# Leaving Flatland behind

## *Algebraic surfaces and the chimaera of pure horizontality in architecture*

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**Abstract.** *We argue that the prevalence of continuous flat floor surfaces in architecture is comprehensible but fallacious, and that this chimaera can be overcome through studying and employing the sculptural potential of algebraic surfaces which suggest spatial possibilities that enrich designers' vocabulary enormously. We continue, deepen and extend research the basics and early results of which were presented at the last two eCAADe conferences in Istanbul and Zürich.We present and discuss a university-based experimental design and research project that demonstrates how Algebraic Surfaces can drastically amplify the so far only tentative exploration of the possibilities of non-flat floor surfaces in Architecture.*
**Keywords.** *Algebraic Geometry; Shape; Sculpture; Design; Tool; Experiment; Methodology; Software.*

### INTRODUCTION

Algebraic surfaces have until recently been out of reach for designers as they are the result of complex mathematical calculations. Today though, the soft- and hardware exists to make them accessible for designers. Hitherto literally un-imaginable objects can now be visualized and manipulated. This in effect means an unprecedented diversity, a cambrian explosion of shapes (Fig 1). They are geometrically and topologically highly complex yet very structured, harmonious and sound. Most prominently, they display many curved parts and are often rather convoluted. This at first sight appears to make them rather difficult to use for architecture. Yet humans in fact have a deep affinity to non-flat surfaces - from the early beginnings of habitation in caves to the way undulating parkscapes are inhabited (Fig 2). Their soft reliefs offer many situations which are used differently: crests as viewpoints, slopes for relaxation or play, swales for gatherings - to name but a few examples.

### NEGLECTING THE NON-HORIZONTAL IN FAVOUR OF THE HORIZONTAL

Non-flat floor surfaces have so far been mostly ignored by architecture. Indeed, horizontality is held as a defining quality of successful architecture, most prominently exemplified, perhaps, in Le Corbusier's Domino House Concept which consists of little else but a series of stacked perfectly flat planes.

We see three main reasons for this negligence: Firstly, architecture for most of its history sought to distance itself from nature, to create a contrast where the man-made stood apart from the found. Natural environments are almost never perfectly flat, so flatness became what architecture strove for. Secondly, flat planes are much easier to build than a

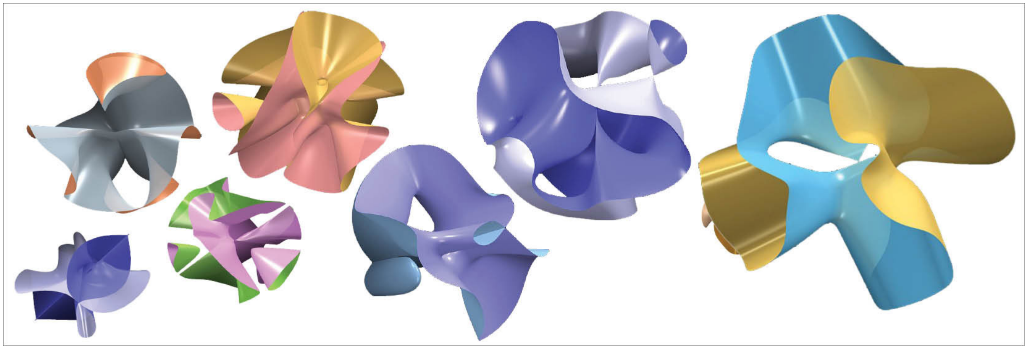


*Figure 1*
*Examples of Algebraic Surfaces with complex geometries and topologies (Eduard Baumann).*

controlled non-flatness, especially in the times of serial mass-production where non-flatness would result in unequal parts - a catastrophe for the methods of serial mass production. Thirdly, a flat plane lends itself to be used uniformly. Non-flat floor plates differentiate various regions and therefore make it difficult to furnish them. Again, the age of serial mass production favoured uniformity over differentiation.

