of how the essays will be marked, and a warning against plagiarism. Surely this is more than the general reader needs to know.

There is a huge amount of information here. It is a book for a mathematically literate audience wanting to learn some history, *not* vice versa. The small number of mathematical exercises at the end of each chapter are challenging. The individual chapters are well written with a good balance of mathematical and historical interest. Perhaps a second edition can improve the framing of the material.

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P. MACGREGOR
Published by Cambridge University Press
46 Heatherslade Road, Swansea, SA3 2DD
on behalf of The Mathematical Association
e-mail: *macgregor.pg@googlemail.com*

Formulations: architecture, mathematics, culture by Andrew Witt, pp. 428, £23.15 (paper), ISBN 978-0-262-54300-2, Massachusetts Institute of Technology Press (2021)

The British architect Philip Steadman reflected on architects 'being a sort of jackdaw people' in their use of the arts and sciences. Taking a grand tour of their activities in this regard, the author of this book covers much ground both in terms of broad content and historical depth. The book is a celebration of the close connection between mathematics, art and architecture.

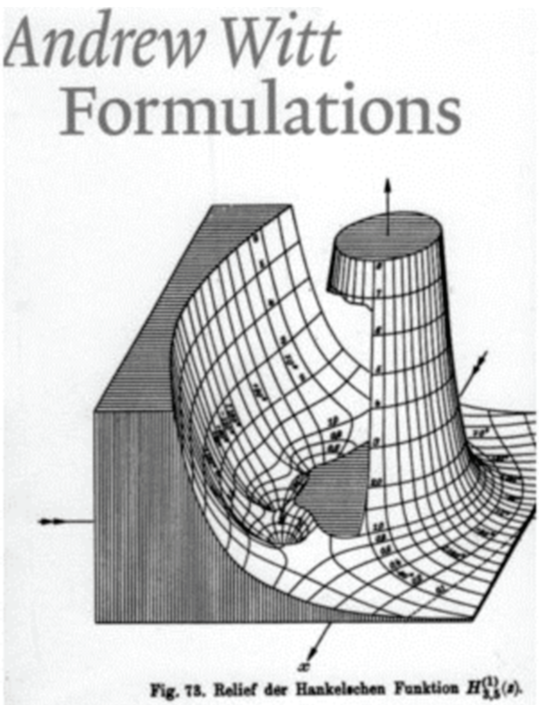

FIGURE 1: The book's front cover

The impression made by picking up this book for the first time might be misleading. On its cover is a three-dimensional graph of the modulus of a Hankel function taken from Jahnke and Emde's catalogue of functions (1945).

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The Hankel graph is not treated here as mathematics but as part of a surrealist collage by the German artist Max Ernst as a ‘suggestive nexus of speculative and tangible realms’. The way the author writes about it indicative of the book's flavour: ‘A paradigmatic case of the use of mathematical forms as surreal found objects is an exquisite 1948 collage *La fable de la souris de Milo*, an image of the Louvre's Venus de Milo grafted to a differential surface taken directly from Jahnke and Emde's catalogue of geometric surfaces’. And a little later he writes, this collage ‘bears all the tensions and dualisms of the relationship between art and science in a single strange image. The uncanny confrontation of a classical mythological statue and a modern mathematical surface makes those polarities tangible and specific’.

It is obvious that architects, who design in three dimensions, will be concerned with geometry and also will be inevitably influenced by prevailing cultural forces. The way these aspects have been played out and architectural design has evolved is the subject matter of the book. It is an interdisciplinary text in which the author sees himself as a ‘meta-architect’. It makes broad connections between seemingly disparate areas in the style of Douglas Hofstadter's *Gödel, Escher, Bach* (1979).

The author is a professor of Practice in Architecture at the Harvard Graduate School of Design. He has a bachelor's degree in mathematics and an Erdős number 3 but his interests are wide-ranging and this book, reaching out from architecture to mathematics, reflects them.

The thread of Visualisation as the key to technological advances runs throughout the book. The presentation is broadly chronological. Mathematics has been in the vanguard and curiously much of it that impinges on architecture comes from the nineteenth century: geometry typically post-Euclid but pre-New Math. Architects see value in ruled surfaces, developable surfaces, minimal surfaces and string models, subjects dear to our mathematical grandparents. The author traces the importance of these developments for architecture through such movements as Felix Klein's Erlangen Program and the physical models manufactured by the Brill brothers in Germany, models which can now be seen in London's Science Museum, or actually made using Cundy and Rollett's classic *Mathematical Models* (1951). Witt's book has a broad sweep, and mathematical readers will find in its pages names they will recognise: Euler, Möbius, Riemann Hilbert make entrances and quick exits.

