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Anthropomorphic Resonances: On the Relationship Between Computer Interfaces and the Human Form and Motion

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This article places the notion of organic user interfaces in a historical context of developments in architecture, art and design, and illustrates the organic design of several recent projects. These examples are drawn from the author's own practice, in musical instrument design, video interfaces and installations, liquid architecture, interactive textiles and 3D printed individually shaped user interfaces. The reciprocal relationship between the human form and function and interface design is discussed, in the historical context of aesthetic and practical responses to technological developments, through the concept of anthropomorphic resonances. The approach proposed and illustrated through the examples aims to shape the (passive as well as the dynamic) shape of the organic user interface to establish these resonances. The use of active feedback and haptic presentation is presented as a way of creating a dynamic organic shape.

RESEARCH HIGHLIGHTS

- Organic interfaces related to historical context of art, architecture and design.
- Personal reflection based on projects carried out in musical instrument design, liquid architecture, interactive video instruments and installations.
- Discussion of organic interfaces related to new technological and conceptual developments of 3D printing and mass customization and the dynamic interactive form.

Keywords: Organic user interfaces; resonance; individual shapes; dynamic shapes; expressive

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1. INTRODUCTION

The relationships between the design of artefacts (including interfaces) and the human forms and functions are complex and often reciprocal. As good furniture and object designs show, merely reflecting or complementing the human form is not always the best strategy. There can be information in the square and sharp forms, potentially and intentionally guiding human behaviour and interaction with the artefact. This is an important realization, which relates to the central aim of the design of technology for use (including research and development processes) which is to make technology less square, more organic with less sharp edges.

Architectural, interior and product design practices, for instance, have had a long tradition of responding to the organic form (Holman and Vertegaal, 2008), through mimicking (Jugendstil or Art Nouveau) and/or incorporating structural principles (Antoni Gaudí) or the liquid and smooth curves (including 'blob architecture') of the last two decades driven by new design tools such as 3D modelling.

Figure 1. A William Morris textile pattern, called Golden Lily Minor.

Figure 2. Gaudí's Casa Milá block of apartments in Barcelona.

It is interesting to note that Art Nouveau, which took its forms inspired not just by nature but by organic principles in general [made accessible, for instance, through the work of Ernst Haeckel (Kunstformen der Natur) and D'Arcy Wentworth Thompson (On Growth and Form; Thompson (1942)) and Herbert Spencer], attempted to use these principles as a whole rather than as mere ornamentation. It was also a response to the perceived flaws and ugliness of the mass fabrication as a result of the industrialization, culminating a passionate and socially engaged endeavour driven by the ideas of, particularly, the writer and artist John Ruskin and practitioner and artist William Morris (Cumming and Kaplan, 2002). Their Arts and Crafts movement successfully reintegrated the artistic and craft skills in a new form into the manufacturing processes, an example of which can be seen in Fig. 1. Their aesthetic was of great influence on the emergence of Art Nouveau around the same time, also known as Jugendstil in Austria and Germany, or Modernista in Spain (the latter not to be confused with modernism) (Fahr-Becker, 2007). It was also related to the aesthetics and shape language of the artists of the Vienna Secession.

In some cases, the manufacturing process or actual technological inventions made new forms and structures possible. For instance, the famous shapes of the Paris Metro stations and entrances was made possible through the new process of iron casting, also reflected in highly transparent and seemingly weightless building structures of that time.

In Spain, the Catalan Modernista architect Antoni Gaudí took the organic idea to an extreme, first being influenced and inspired by the forms and shapes of natural elements, such as the flowing and curved walls and façade of the Casa Mila block of apartments in Barcelona as can be seen in Fig. 2. Secondly, Gaudí was influenced by nature's structures and mechanical principles, as can be seen, for instance, in the roof structure of Casa Milá, a lightweight elegant brick construction that resembles the spine of a python snake as shown in Fig. 3. This can also be seen very clearly in his roof support structures in his earlier work such as Parc Guell (Fig. 4) and later work of the nave of the Sagrada Familia church both in Barcelona, where different types of stone were applied depending on the load-bearing strength needed (see Fig. 5). The Sagrada Familia is to be completed posthumously, in fact only now, nearly a century after Gaudí's death it is nearing completion, while most of the plans and models were destroyed or at least severely damaged during the Spanish Civil War. The reason why it was possible to still complete the design with so many details unknown was the mathematical and structured basis of Gaudi's approach, which for a large part was unravelled since the late 1980s by the architect Mark Burry, the present professor at the Spatial Information Architecture Laboratory at RMIT in Melbourne (Burry, 2007, 2011).

