

Paper-folding and Digital Systems: A New Approach to Architectural Logic and Structural Design

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Abstract. How does an architect use a sheet of paper and a digital system?

Paper is a two-dimensional support on which the architect carries out the creative drawing process. However, if we fold the paper, the architect is now able to begin to manipulate and even create space.

A digital system, to put it succinctly, uses “*electronic technology to manage, store and process information*” allowing its user to work quickly and flexibly.

So what is the relationship between these two tools? At first sight, none, as they exist independently. However, the fusion of the two has powerful consequences, as can be seen in the work of the architect Michael Hansmeyer who manages to incorporate all the beauty of the action of folding through a digital sheet with the help of a computer, where the final result is a shape that approaches a real application at an architectural level – Proto-architecture.

Paper-folding, or *origami* as it is usually known, can be taken out of its original role and turned into a digital language.

This paper is part of wider ongoing research which takes in paper architectures, morphogenesis and parametric design.

In our previous articles (Kong 2014, and Kong & Calretas 2014), we identified the role of paper-folding as a tool in the creative process of architecture. Taking this one step further, we now intend to focus on the relationship between paper-folding and digital systems, treating it as a methodology in a new approach to architectural logic and structural design.

Keywords: paper folding, *origami*, digital systems, generative design, parametric design, morphogenesis, proto-architecture.

1. Introduction: Paper, Digital Systems and The Architect

Paper is a two-dimensional support on which the architect carries out the creative drawing process.[1] However, this is not its only use. If we fold the paper, the architect is now able to begin to manipulate and even create space. After all, by folding we transform one surface into several, and thus achieve three-dimensionality.

So the architect as a professional who controls the exploitation of space through drawing and other representational systems must be attentive to advances in technology, and to what these can provide. It is an inherent characteristic of digital systems that they can amplify any ability, so the training of a present-day

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Fig.1 Hansmeyer's Subdivided Columns Information on <http://faumfablab.wordpress.com/category/fabrication/>

architect must ensure that he or she is proficient in the use of the hardware and software tools at his or her disposal.

How does an architect use a sheet of paper and a digital system?

Rui Vaz[2] says that a digital system makes use of “*electronic technology to manage, store and process information*”[3], and goes on to say:

“Digital systems help us to calculate, (...), combine and relate, and augment our ability to choose, order, classify and select, by expanding our perceptive powers. The computer makes it easier to produce, reproduce and transmit cultural work, potentially accelerating intellectual advances and opening up cultural access to unprecedented forms. It can expand enormously our capacity for selection, memory, perception and calculation, and has the potential to increase the intelligence of each one of us.”[4].

The value of these two tools available to the architect has been amply demonstrated, so what in fact is the relationship between paper and digital systems?

2. Methodology: Paper-folding as a digital language

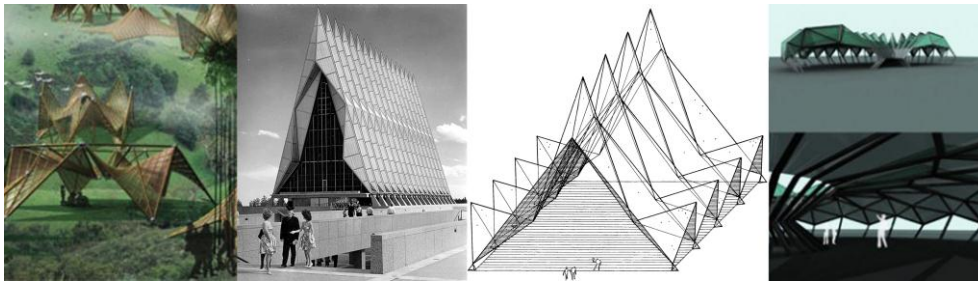
Paper and digital systems are tools that have emerged to assist the natural and intellectual development of Mankind: “*The eye and the hand are the mother and father of artistic activity. Drawing, painting and modelling are types of human motor behaviour, and it can be supposed that they developed out of two older, more general types of behaviour – expressive and descriptive movement.*”[5].

Beyond this common link, there does not appear to be any other direct relationship. After all, these two tools exist independently of each other. However, experiments carried out so far show that their fusion turns out to be both valuable and prolific.