The geometers of the nineteenth century struggled with attempts to ‘see’ the objects they were dealing with, such as Cayley's attempt in the 1840s to see the lines on a cubic surface which turned out to look like a random bundle of sticks. James Clerk Maxwell constructed hand-drawn stereograms to illustrate spherical curves as early as 1868. In the pathway to visualisation, pioneers made fascinating use of stereo imagery and this is described and illustrated with their stereograms. We are told how the work of *The Mathematical Gazette's* own E. M. Langley in his *Solid Geometry through the Stereoscope* (1907) led to the kinds of development which interested the conceptual artists Marcel Duchamp and Naum Gabo. Some artists worked overtly with mathematics, for example Georges Vantongerloo's painting entitled: *Composition émanante de l'équation* $y = -ax^2 + bx + 18$. No less interesting to the author are the machines used to make drawings and three-dimensional models (maquettes). Antecedents of the spirograph are discussed and so too are the mechanical contraptions used to measure space using trigonometry.

Perhaps the best-known mathematician/artist/architect is Le Corbusier, who based his work on symmetry and often appealed to the golden ratio. Here the author castigates those historians and popularisers for reducing geometry in architecture to such ‘mystic associations’. Apart from Le Corbusier, there has been a raft of mathematically trained individuals who came to architecture from this background.

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Steadman and his friend Lionel March have been noted, but Zaha Hadid, known from her use of mathematical thinking, went under the author's radar. In her designs mathematics was put to good use. In particular Hadid designed the Aquatics Centre for the London Olympics with a revolutionary geometric design, notably its wave-like roof with detachable wings. In her design for the mathematics gallery for the Science Museum in South Kensington a statically suspended Handley-Page aircraft simulated exotic surfaces generated by turbulence as if in a wind-tunnel. While these designs won prizes, emblematic examples of mathematics in architecture are all around us. In Britain we may think of the water tower in Cockfosters, North London, by Percy and Milne, based on the geometry of the hyperboloid of one sheet. Wider recognition of architecture as an artistic endeavour is recognised by the allocation of a salon dedicated to architectural models at the annual Summer Exhibition at London's Royal Academy.

In this book there is no attempt to engage with the mathematical technicalities as there was with March and Steadman's classic *Geometry of Environment* (1971). I must admit I struggled with the meaning of the occasional paragraph, for instance in explaining the relationship between the practitioners of mathematics and architecture: ‘For the architect, the uniquely expansive symbolic language of mathematics encodes polarities of geometry and perception, science and aesthetics, culture and nature, bringing intellectual dichotomies into intimate creative contact’.

Following on from classical geometry, architects at the beginning of the twentieth century embraced the young subject of Topology, and here the author highlights the drive for classification. He observes Tait's classification of knots by crossing numbers (in the same vein, he might have included Thomas P. Kirkman's classification of convex polyhedra by the number of faces made). Due attention is paid to crystallography as an inspiration for architects. Here we meet Klein’s assistant Walther Dyck, a mathematician recognised for his work in group theory but here discussed in the context of geometric models and instruments.

The last chapter is entitled ‘Dabblers and Virtuosos’ and in it the author discusses the different perspectives of architects and mathematicians. The mathematician might be suspicious of architects who in their jackdaw fashion pick up and just as easily discard mathematical ideas with an assumed authority, ideas which the mathematician took years to assimilate. No research mathematician of today can be a professional architect, and the reverse is also true; the mathematician strives to understand geometry and the architect to use it. It was different in the seventeenth century. Was Christopher Wren who designed St Paul's Cathedral in London a dabbler or a virtuoso? In his lifetime he also made a mark in mathematics. We should not fall back, as the author does, on Derek Whiteside's assessment of seeing Wren as a ‘skilled dabbler, an amateur’ in mathematics.

The author has written a fascinating study. There are many diagrams, photographs, and endnotes, which go together to make a substantial body of work. It will certainly deserve a second and subsequent rereading. Its interdisciplinary nature will strongly remind mathematicians that their subject is not just an abstract study detached from arts and science; in particular, as is shown in this book, it occupies a central place in the design of architecture. Moreover, its mathematical practitioners, as shown in this book, have often been in the vanguard of progress.

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TONY CRILLY
10 Lemsford Road, St Albans,
Hertfordshire AL1 3PB
e-mail: *tonycrilly42@gmail.com*

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