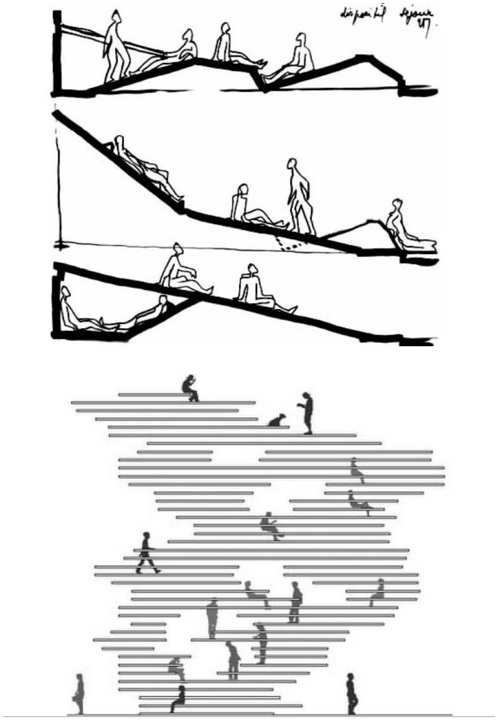
Today, all three reasons no longer hold the importance they once had. Instead of averting from nature to claim a superiority over it, architecture has started to learn from natural environments, to emulate and amplify their qualities. Serial mass production has been superceded by customized mass production and therefore uniformity by differentiation, making it possible not only to design and economically manufacture much more complex geometries than before, but also to design and build manifold different spatial situations. The differences between floor, wall and roof, even between envelope and furnishing, can today be dissolved into diversified surfaces that offer a multiplicity of human use.

## NON-FLAT SURFACES IN 20TH CENTURY ARCHITECTURE

Slowly, architects have started to exploit the possibilities non-flat surfaces offer. In the second half of the 20th century, a strand emerged within modern architecture that seeks to elaborate the potential of non-flat surfaces, starting with Claude Parent's idea of the Oblique and leading, so far, to Kazuyo Sejima's and Ryue Nishizawa's Rolex Learning Centre in Lausanne.

Claude Parent, together with Paul Virilio, in the early 1960s started to argue for the advantages of inclined surfaces: 'The function of the Oblique

*Figure 2*
*Visitors exploring various ways of inhabitating the Tilla Durieux Park in Berlin.*



*Figures 3, 4*
*Claude Parent's inclined planes and Sou Fujimoto's, "Future Primitive House".*

makes the parcours possible. Architecture becomes the carrier of movement; movement is freed from the restraint of defined pathways; the choice of way is open. It's not any more about channelling, but about dispersal; not any more about restraint but exploration.' (Claude Parent, 'Architecture Principe', Fig.03). Towards the end of the 1960s, Verner Panton designed the 'Living Tower', a piece of furniture that invited various form of sitting and lingering. Shortly after, Paolo Mendes da Rocha built Brazil's Pavilion for the Expo 1970 in Osaka as two vertically opposed gently undulating topographies, creating a space that was diversified yet borderless. In 1992, O.M.A.'s competition design proposal for the Jussieu Libraries in Paris consisted of one single inclined surface that was wrapped around itself as a continous ramp, creating a building with many different levels and yet only one floor. In 1995, Farshid Moussavi and Alejandro Zaera-Polo's F.O.A. won the competition for the Yokohama Ferry Terminal with a design that channeled Parent's Oblique and da Rocha's Expo Pavilion into an interwoven topography - although the finished building did not adress the non-horizontal potential as decisively as the competition proposal had. In 2001, Sou Fujimoto proposed his so-called 'Future Primitive House' (Fig 4), a complex multi-leveled space that could be interpretated freely by its users and built a small prototype version of it in 2008 as the 'Final Wooden House'.

In 2006, Toyo Ito effectively recreated a version of da Rocha's Osaka space inside Mies van de Rohe's New National Gallery in Berlin as an exhibition architecture for the 'Berlin-Tokyo/Tokyo-Berlin' exhibition, using a softly undulating topography to create various zones with fuzzy boundaries and juxtaposed an artificial interior landscape with the rigidity and uniformity of van de Rohe's building.

Finally so far, in 2010 the Rolex Learning Center in Lausanne opened, designed and built by Kazuyo Sejima and Ryue Nishizawa following a competition win in 2004 - again, like Ito's exhibition space in Berlin, a large softly undulating topography where various zones of use softly flow into one another without clear boundaries (Fig 5).

## FIVE-STEP DESIGN RESEARCH PROGRAM

To study the potential of non-flat and non-horizontal surfaces, we start experimental design projects with geometries that are unusual to the extreme: algebraic surfaces with the exotic plastic qualities described above.

Our program is divided into five steps: generation, interpretation, adaptation, application and production.

