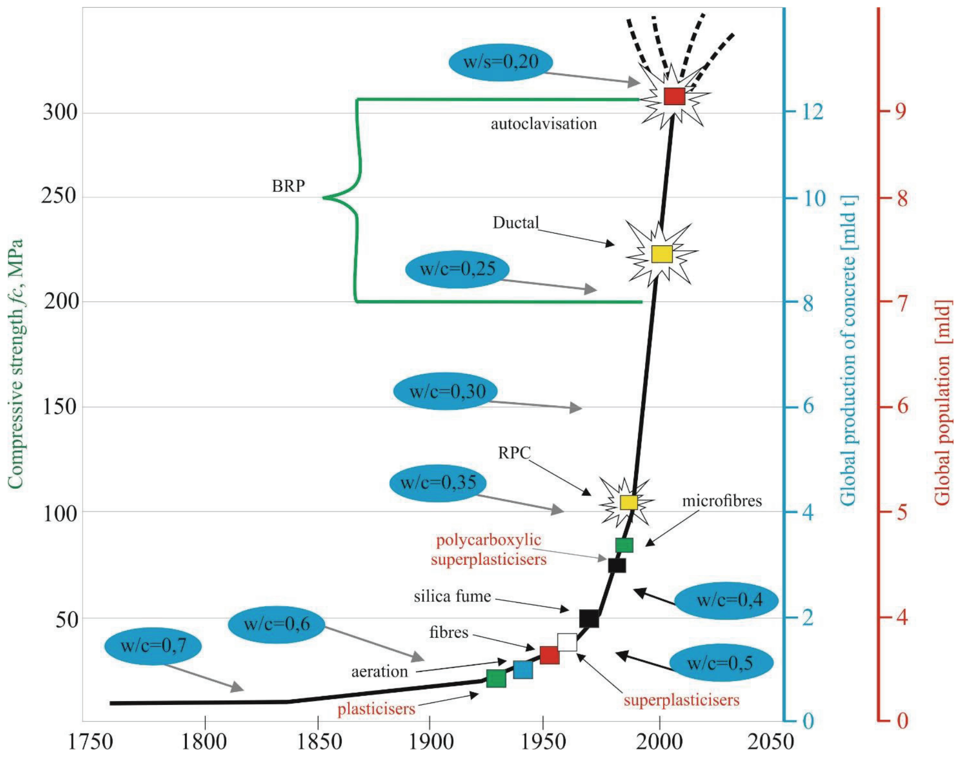


Fig. 17. Generalised concrete development curve [36]

Demographic growth will exert significant pressure on the quantitative development of concrete; greater geographic diversity is highly likely to occur. Though it is hard to believe, there is a forecast predicting that by 2050 the production of concrete will stop growing [63]. The production of concrete is expected to reach its maximum during this period (2050 – 18 billion tonnes/year) and will start to decline gradually. The decrease after 2050 will depend on how intensively we will be implementing the sustainable development rules and to what extent the durability of concrete will be improved (Fig. 18).

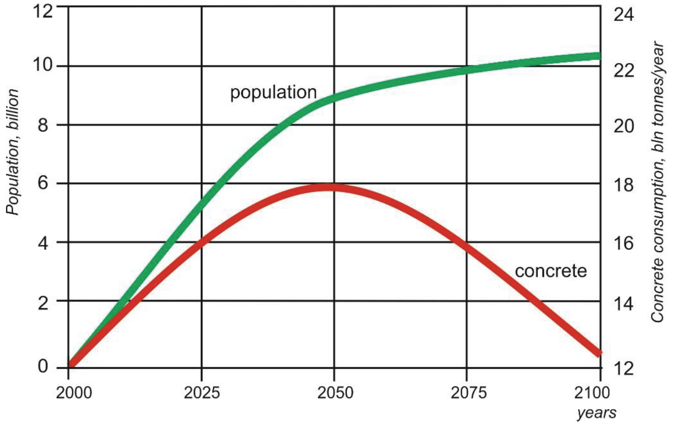


Fig. 18. Forecasted growth of population and concrete production [63]

The logistic S-curve (cumulative curve) [64] completes the bell-shaped curve (Fig. 19). The forecasted development, according to the survival paradigm, is presented according to this convention (Fig. 14a). It has the same meaning but carries a far more optimistic message.

