David Avnir*
*Corresponding author
Institute of Chemistry
The Hebrew University of Jerusalem
Jerusalem 91904, ISRAEL
david.avnir@mail.huji.ac.il

Dirk Huylebrouck

Department of Architecture,
Sint-Lucas University
9000 Gent, BELGIUM
huylebrouck@gmail.com

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Research

On Left and Right: Chirality in Architecture

Abstract. Chirality of an object is the property of potentially having a left-form and a right-form: a pair of hands is a classical example. Spiral elements in buildings are well known, and their spirality renders them chiral, yet we are unaware of a routine reference to the following basic question: Having designed a building which is chiral, which form should be constructed – the left-handed or the right-handed one? Whereas in natural science the investigation of handedness effects is central and appears in many of its branches, in architecture, which relies heavily on shape, form and symmetry, considerations of chirality – a key structural descriptor – are non-existent, although asymmetry and twisted shapes have been commonly used. The aim of this paper is to familiarize architects with the language and concept of chirality, and to describe the intimate, relevant link between chirality and architecture.

1 Motivation

Chirality of an object is the property of potentially having a left-form and a right-form.[1] A pair of hands is a classical example; a pair of oppositely spiraling horns is another one (fig. 1); and a pair of coordinates (fig. 2a) is an example of purely mathematical chirality. To be labeled “chiral” it is enough that one of the forms exists in reality; a standard screw (or a spiral, fig. 2b) is chiral and right-handed, and in most cases a left-handed counter screw is not produced.

Fig. 1. Classical chiral objects – a pair of hands, a pair of spiraling helical horns. In each example, there are two forms, or enantiomers: left and right

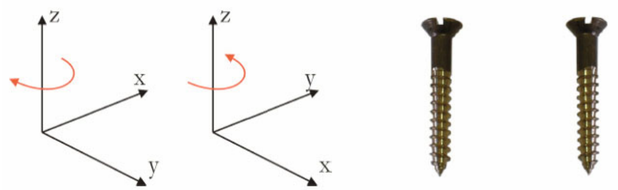

Fig. 2. a, left) A pair of enantiomers may be an abstract mathematical entity, such as coordinate system (compare the *x*- and *y*-axes); b, right) a screw, spiral or helix are chiral – the real right-handed screw is shown on the right; the left form (on the left) is very hard to find; it is a virtual enantiomer

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Spiral elements in high-rise buildings are well known, and their spirality renders them chiral as well, with either right-handedness (following the example of the screw) or left-handedness, as in the case of Calatrava's Chicago Spire (fig. 3a). The opposite handedness (fig. 3b) is a realistic possibility and could have been selected for actual construction. Chiral buildings are quite common, much beyond spiral high-rise buildings, and yet we are unaware of a routine consideration of the following basic question: Having designed a building which is chiral, which form should be constructed – the left-handed or the right-handed one? That question, as we show, is of importance from two points of view: First, the difference in aesthetic perception between left and right objects; and second, the relation between a chiral building to its natural and urban surroundings and environment, which, in most cases are chiral as well. In chemistry, biology and physics, the investigation of the effects of handedness is central; for example, the fact that our bodies are built from left-handed chiral amino acids and not from right handed ones, continues to occupy the life sciences since it was first discovered. In architecture, which relies heavily on shape, form and symmetry, and which has had a lively discussion of the role of asymmetry (see for instance [Vollers 2001; Rodrigo 2008; Patt 2010]), considerations of chirality – a key structural descriptor – are practically non-existent. It is the aim of this report to familiarize the architects' community with chirality and with situations were chirality becomes relevant as a design consideration.