First we generate the surfaces via the software packages Surfer, SingSurf and K3DSurf. All three accept a polynomial as input and output visualizations or/and 3D models. Surfer is restricted to visualization, but highly interactive. SingSurf and K3DSurf are not as interactive but generate 3D data that can be exported as polygon meshes. All programs do

*Figure 5*
*Kazuyo Sejima and Ryue Nishizawa's Rolex Learning Centre building in Lausanne.*

not determine the zero-sets of the polynomials by solving those equations exactly - currently no applicable algorithm for this exists. Instead, they offer approximations, leading to inaccuracies in the models which occasionally show up as imperfections but can be smoothened out and repaired via – amongst others - the Catmull-Clark subdivision surface algorithm available in most mesh modellers and specialized software like MeshLab.

Secondly the surfaces are analyzed in terms of their geometric properties and interpretated as to their architectonic potential. The shapes exhibit exotic sculptural situations that so far are unnamed: connections between different regions that are neither holes nor tunnels and might be named 'passages', self-intersections, singular points that mathematicians call singularities, to name but a few (Fig 6).

In a third step, the algebraic surfaces are adapted, that is modifiyed geometrically to facilitate humans use - i.e. stretched, twisted, compressed. Additionally, they are turned from just surfaces into enclosures through various operations like for example section with a cuboid or thickening of the surface until it becomes a volume (Fig 7).

In a fourth step, experimental architectures are generated by synthesizing the knowledge and know-how acquired in the first three steps (Fig 8).

The last step consists of printing the designs in 3D. While we use the technology to print only models of the designs, it is rapidly progressing to print larger and larger objects, the largest at the moment exceeding telephone box size. While it is as a matter of course not satisfactory to see building construction as a matter of simply printing large objects of a uniform material, for us in our project the printability of the shapes is proof of concept enough insofar that unprecedented, new and never seen or touched objects are transported from the intellectual world of mathematics into a tangible physical reality. (Fig 9)

## FUNCTION INSPIRED BY FORM?

The steps we take in the experimental design project changes the common design procedure of 'Form follows function.' to 'Form inspires function' or even 'Function follows form'. At first, this can be understood as a severe restriction of designers' capabilities, restraining their options to a corset defined by a given algebraic surface. Yet, we understand our project merely as acquiring a new vocabulary. And in any such undertaking, existing new vocables have to be learned, played and experimented with before they can become part of the active vocabulary and used at will and as different situations and problems of formulation necessitate. This can also be seen in the way that children learn and get to know new shapes: nobody is born with a knowledge of eucledian geometry or, for that matter, any shape at all. Those have to be encountered in the world through perception and thus build up a spatial vocabulary. We think that only when one forgets these learning experiences our procedure, mimicing them, appears wrong.

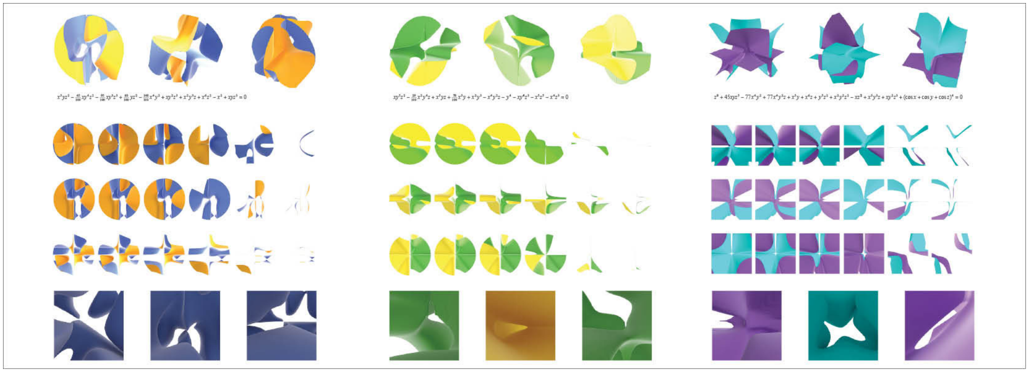


*Figure 6*
*Creating, visualizing and analyzing three algebraic surfaces (Michael Göhlert, Cottbus University 2011).*