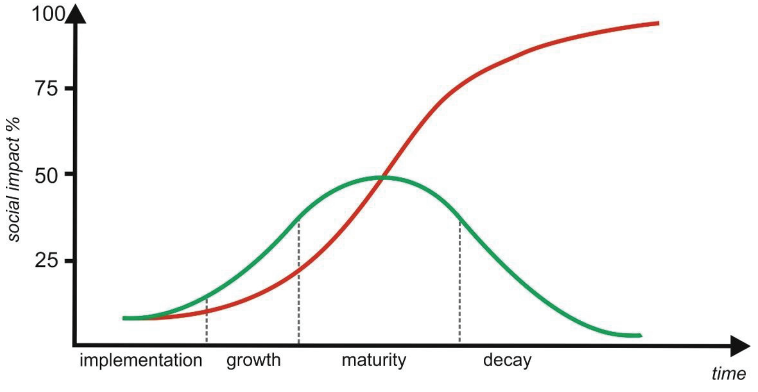


Fig. 19. Full life cycle of an object: bell-shaped curve (green) and logistic S-curve (cumulative; red)

In my opinion, the development of science in small and medium scientific workshops occurs according to "delusional hysteresis" (Fig. 20). Rapid development of the discipline and collection of new knowledge follows the incubation period. At a certain point, publications start to bring less new knowledge (there is only confirmation or revision) or even reduce it. These are contributions, doubts and negations, secondary discoveries or even repetitions. The maturity period is followed by "fatigue with the topic". The end of the cycle marks the beginning of new hysteresis (typically with a newly formulated paradigm), which is initiated on a much higher level of knowledge.

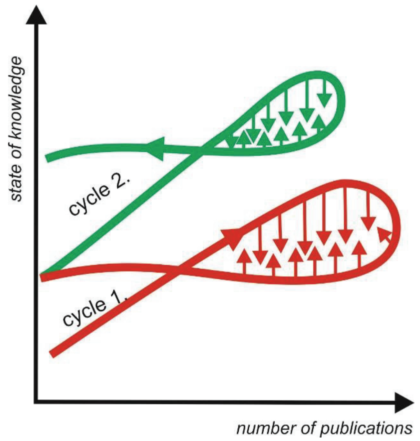


Fig. 20. Development of the state of knowledge according to the "delusional hysteresis" model

"Delusion of hysteresis" intrinsically includes a negative arrow of time and is not possible in physics categories. The entropy determines the arrow of time. Such a presentation is parallel to my perception. The "time trap" can be bypassed by introducing discontinuity between the displaced logistic curves (Fig. 21). The sense of hysteresis remains, which in my opinion corresponds to the researcher's state of mind in the reference period.

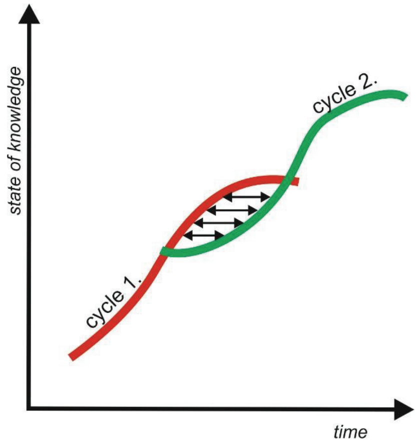


Fig. 21. Development of the state of knowledge according to the model of displaced logistic curves

In my field of C-PCs (Concrete-Polymer Composites), I have experienced the whole cycle, and in the period between 2001 and 2013 I felt responsible for its development, initially as the Deputy President and then as the President of the International Congress on Polymers in Concrete. It took nearly 50 years from my first publication in the field in 1974 [65, 66] and the first International Congress in 1975 (Tab. 1). I experienced the effect of the unexpected [pat. 108380 (1975) and pat. 122507 (1975)], resulting from a combination of the state-of-the-art materials of that time, i.e. polymer with the most traditional material: concrete. I felt highly satisfied as the co-creator of the material models of new solutions, observing the resulting disputes [67, 68, 69] and having the sense of maturity to search for new development paths [70, 71], until finally asking the question if polymer is still the factor which contributes to progress in concrete technology [72].