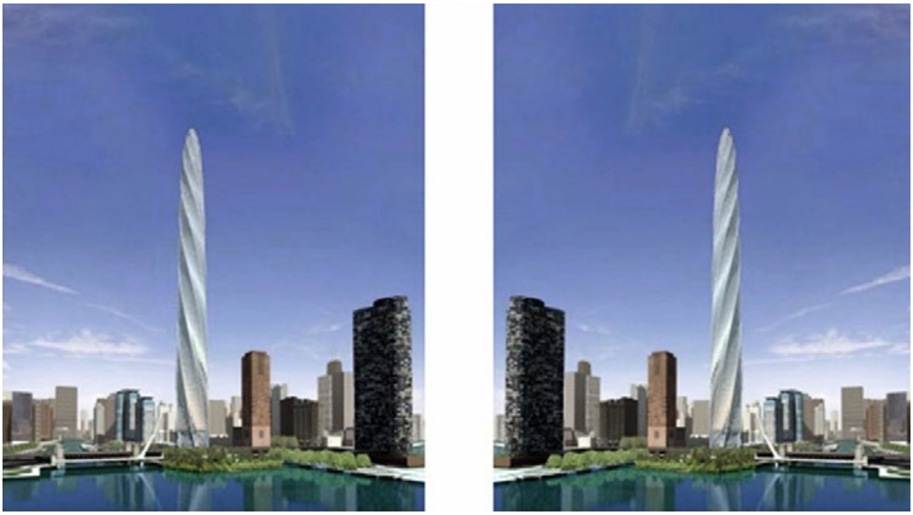

Fig. 3. Calatrava's Chicago Spire (on the left) is a chiral building; it is left-handed. The virtual right-handed optional enantiomer is shown on the right. The two enantiomers are mirror images of each other (as are the examples shown in figs. 1 and 2)

2 Chirality for architects

Enantiomers and the lack of mirror symmetry

Our focus here is on the property of a structure to have, in principle, a left form and a right form. A pair of structures of opposite handedness are termed *enantiomers*. *Enantiomeric pairs* are shown in figs 1-3. A first inherent property of chirality is that one enantiomer is a mirror image of the other. To convince yourself that this is indeed the case, use an imaginary mirror which is perpendicular to the plane of the page and is placed between the enantiomers (to see it in fig. 2a, first turn one of the coordinates systems upside down). A second, related property is that enantiomers cannot be brought to fully overlap with each other; try to do it with your hands to be convinced. In fact, the non-coincidence of an object with its mirror image has been used as a definition of chirality. We therefore see that enantiomers are on one hand very similar, but on the other hand very different: they are similar because they are reflections of each other; they are different because they cannot overlap with each other, that is, they are not superimposable.

The inverse statement therefore defines achirality: If an object does coincide fully with its mirror image it is not chiral, that is, it is *achiral*. In architectural history this has been by far the prevalent case: From the early pyramids, to the Greek Pantheon, to the Taj Mahal, to the Empire State building (fig. 4), all are achiral, that is, they do not have distinctive left and right forms, and they do coincide with their mirror image.

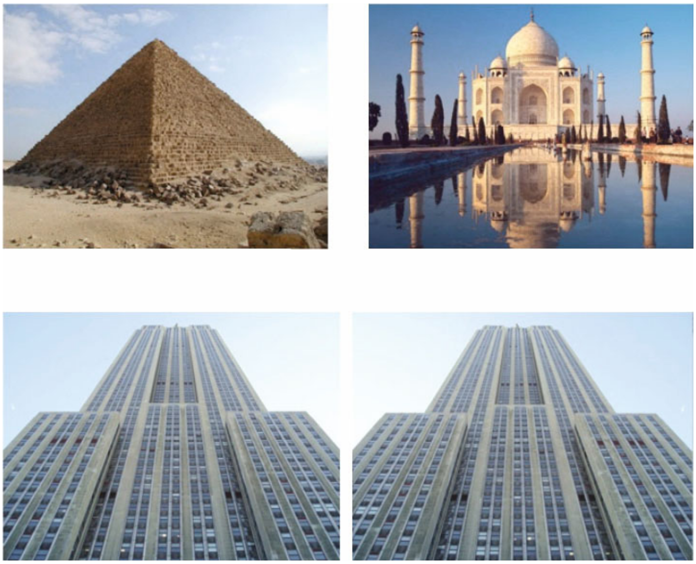

Fig. 4. Architecture has been governed by achiral structures: these do not have left and right forms, and they coincide with their mirror image (the original Empire State building is on the left)

So when does an object coincide with its mirror image? or, what is characteristic of a structure which is achiral? Note that the structures in fig. 4 are highly symmetric; and indeed, for an object to be achiral it has to have mirror symmetry, also known as reflection symmetry and bilateral symmetry, which bisects the object into two similar halves (in all cases of fig. 4 it is an imaginary vertical line that passes through the center and top of the structure).[2] We therefore have at hand yet another simple criterion for identifying chiral objects: An object is chiral if it does not have mirror symmetry – indeed, none of the objects in figs 1-3, has that symmetry. Although spirality is a major source of chirality in architecture (fig. 5), from these definitions and properties it follows that chirality is not limited to helical structures, but is a property of any structure which is devoid of mirror symmetry. A few examples are shown in fig. 6. As already noted in Section 1, the realization of chiral objects need not be in both enantiomers; it is enough to have one of the enantiomers in reality, as is usually the case in architecture. Therefore, a distinction is made between the real chiral object (the real enantiomer) and its virtual enantiomer (which may be obtained, for instance, by picture reversal, as done in fig. 3).