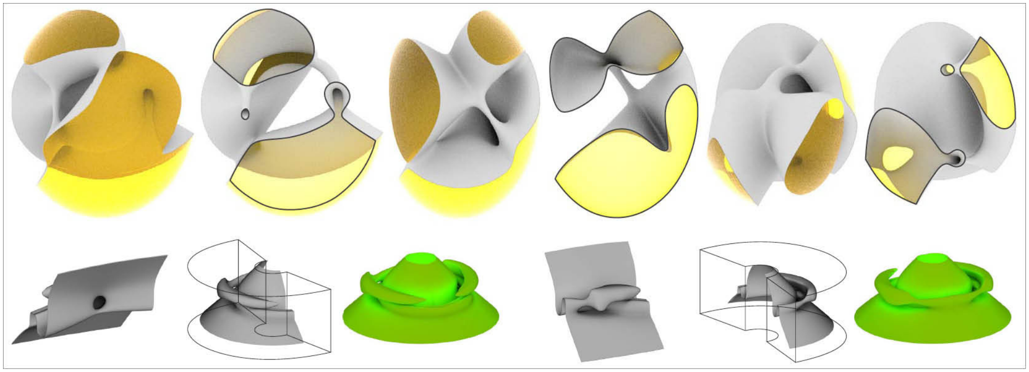


*Figure 7*
*Adapting the surfaces into enclosed volumes (Dana Kummerlöw [top] and Christopher Jarchow, Cottbus University 2011).*

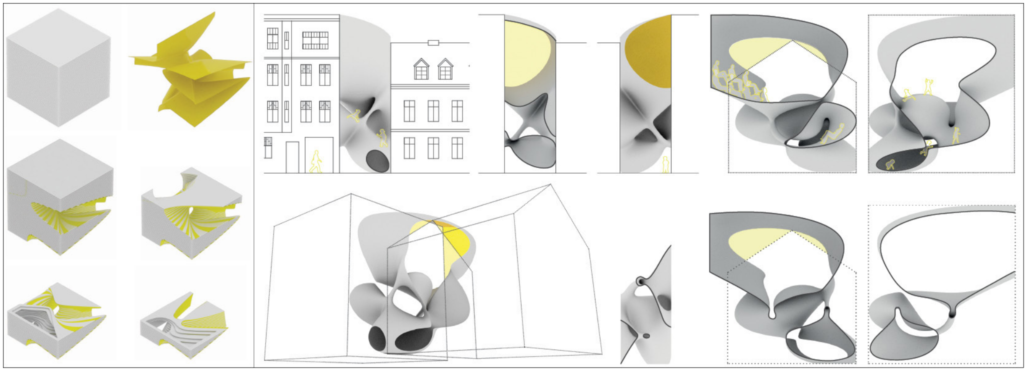


*Figure 8*
*Experimental Design projects based on algebraic surfaces (Jörg Burkardt and Dana Kummerlöw, Cottbus University 2011).*

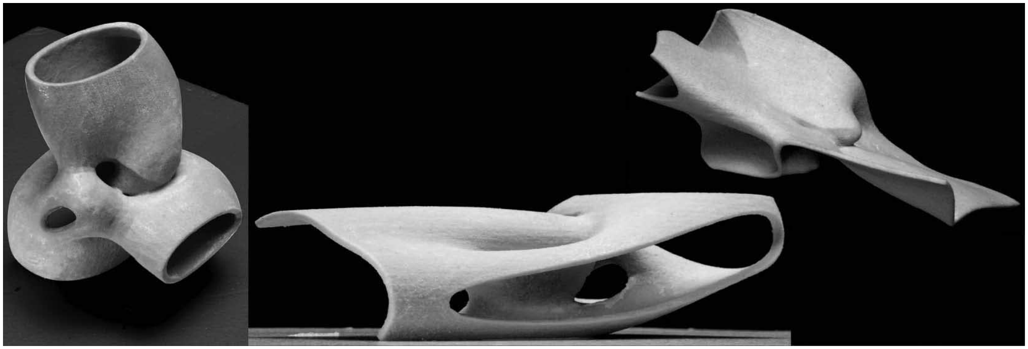


*Figure 9*
*3D prints of experimental designs based on algebraic surfaces (Joanna Kollat, Natalia Kicińska, Ewelina Zróbecka, Cottbus University 2010).*

Additionally, having to find uses for a given geometry provokes thought and forces students - and architects generally - to stretch their imagination and dare possibilities that they otherwise would be too timid to explore.

As new shapes are encountered via computerized tools, new possibilities for design are found and the scope of architectural design widened.