As an example of this connection, we can look at the experiments conducted by the architect Michael Hansmeyer[6], which embody a digital poetry with the roots of its inspiration in both morphogenesis and *origami*, in which the final result is a structural form that approaches a real application at an architectural level – proto-architecture. When he employs the paradigms of *origami* and generative design, Hansmeyer is proposing a new approach to project praxis in the generation of new structures of an organic nature. The principle that Hansmeyer uses is based on the analogy between the folding of a sheet of paper (a simple, flat geometric surface) and the folding of the faces of a volume or solid, thus transforming its faces into various surfaces equivalent to the original sheet of paper. In this way, Hansmeyer transforms the surfaces of the volumes into surfaces of high complexity through geometric and morphogenerative processes analogous to those existing in Nature. In the final analysis, these high levels of complexity would be difficult to achieve without recourse to a digital thought[7]. Fig.1.

Paper-folding, or *origami*, thus has the ability to abandon its original support and metamorphose into a digital language.

3. Analysis: Digital language of *origami*: inspiration or parametric/generative design?



From to the Left to Right Fig. 2: Folded Bamboo Houses | Fig. 3: American Air Cadets Academy Chapel of the U.S.A. | Fig. 4: A Folded Plate System Surface | Fig. 5: Paper House - Information on <http://cubeme.com/blog/2008/11/03/folded-bamboo-and-paper-housestemporary-shelters-for-earthquake's-homeless-by-ming-tang/>; American Air Cadets Academy Chapel of the U.S.A. Information on <http://www.archives.gov/global-pages/larger-image.html?i=/denver/holdings/images/chapel-1.jpg&c=/denver/holdings/images/chapel.caption.html> | Fig. 4: A Folded Plate System Surface H. Engel, *Sistemas Estructurais*. Barcelona: Editorial Gustavo Gili. 2001, p. 226; Fig. 5: Paper House Information on www.archdaily.com/8124/folded-bamboo-paper-house-ming-tang/

We need to be aware of the evolutionary difference that a final work originating in *origami* may have. It can now be taken for granted that these days the architect uses computers to assist him in his work. However, how might the architect think about the final product when he or she uses *origami* as a procedural methodology in digital systems?

- Hypothesis A: It is a question of an idea reproduced simply by visual inspiration **without** an apparent base of intrinsic geometry coinciding with the original *origami*;
- Hypothesis B: an idea reproduced simply by visual inspiration **with** an apparent base of intrinsic geometry coinciding with the original *origami*;
- Hypothesis C: an idea based on an intrinsic geometry that coincides with the original *origami* with the present help of digital systems through so-called parametric design[8];
- Hypothesis D: an idea based on an intrinsic geometry that coincides with the original *origami* with the present help of digital systems through so-called generative design[9].

If we are aware of this, we can produce classificatory terminology which may or must arise in the future. The four hypotheses are valid when *origami* is used as a project praxis (more on this subject Kong 2014, and Kong & Calretas 2014)[10].

4. Discussion: Origami digital language of - inspiration or parametric/generative design?

In the case of Hypothesis A, the *Folded Bamboo Houses*[11] project of the architect Ming Tang is a paradigmatic example. If we take as a reference the study of Heino Engel (2001) in “*Structural Systems*”[12] and if we analyze Ming Tang’s proposal, we can see that these shelters created in response to a catastrophe in China are structures inspired in the form of *origami* but derive from the behavioural aspect of the hyperbolic paraboloid[13] and vaulted grids[14] in conjunction with the gridshell[15] (concept that was not found in the Engle’s book). In this way, Tang makes use of the flexible nature of the paper fold to reach other structural systems: the new form allows an escape from the original structure of *origami* and acquires a structural behaviour different from the geometry intrinsic to this, Fig.2.

For hypothesis B, the example given is the American Air Academy Chapel of the USA, by Walter Netsch[16]. If we put Netsch’s proposal next to our analysis of the studies of Engel[17], we can identify the use of a behavioural system which originates in paper-folding. The system is categorised by Folded Plate System[18] and the observation of its representative drawings are clearly an *origami*. However, as the building was completed in 1962, at the dawn of the computer, there can hardly have been a digital influence. Rather, it is a clear mathematical-geometric structure, Fig.3.