Fig. 5. Spirality is a major source of chirality in architecture: The right-handed Mode Gakuken spiral tower (Nagoya, above left); the left-handed La Défense tower model (Wilmotte et Associés, Paris, above right); Calatrava's HSB Turning Torso building (Malmö, Sweden, below left). A screw is deliberately manufactured as right-handed but why was the Blossoming Dubai model (Petra Architects, Greece, below right) designed as left-handed?

Fig. 6. Chirality is not limited to helical structures, but is a property of any structure which is devoid of mirror symmetry: above left) Frank Gehry's InterActiveCorp worldheadquarters, New York; above right) Guggenheim Museum, Bilbao; below left) SANAA's Rolex Learning Center, Switzerland; below right) SANAA's Museum of Contemporary Art, New York

Induction of chirality: the façade, illumination and shadows, motion and dynamics

Having the definitions of chirality and enantiomers at hand, it is clear now that chirality can be induced in buildings which are achiral (in fact, the majority of buildings) – one only needs to break the bilateral symmetry. A common way to break that symmetry is by adding visual information to the façade of the structure: placing windows in an asymmetric way (fig. 7, above), or using tiles to break the symmetry (fig. 7, below), are two of a variety of similar options. In both examples, an achiral box-shaped construction was pierced with elements which induce chirality in the whole. Light (sunlight, internal or external illumination), shadows and reflections all play an important role in inducing visual chirality in objects which are not chiral – see section 4, below.

Assigning a handedness label: Is the Guggenheim Museum a left- or right-handed building?

Once chirality has been established, the question may arise if the object should be labeled "left" or "right"; and indeed it is not more than a label. Left/right labeling is based on an agreed convention: We all agree which of two hands is a left hand and which is right; or which screw is left-handed and which is right-handed; or which amino-acid is left-handed and so on. Common to all of these examples is the fact that such an agreed-upon convention exists.

Fig. 7. Chirality can be induced in achiral buildings by breaking the bilateral symmetry with façade features, such as windows (above) or large tiles (below). Above left) Zollverein School of Management and Design, Essen, by SANAA; above right) The Public, West Bromwich, by Will Alsop; c-d, below) TID Tower, Tirana, Albania by the design practice 51N4E. The real building is on the left; the virtual enantiomer is on the right

However, for many chiral objects – see for instance fig. 6 – no convention exists; yet this lack of convention does not take away from the object the inherent property of being chiral. In such cases one has the freedom to label that chiral object as one wishes – we can decide to call it "left", or "enantiomer 1", and so on, and then the counter mirror image will be "right" or enantiomer 2, and so on. Most of the chiral objects in architecture fall into this category; furthermore, since most of the chiral architectural constructs are single enantiomers, the labeling is practical for the early design stages, when one wishes to select which of the two options will be realized. This selection procedure has been, at best, very rarely practiced; an architect will routinely rotate the model until an optimal angle is reached, but rarely reflects it to obtain and examine the enantiomer and its relation to its environment (see below).

Chirality of objects which have an element of randomness: the environment

Environmental chirality is crucial to our discussion in Section 3 (following). In general, in natural and urban environments, chirality prevails, that is, landscapes and urban layouts lack mirror symmetry (fig. 8). The main reason for this distinction is that such environments have a certain level of randomness; the chance that under the (partial) influence of randomness exact symmetry will be obtained, is extremely small.[3] Chirality which originates from randomness is special from the following point of view: hands are chiral (fig. 1) because there is an inherent biological process that forms them in that shape; this kind of chirality is termed *inherent chirality* [Katzenelson et al. 1996]. In contrast, there is nothing inherently chiral in the process that forms the riverbed; in such cases one talks about *incidental chirality*.