## USES FOR NON-FLAT AND NON-HORIZONTAL SURFACES: MOVEMENT, POLYVALENCE AND GRADIENT THRESHOLDS

We found that humans might use the non-flat and non-horizontal, but continuously curving algebraic surfaces in many ways which range from the non-active, not moving to the active and moving: people might lounge, crouch, lie, and sit on the surfaces. Because the complex geometries are ever-changing and not repetitive, users or inhabitants can find positions which fit their anatomy. Quite opposite from an adjustable object like an office chair where the object's parts can be moved to fit its user's anatomy, on the algebraic surfaces the users would move to find positions that fit them. To put it more succinctly: It is not the piece of furniture or architecture that is fitted to the user, but the user finds a position within the architecture that fits. And because the geometry offers many different situations, people do find fitting ones. This puts inhabitants into an explanatory role where they have to search, interpret and thereby find. Thus, not only are their bodies moved, but also their minds. Moreover, new uses might be discovered as users interpret the surfaces in moving above them, trying out different ways of inhabitating them.

Apart from different degrees of lounging, the surfaces might be used for various sports: skateboarding, rollerblading, climbing.

The surfaces thus literally become moving: they motivate bodies to move, minds as well, and interpretations and habits, too.

Additionally, a range of different uses can happen on one and the same continous surface, as the surface's shape is continually changing from one position on it to the next. With different activities happening next to each other, the surfaces can be understood as polyvalent (Figs. 10-16).

Moreover, these regions of different use are almost never exactly demarkated but flow gradually into one another. The threshold between them is not a line but a gradient. This can lead to a new kind of multifunctionality or hybrid use where the different zones are not seperated as i.e. different floor levels but share common areas of ambivalent use. The rigid territories of much architecture might thus be enriched by polyvalent areas with gradient thresholds - meditative, passive rest nearby fast, active movement, close and connected but at the same time separated through the geometry of the surface.

Figure 10
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces (Dana Kummerlöw, Cottbus University, 2011).*

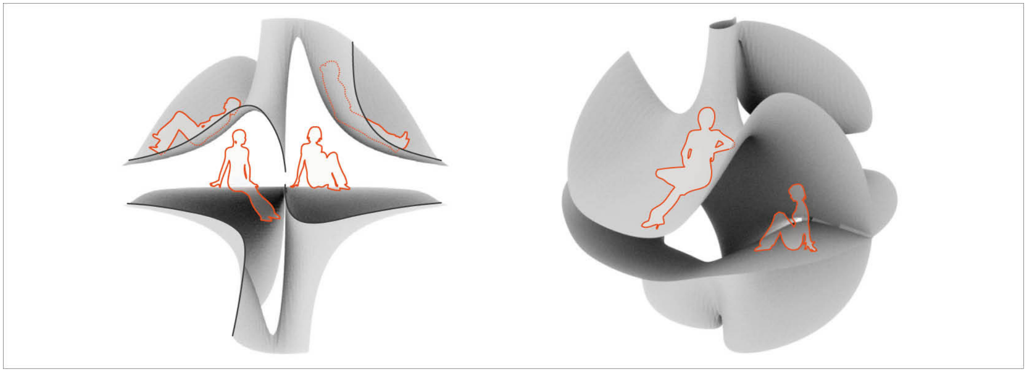


Figure 11
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces (Dana Kummerlöw, Cottbus University, 2011).*

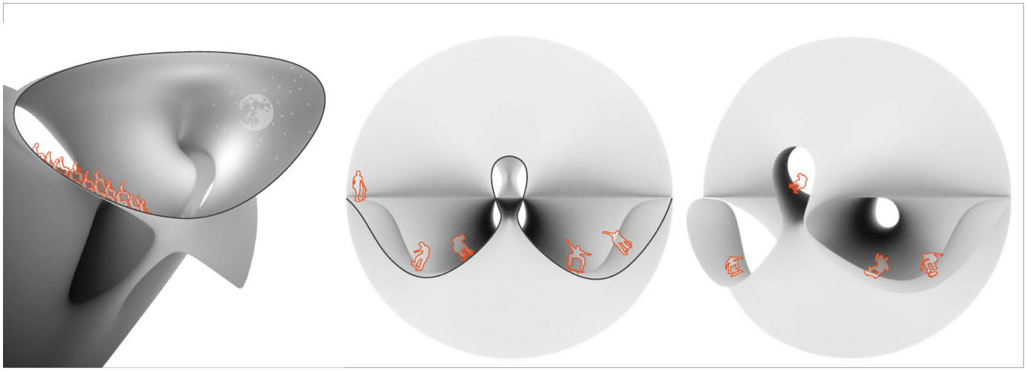


Figure 12
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces (Stefanie Otto, Cottbus University, 2011).*