In the case of hypothesis C, Ming Tang proposes an alternative approach to his Folded Bamboo Houses with a project called Paper House[19] whose name alluded directly to the material that underlies its principle. This dwelling reveals a behavioural system originating in paper-folding according to various analyses. We observe that this structure lies within what Heino Engel calls Folded Plates System, too. However, the stages

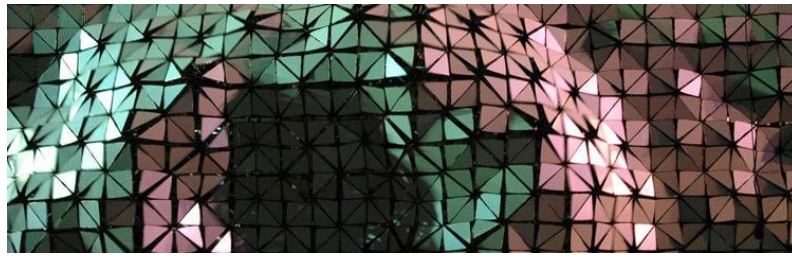


Fig. 6: Mark Goulthorpe's Hypo-Surface Information on <http://www.gdfitcaad2011.altervista.org/diary.html>

of the project appear to have been accompanied by digital systems, finally developed according to algorithms[20] in accordance with parametric thinking, Fig.4.

Finally, in hypothesis D the digital language present in the work of Michael Hansmeyer springs from the concept of folding to replicate systems of morphogenesis[21] associated with processes that exist in nature. Fig.5.

In spite of the fact that *origami* and morphogenesis are different concepts, they may have a common geometric-mathematical basis. *Origami* may give rise to parametric, generative or generative-parametric designs, and morphogenesis gives rise to generative designs. *Origami* may or may not represent morphogenesis and morphogenesis may or may not present a pattern (*tessellation*)[22]. However, both concepts, *origami* and morphogenesis, are present at the dawn of modern architecture and may be linked[23],

5. Results: Proto-architecture and digital thought

We can read in books like the *Architecture of Variation*: “Today, architects around the world are resetting the tools of design and creating a language that incorporates variation and complexity. (...) design techniques and computer-based fabrication technologies (...) give us a first peek into what the future of architecture may look like.”[24].

In the transcription of this 2009 book there are reports of the existence of a complex language based on computational techniques which may give rise to an architecture that still does not completely exist. It exists in thought and imagination, and in theory, but it has not reached the stage of maturity which will allow its basic concepts to become widespread and consolidated. The preliminary attempts in this direction so far by researchers all over the world are designated proto-architectures, that is, experimental or early architectures[25].

The digital thought associated with paper-folding is one of the ways these still embryonic architectures may be achieved. In this respect, Hansmeyer is presently working to give physical realization to his pieces, but comes up against long execution times and the restrictions imposed by his materials. The limits that Hansmeyer has found are experienced by explorers travelling along these complex paths. Many of these experiments have been the subject of development in several North American and European universities. In the case of MIT-Massachusetts Institute of Technology[26], such names as Neri Oxman, Meejin Yoon and Mark Goulthorpe stand out[27].

In fact, researchers such as Neri Oxman, who was responsible for Mediated Matter[28], have centred their efforts in the search for other ways of imparting materiality to architecture and of changing the way of thinking about materials, which may indirectly meet Hansmeyer's needs. Alongside this, Meejin Yoon, who was responsible for Hower+Yoon Architecture[29], maintains that environments experienced by us have to be more intelligent, interactive and flexible with the public. Mark Goulthorpe, founder of dECi Architects, Hypo surface Coro and Zero+[30], Fig. 6, explores the algorithms to get great machines working in order to accelerate the pace of the construction industry

6. Conclusion

In conclusion, all these researchers are working in apparently different areas, but in fact they are all contributing to the building up of a corpus, as it were, in layers, that is to say, in parallel research but all with

digital systems in common. So they are all globally contributing to the creation of a new *modus operandi* in the shape of understanding and designing methodologically the process of architecture on a global scale. [31]

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