Table 1. Milestones in the development of C-PCs – Concrete-Polymer Composites, marked by International Congresses on Polymers in Concrete, ICPIC

| Congress No. | Year | Main theme |
|---|---|---|
| I | 1975 | Innovation – progress in concrete technology: PIC, PCC, PC[3] |
| II | 1978 | Applications – trials and errors |
| III | 1981 | Usability testing |
| IV | 1984 | Material model |
| V | 1987 | Control of properties |
| VI | 1990 | Effectiveness of polymer utilisation |
| VII | 1992 | Evaluation, simulation, optimisation |
| VIII | 1995 | Modelling: durability and synergy |
| IX | 1998 | Micro-macrostructure relations (nanotechnology, application of plastic recyclates) |
| X | 2001 | Sustainable C-PC |
| XI | 2004 | Integrated PCC model; synergy. Water-soluble polymers as modifiers |
| XII | 2007 | Sustainability; nanotechnology as the driving force |
| XIII | 2010 | C-PC of high usability |
| XIV | 2013 | Modelling the processes of binding and curing. Synergy between the components. Pursuing new development directions |
| XV | 2015 | Great expectations. Potentially "mature" C-PC |
| XVI | 2018 | Does polymer still create progress in concrete technology? |

In a paper published last year, called "Would recycled plastics be a driving force in concrete technology?" [73], I outlined the paradigm setting the direction for a new development cycle:

- The objective is not to develop better concrete owing to polymer introduction but concrete with non-deteriorated characteristics despite the use of plastic waste.
- The modifier is not the original liquid polymer used as a binder or co-binder but solid plastic waste as partial filler.

[3] PIC – Polymer Impregnated Concrete; PCC – Polymer Cement Conrete; PC – Polymer Concrete

- The changes should be attributed not to the pursuit of concrete refining and its provision with specific functionalities but to "taking the load off" from plastic landfills, which now contain 70 bln tonnes of plastic and are still growing, estimated to last for 450–600 years. During this period they will contaminate water, destroying organisms living in natural water, and damage the environment and also its appearance.
- The action does not result from the fact that concrete needs more polymer but from the environment not being able to take on more plastic waste – a higher amount of used plastic products. In this context, the slogan "good concrete is sustainable concrete" gains new meaning.

I have made my observations with some nostalgia. In order to maintain balance, I need to emphasise that forecasts developed at a different stage of the development cycle and addressed to other areas of science can be far more optimistic. Let me quote the example of a study by W. Bonenberg and O. Kapliński [74] referring to architecture, and a study by K. Furtak [75] devoted to engineering. The future is always more unpredictable than it seems, which does not undermine the significance and the need for forecasts.

## 6. SPLENDOUR OF SCIENTIFIC TRUTH

Truth is the objective and the ideal of science, and the scientist is responsible for science. John Paul II in his *Veritas Splendor* encyclical attributes splendour to truth. Don't we feel that our works should be accompanied by splendour? It is important not only to know the rules of the game when we choose the effective strategy of scientific activity but also to remain faithful to values. A doctoral oath contains a warning and a promise: *the truth on which the future and the happiness of humankind depend.* The academic oath says in turn that *one should testify the truth with one's behaviour,* which makes actions more specific. If science is subject to commoditisation, if science becomes a commodity, it needs to have its "weights and measures", its price and its marketing [76].

The question which arises is whether science loses its splendour in this fair. Don't we give priority to form over content and, consequently, we praise glitter more than splendour, when we say that only papers published in some journals matter? [77] Aristotle [*Nicomachean Ethics*] claims that *for though both are dear, it is a pious thing to hold the truth in higher esteem.* There are certainly some periods in history when truth becomes a special challenge. The pursuit of truth during anti-elite populism becomes more important than ever.