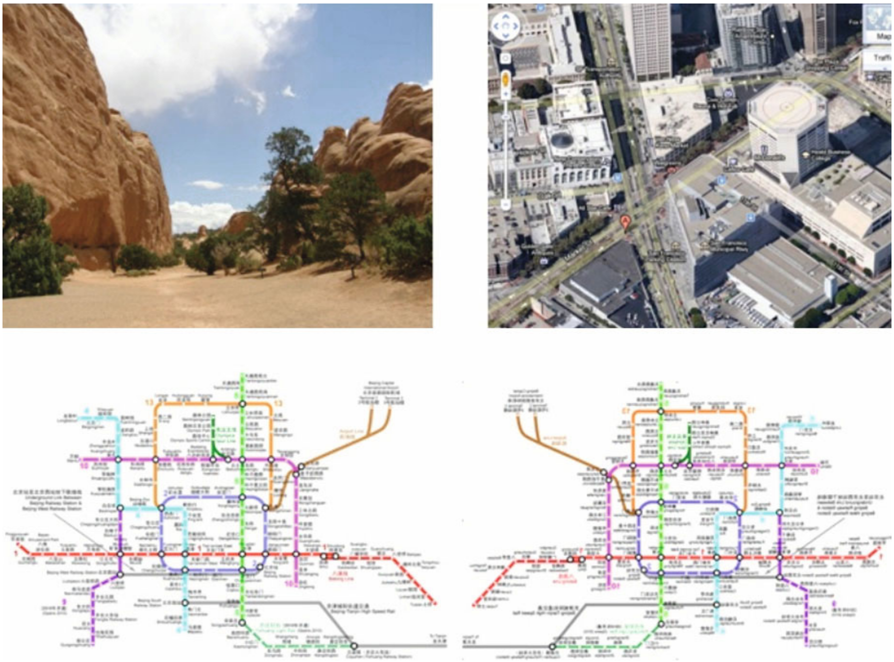

Fig. 8. Natural (above left, Arches Park, Utah) and urban (above right, San-Francisco) environments are always chiral – they do not have bilateral symmetry. Below) The two enantiomers of the Beijing subway map (note that this is chirality in two dimensions)

3 The relevance of chirality considerations in architecture

Are chirality considerations of relevance to architecture? Is the choice of a specific enantiomer important? A standard screw is deliberately manufactured as right-handed but why was Blossoming Dubai (fig. 5) modeled as left-handed? Should Petra Architects, who designed it, have considered the two options? In this section we present arguments which suggest that, yes, chirality considerations are relevant, considering, first, that right- and left-handed versions of the same building are entities which may be perceived differently; and second, that right- and left-handed versions correspond with their environment, both natural and urban, in a different ways. Here are the details.

On the perception difference between enantiomers

There is a difference in how we perceive left or right objects. On the molecular-scale, this is a well-known fact. For instance, the left- and right-handed forms of the fragrant molecule carvone (fig. 9), provoke completely different olfactory feelings: while the right form (marked *R*-(–)-carvone) smells like spearmint, the left form (*S*-(+)-carvone) smells like caraway [Leitereg et al. 1971]. This left-right distinction is particularly important in pharmacology, because chiral drugs – and many are indeed chiral – must be used in only one of their enantiomeric forms – either the left enantiomer or the right, but not both.

The reason for this strict injunction is that the "wrong" handedness version is perceived and processed by the body differently then the therapeutic handedness, to the degree that the wrong one can be very toxic. Thalidomide is a notorious example of the devastating effects of contaminating the therapeutic enantiomer with the opposite enantiomer (fig. 9).

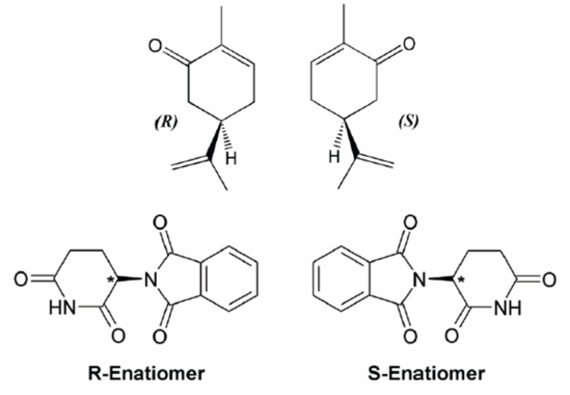

Fig. 9. Chirality is highly relevant and important in biochemistry and medicine, because right- and left-handed molecules are perceived completely different. Above) The natural molecule carvone has a spearmint aroma for its right form (R), but a caraway smell for the left-enantiomer (denoted S in chemistry); below) the R-enantiomer of Thalidomide, a synthetic drug, is a sedative, but the S-enantiomer is highly toxic

The reason for the difference in perception and processing of left and right input is the fact that the perceiving entity – the receptor – is chiral as well.