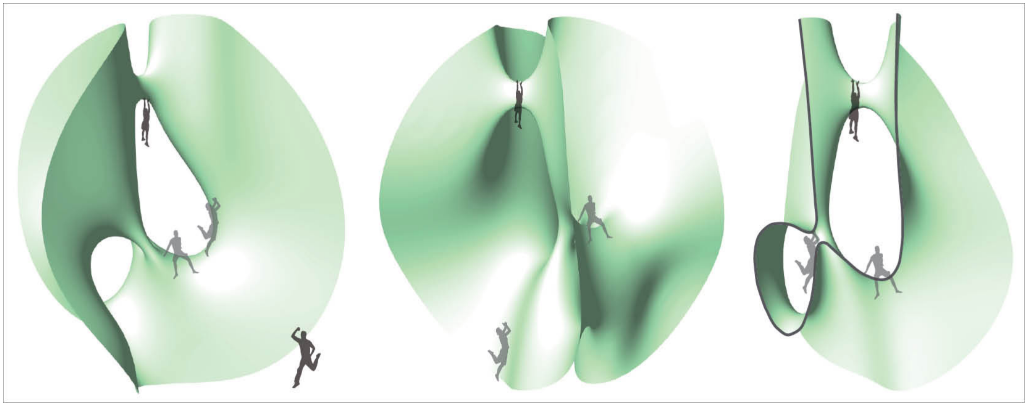


*Figure 13*
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces (Stefanie Otto, Cottbus University, 2011).*

*Figure 14*
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces (Susann Seifert, Cottbus University, 2011).*

*Figure 15*
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces (Susann Seifert, Cottbus University, 2011).*

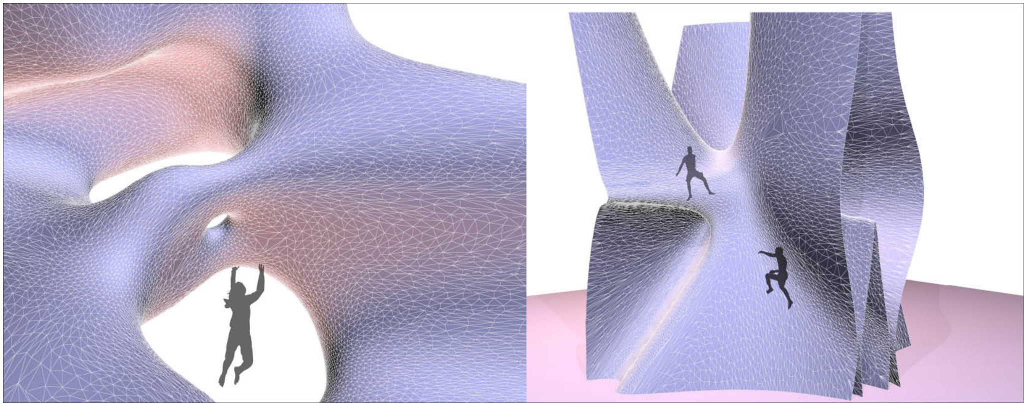


*Figure 16*
*Inhabitation possibilities for experimental architecures designed on the basis of algebraic surfaces with a climbalbe surface texture (Marlies Schneck, Cottbus University, 2011).*

To supplant the different useabilities of the surfaces, their materiality would have to change gradually, too - between rough and sleek, hard and soft as sitting, as would be fitting to the various imaginable functions (Fig 16).

## CONCLUSION

Our work picks up a thread of investigation within modern architecture that started in the 1960s and began to recognize the potential in non-horizontal surfaces, leading to current architecture that actually begins to realize this potential. We radicalize this research via confrontation with the exotic geometries of algebraic surfaces that are almost never flat or horizontal. We find that the surfaces offer manifold uses, which are moving in more ways than one, within zones that display gradient thresholds.

As a matter of course, the work so far is still hypothetical and in its early stages. We see it more as tentative and provocative, to open up new ways of understanding the shape of space and how it might benefit its occupants.

Although some of what we present in this paper might appear to be far-fetched or even nonsensical, we are optimistic: if it took almost half a century for Claude Parent's early provocations to mature into a building like SANAA's Rolex Learning Centre, what spaces will we inhabit in days to come in the light of the suggestions shown here ?

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