There is only one Earth and terrestrial resources are limited. Only human creativity is unlimited in its potential for good and evil. We can attribute the hope to overcome constraints and to manage these resources reasonably only to human inventiveness. Nature guards its secrets and the road to truth in science is curved [78]. It is important for the domains of truth and cognition to be identical. I am convinced that good ideas have their causative power.

*The paper was written during the Covid-19 pandemic: April and May 2020.*

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## LIST OF FIGURES AND TABLES:

Fig. 8. a) Change in the step of coordinate scale (3x) versus visualisation of a straight line arrangement (dark blue). Running the lines exactly through the points (red lines); a suggestion of numerous discontinuities and a multiple change in the phenomenon mechanism; b) Relationship described with a power regression function - a permanently increasing function; c) The same experimental data (as in b) described with a logarithmic function - a sense of aiming at an asymptotic value.
Rys. 8. a) Zmiana kroku skali rzędnych (3x) a wizualizacja przebiegu prostej (linie granatowe). Prowadzenie linii skrupulatnie przez punkty (linie czerwone): sugestia licznych nieciągłości i wielokrotnej zmiany mechanizmu zjawiska; b) Zależność opisana funkcją regresji potęgowej – funkcja stale rosnąca; c) Te same dane doświadczalne (jak w b) opisane funkcją logarytmiczną – wrażenie dążenia do wartości asymptotycznej.
Fig. 9. A change in the coordinate system deforms the square
Rys. 9. Zmiana układu współrzędnych deformuje kwadrat
Fig. 10. A change in the coordinate system turns a pig into a bison
Rys. 10. Zmiana układu współrzędnych przeistacza prosiaka w bizona
Fig. 11. Cluttered aramide fibres after mastification
Rys. 11. Kłębowisko włókien aramidowych po mastyfikacji
Fig.12. A beauty or a witch?
Rys. 12. Piękna czy czarownica?
Fig. 13. Illustration of "the art of simplification" in building materials engineering
Rys. 13. Poglądowa ilustracja „sztuki upraszczania" w zagadnieniach inżynierii materiałów budowlanych
Fig. 14. Illustrative presentation of scientific research dynamics [47]; A – mature phase, B – breakthrough; marginal results turn out to be ingenious and trigger a new development phase
Rys. 14. Poglądowe przedstawienie dynamiki badań naukowych [47]; A – faza dojrzała, B – moment przełomowy; rezultaty marginalne okazują się genialnymi, dając zalążek nowej fazy rozwoju
Fig. 15. Megatrends in technology development: the blue lines represent 'technology waves which affect society', published in 2013, according to T.A. Volde, 1998. The green and red lines are the forecasted trends
Rys. 15. Megatrendy w rozwoju technologii; niebieskie linie to „fale technologii wpływające na społeczeństwo", opublikowane w 2013, w ślad za T.A. Volde, 1998. Linie zielone i czerwone to trendy prognozowane
Fig. 16. Schematic presentation of the concept of sustainable development (following A. Ilomaki)
Rys. 16. Schematyczne przedstawienie idei zrównoważonego rozwoju (wzorowane na A. Ilomaki)
Fig. 17. Generalised concrete development curve
Rys. 17. Uogólniona krzywa rozwoju betonu
Fig. 18. Forecasted growth of population and concrete production
Rys. 18. Prognoza wzrostu populacji i wytwarzania betonu
Fig. 19. Full life cycle of an object: bell-shaped curve (green) and logistic S-curve (cumulative; red)

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POLSKA AKADEMIA NAUK



Rys. 19. Pełny cykl życia obiektu: krzywa dzwonowa (kolor zielony) i logistyczna S-krzywa (kumulatywna)(kolor czerwony)

Fig. 20. Development of the state of knowledge according to the "delusional hysteresis" model

Rys. 20. Rozwój stanu wiedzy według modelu „urojonych histerez"

Fig. 21. Development of the state of knowledge according to the model of displaced logistic curves

Rys. 21. Rozwój stanu wiedzy według modelu przesuniętych krzywych logistycznych

Table 1. Milestones in the development of C-PCs – Concrete-Polymer Composites, marked by International Congresses on Polymers in Concrete, ICPIC