To understand this phenomenon (and its relevance to architecture) let us consider the interaction between hands and gloves, and specifically between each hand – left hand (Lh) or right hand (Rh), and a right-glove (Rg). Let us now compare the two options of interaction: First, the interaction between the right hand and the right glove – Rh-Rg: the fingers of Rh, the input, identify easily the corresponding finger sleeves of Rg – the perception – and they slip easily (the process) into Rg, feeling comfortable in it. The second possible interaction is between the left hand with the same right glove – Lh-Rg: now the interaction between the two is quite different, and Lh fits only very awkwardly into Rg. All biological receptors are chiral and therefore possess this type of different interactions with either left or right molecules; that is why left and right carvone smell differently, and that is why the two enantiomers of thalidomide affect the body so differently. For our purpose we focus on a very special biological receptor/processor – *the brain*.

Two properties of the brain are important here: 1) it is a receptor and processor of *information*, and in particular, for visual information; 2) it is a chiral receptor/processor. At first glance it seems the brain has mirror symmetry between its two halves (the hemispheres), but this is far from true: Not only are the fine details of the geometry of the winding lobes different, but the function of the two hemispheres is completely different (the literature on this basic structural property of the brain is voluminous; see for instance [Wang et al. 2007; Magnus and Laeng 2006; Goertz and Goertz 2004]). Let us then analyze what happens when this special chiral receptor/processor (let us denote it arbitrarily as a "right-glove, Rg") interacts with a chiral visual input which may be either right (the "right-hand, Rh") or left ("Lh"): left-handed and right-handed versions of the same object are perceived differently, again, because Rh-Rg and Lh-Rg are completely different interactions. Studies in psychology of aesthetics have indeed addressed the issue of differences in the perception of left and right objects, and found that such differences do exist (for instance [Levy 1976; Christman and Pinger 1997; Branndt and MacKavey 1981]). For instance, here are some citations from Andrew Mead and John McLaughlin: "When some pictures are mirror reversed [that is, when one creates the virtual enantiomer of the original picture] aesthetic evaluation of them change dramatically" [1992: 300]; "When a painting is viewed in a mirror…even the meaning can change…" [1992: 300]; "…painting containing left-to-right cues were preferred [over the enantiomeric right-to-left cues]…" [1992: 305]. Fig. 10 gives a feeling of what these statements mean.

Fig. 10. The brain is a chiral information-processing receptor, and perceives left-handed and right-handed objects differently: left-to-right cue (left) compared with the enantiomeric right-to-left cue

We are unaware of deliberate evaluation of the aesthetic appeal and visual impact of left vs. right architectural objects in a decision-making process regarding which of the two possible enantiomers of a building will be constructed in practice.

A chiral building in a chiral environment

The second major reason for the relevance of chirality considerations to architecture relates to the chirality of the environment in which the structure is placed, discussed above (fig. 9). Following the previous section where we concentrated on the different interactions of left and right versions of the same object, we now follow a similar rational by focusing on the interaction of enantiomeric versions of a building with its chiral environment. Suppose that our specific environment is a "right glove", Rg, and that the two options we have for our chiral building, are right- and left-handed spirals, Rh and Lh; then placing either Rh or Lh building in an Rg environment amounts to creating two distinctly different building-environment correspondences, Rh-Rg and Lh-Rg[4] (fig. 11). The correspondence of a building with its immediate environment is a key issue in architectural design, but again, we are unaware of considerations which deliberately compare left and right versions from that point of view.

4 Conclusion and a brief mention of some advanced topics

Architecture relies heavily on shape and form. A key structural concept that seems to be missing in architectural design is chirality, and the practice of selection between the inherently different left or right versions of the same form. We believe it should be embraced at least for two reasons: first, left and right forms are perceived as communicating different visual messages, and give rise to different aesthetic appeals.

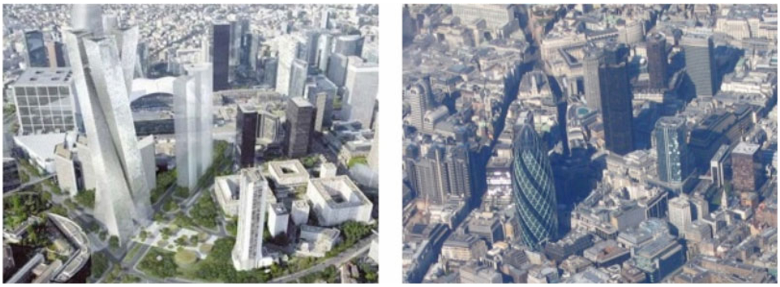

Fig. 11. The chiral left-handed La Défense tower model (on the left; see also fig. 5), and the chiral left-handed Gherkin building (London; on the right) are examples of chiral buildings in chiral environments. The right-handed spiral versions would have corresponded differently with these environments

Second, as most environments in which a building is placed are chiral, left or right forms of that building interact differently with that environment.