Tablica 1. Kamienie milowe rozwoju betonowych kompozytów polimerowych (C-PC, Concrete-Polymer Composite), znaczone międzynarodowymi kongresami International Congress on Polymers in Concrete, ICPIC

## MOJE POSZUKIWANIA PRAWDY W INŻYNIERII MATERIAŁÓW BUDOWLANYCH

Słowa kluczowe: *Inżynieria Materiałów Budowlanych, Wymagania Podstawowe, Entropia, Egzergia, Digitalizacja Nauki, Histereza Rozwoju*

### STRESZCZENIE

Artykuł jest osobistą refleksją autora nad wywiązaniem się ze ślubowań akademickich *dociekać prawdy, głosić ją oraz dawać świadectwo*, a także doktorskich - *aby szerzyła się coraz bardziej prawda, od której zawisła przyszłość i szczęście rodzaju ludzkiego*. Rozważania te są zaadresowane do Inżynierii Materiałów Budowlanych – obszaru nauki, który formalnie nie był zdefiniowany ani wyodrębniony w momencie składania ślubowań. Nauka może być zdefiniowana jako dążenie do prawdy; w prawdzie zaklęty jest cel, ale i etos nauki. Postęp nauki nie zawsze prowadzi prostą drogą do prawdy. Często odpowiadamy tylko na pytanie czy model opisujący dane zjawisko jest wystarczająco prawdziwy. Prawda inżynierii materiałów budowlanych ma nie tylko wymiar wartości, ale również waży materialnie. „Prawdziwość" metody pomiaru może decydować o bezpieczeństwie konstrukcji, ale również istotnie znaczy w jej koszcie. Obszar rozważań został określony jako relacja „materiał – konstrukcja" i przypisano tu myśl przewodnią „nośność i stateczność a entropia".

Wymagania podstawowe wobec obiektu budowlanego brzmią bardzo zdecydowanie, bardzo mechanistycznie, wręcz w stylu Newtona. To mechanistyczne ujęcie dominowało od zawsze, począwszy od kodeksu Hammurabiego (XVIII w. p.n.e). Dopiero w roku 2011 powstała nowa wersja Wymagań Podstawowych (CPR 305/20), w której znalazło się dodatkowe wymaganie (siódme!), które głosi zrównoważone wykorzystanie zasobów naturalnych. Jest to nawiązanie do I zasady termodynamiki – prawa zachowania energii; ilość energii w układzie pozostaje niezmieniona. Natomiast we współczesnym zbiorze Wymagań Podstawowych, ani też w historii kodów budowlanych, nie można dopatrzyć się nawiązania do II zasady termodynamiki – prawa entropii.

Entropia jest miarą prawdopodobieństwa termodynamicznego układu, którą przywykło się traktować jako miarę stopnia nieuporządkowania układu. II zasada termodynamiki określa kierunek i nieodwracalność procesów samorzutnych. Układ samorzutnie dąży do stanu maksymalnego prawdopodobieństwa termodynamicznego – zwiększenia entropii. Zagadnienie jest trudne i skomplikowane; budziło wśród uczonych szereg kontrowersji. Zapewne jednak nie te kontrowersje były powodem, że zasady termodynamiki znalazły tak skromne odzwierciedlenie w Wymaganiach Podstawowych. Istotna, a być może decydująca różnica, jest w skali czasowej. Pogwałcenie zasad mechaniki kończy się z reguły gwałtownie i spektakularnie – katastrofą. Entropia rośnie pełzająco, a jej skutki odłożone są w czasie. Niemniej efekt końcowy również może być dramatyczny, szczególnie w przypadku konstrukcji sprężonych. Przykładem jest tu katastrofa Mostu Morandi w Genui w 2019 roku, którą przypisuje się pęknięciu skorodowanych stalowych cięgien sprężających po ponad 50 latach pracy. W tym kontekście przywołuje się jako model „klif Seneki". Diagram klifu Seneki, w odniesieniu do obiektów budowlanych, ma w pewnym stopniu odmienny przebieg z uwagi na wyróżniającą te obiekty trwałość użytkowania.

Nie możemy prosto przekształcić jednej formy energii w inną, procesom rzeczywistym zawsze towarzyszy wzrost entropii; energia zostaje rozproszona w postaci ciepła, powstają produkty odpadowe. Tylko część energii może być wykorzystana jako praca użyteczna, co odpowiada energii użytecznej – egzergii. Punktem osobliwym jest zrównanie entropii z egzergią, a następnie stale rosnąca przewaga entropii nad egzergią. W odniesieniu do wybranych układów (sytuacji lokalnych i chwilowych) można to interpretować jako wystąpienie bariery termodynamicznej. Egzergia może być traktowana jako miara zrównoważoności oddziaływań środowiskowych. W kategoriach ogólnych do okresu przed wystąpieniem bariery termodynamicznej można odnieść zalecenie wynikające z „piramidy energetycznej": oszczędność energii (racjonalizacja zużycia energii, izolacyjność cieplna), priorytet wykorzystywania energii ze źródeł odnawialnych oraz ograniczenie wykorzystania energii ze źródeł kopalnych do wykreowania metod pozyskiwania energii ze źródeł odnawialnych. Ziemia jest jedna, podlega prawu zachowania energii i prawu rosnącej entropii, a nie tylko prawu grawitacji.

W odniesieniu do inżynierii materiałów budowlanych przeanalizowano szereg prawd cząstkowych: prawda wywodu naukowego, prawda oceny naukowej, prawda kierunków rozwoju i blask prawdy naukowej. Rozważając różne aspekty wywodu naukowego, wyróżniono z kolei: prawdę faktu doświadczalnego, prawdę wnioskowania naukowego i prawdę prezentacji naukowej.

Prawda pojedynczego pomiaru wydaje się w odczuciu badacza „najprawdziwsza", jednakże w odniesieniu materiałów makroniejednorodnych jest nikła. Trzeba się odwoływać do zbioru wyników i określać ich dokładność. Dążąc utworzenia modelu zjawiska, coraz bardziej oddalamy się od prawdy pojedynczego pomiaru a „cenę w prawdzie", którą ponosimy za uogólnienie poznania, określamy za pomocą statystycznych miar zależności. Wyzwaniem staje się wydobycie istoty zjawiska z gąszczu wyników badań a wykazanie jego istotności; zachowanie równowagi „dokładność – prostota". Na przykładach pokazano konflikt między sugestywnością wizualizacji a sugerowaną prawdą.

Zwrócono uwagę, że uprawnienia do oceny osiągnięć innego autora (dzieła czy też wniosku awansowego) są zbyt wielkim przywilejem, aby go nie stosować z umiarem. Digitalizacja oceny ma też szereg różnych skutków dla warsztatu naukowego, w tym również zdecydowanie negatywnych. W tym kontekście przytoczono dwie oceny. M. Porter, autor „Wiary w liczbę" stwierdza, że znaczenie liczby – parametryzacja – staje się tym ważniejsza, im elity okazują się słabsze. A. Einstein głosił, że *większość ludzi jest przekonana, że to intelekt czyni uczonego. Są w błędzie – to charakter.* Ten

atrybut nie jest w żaden sposób ujęty w parametryzacji nauki, rzadko też niestety znajduje swoje odzwierciedlenie w recenzjach wniosków awansowych.

Przeszłość stała się, więc jest deterministyczna; przyszłość staje się, więc jest probabilistyczna; prognoza realizuje się tylko w pewnym stopniu, więc jest rozmyta. idee powinny poprzedzać programy badawcze. Koniecznie są studia dotyczące podstawowych kierunków rozwoju (megatrendy), a także przewidywanych paradygmatów małych i średnich warsztatów badawczych. Przedyskutowano czy rozwój będzie przebiegał według paradygmatu postępu czy paradygmatu przetrwania. Przedstawiono hipotezę rozwoju nauki w obrębie małych i średnich warsztatów naukowych według „urojonej histerezy". Przeanalizowano kamienie milowe rozwoju bliskiej autorowi dziedziny betonowych kompozytów polimerowych. W nauce ważna jest nie tylko znajomość reguł gry przy wyborze skutecznej strategii działalności naukowej, lecz również troska o zachowanie wartości.

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