In order not to exceed the self-imposed limit of focusing on the basics of chirality, more advanced topics will be treated in a future paper. Here is a brief mention of these topics.

There has been an implicit statement in all of the above: Chirality is a structural property which either exists or not. However, let us compare two of Calatrava's buildings, the Turning Torso (fig. 5, below) and the Chicago Spire (fig. 3): the former one is only twisted 90° while in the latter is a fully developed spiral; our intuition is that Chicago Spire has a higher degree of chirality than the Turning Torso building. Changes in level of chirality are also due to the fact that chirality depends on the resolution of observation, for instance, on the distance from which they are observed. To observe the chiral arrangement of tiles in fig. 7, one has to approach the building to a distance where these details are seen – from farther away, the building looks to be an achiral box, and from very close, one can see again only an achiral single tile. We therefore propose that not only chirality per se should be considered, but also its degree. Computational tools for the quantitative evaluation of chirality exist; see [CCM].

Yet another concept to be further developed is that chirality may be a dynamic property. Since quite often illumination details change with time – due not only to the motion of the sun, but also the wind-driven motion of scattered clouds, night illumination and darkening of windows and so on – another interesting element is added here to the discussion of chirality, namely its dynamics. We term this situation *dynamic chirality*. The dynamics can be either of the object itself – rotating structures – or the dynamics can be in the surrounding environment. Dynamic chirality and degree of chirality are linked: Temporal changes can even turn a left-handed object into a right-handed object, as in the interesting concept of "dynamic towers", proposed by David Fisher (http://en.wikipedia.org/wiki/David_Fisher_(architect)#Dynamic_Tower). These and other topics which bring chirality and architecture under the same umbrella, will be described elsewhere.

Acknowledgment

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Notes

1. The word *chirality* is derived from the Greek, χειρ (*kheir*), "hand". It is pronounced *kai-ralley-ty*.
2. There are other symmetries that render an object achiral (such as inversion symmetry), but these are less relevant to architecture.
3. It is an interesting question – beyond the scope of this report – why man-made objects are so commonly symmetrical, and why a certain level of randomness is not allowed in their production processes.
4. Note that in general, the pair of interactions Rh-Rg/Lh-Rg is equivalent to the pair Lh-Lg/Rh-Lg.; and that the two pairs are enantiomers of each other.

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About the authors

David Avnir is a Chemistry Professor at the Institute of Chemistry, The Hebrew University of Jerusalem, where he received all his academic education, and where he is currently head of the Graduates Authority in the Experimental Sciences. His current scientific activities include theoretical and experimental aspects of chirality, theoretical studies in symmetry, and a variety of topics in materials science including organically doped metals, sol-gel organic hybrid materials, and biomaterials. He has co-authored more than 340 scientific papers, and holds several key-patents in materials science. His publications have received more than 13,000 citations in over 8000 articles, with an h citation index of 59. He is co-founder of Sol-Gel Technologies, Inc. Some of his recent citations include the 2011 Israel Chemical Society Prize, his election to the Academia Europaea, and his placement on the Hebrew University's "Wall of the Innovators" (2012).

Dirk Huylebrouck obtained his Ph.D. in linear algebra from the University of Ghent, Belgium, in 1986. He spent nine years in Congo, until an official diplomatic incident interrupted his stay. This propelled him to the European Division of Maryland University, until his American (military)

students went to Iraq. He returned to Africa, to Burundi, but only for three years, because of the genocide in neighboring Rwanda. Since 1996, he has taught in the Department of Architecture Sint-Lucas, Brussels-Ghent, Belgium. He has edited the column "The Mathematical Tourist" in *The Mathematical Intelligencer* since 1997. In 2002 he won the "Lester Ford Award" for best mathematical paper published in *The American Mathematical Monthly*, but he is probably better known for his re-discovery of the Ishango rods (the oldest mathematical objects) or for having revealed errors in the mathematics of Leonardo da Vinci.