After the Art Deco movement which reacted against the flowing and organic lines of Art Nouveau, Modernism can be seen as a reaction against the ornate styles of both Art Nouveau and Art Deco. Modernism put its emphasis on clear and straight lines and removing the ornament; however, it is ironic that Frank Lloyd Wright influentially wrote about Organic Architecture (Wright, 1970) and indeed his work often aimed to resonate with nature, while the form language of modernism can be seen as a contrast with the natural form. This dualistic nature, of resonance and contrast, is something that I am addressing throughout this paper. For Frank Lloyd Wright, organic did not mean literal imitation of natural forms but rather the understanding of nature's principles (Laseau and Tice, 1992, p.101). And he had already indicated how he intended to take the ideas of Morris and Ruskin further, by giving 'the machine' a place in design practices rather than fearing it, in a lecture in 1901 (Wright, 1992).

Another strong resonance from the early 20th century was the architecture of Rudolf Steiner, reflecting his ideas on the relationship between humanity and nature. This can be seen in the Steiner Clinic, an anthroposophic care building in The Hague in The Netherlands. This building was designed in the late 1920s by architect Jan Buijs with a strong influence of

Figure 3. The roof structure of Casa Milá: overview maquette, detail of actual structure, skeleton of a snake.

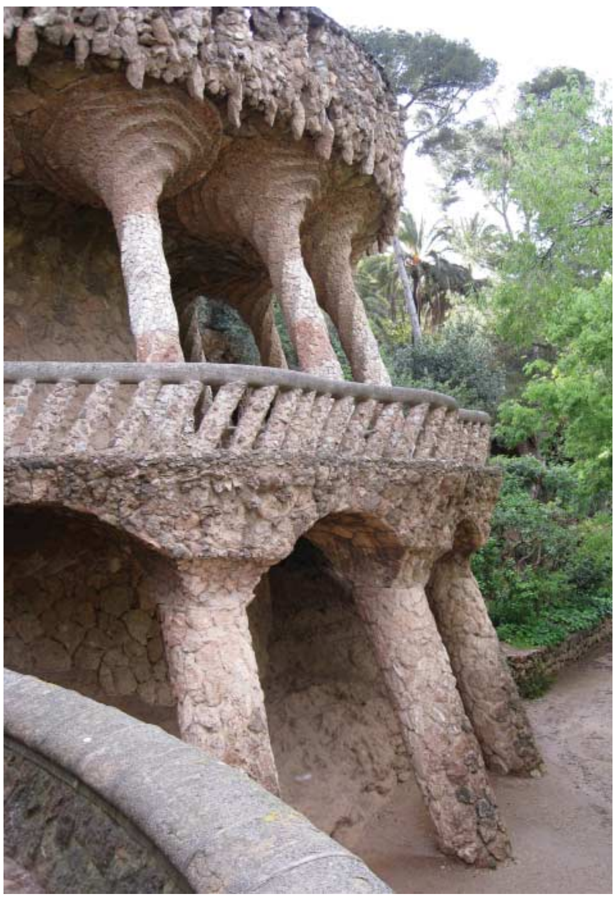

Figure 4. Support structures in Gaudí's Parc Guell.

Steiner, as can bee seen in Fig. 6. Steiner's work was also of influence on the Dutch architect Ton Alberts, who in the late 1980s became well known for his buildings in The Netherlands representing organic architecture and anthroposophic ideas, such as the NMB Bank building in Amsterdam (Travi, 2001, p.28–31).

Figure 5. Roof support structure of the central nave of Gaudí's Sagrada Familia church.

In more recent times, the work of Spanish architect Santiago Calatrava stands out, with his amazing organic structures which seem often to have been inspired by skeletons in nature (Tzonis, 2007; Zardini, 1996). His structural designs excel in elegance and optimization, and are another good example of drawing inspiration and insights from nature, mimicking its principles rather than just its external appearances as can be seen in Figs 7 and 8.

The history of technological development is one of a continuous ebb and flow of motions, moving spirally to higher levels (and sometimes crashes down). The interface is where humans meet the technology, with a potential for deep interaction. Adequate interfaces allow for profound ways of expression, development of human thinking, ideas and behaviours through interaction. A successful interface is not just on the surface, added to the technology at the last stage, but has to be developed with the technology from the ground up. To allow deep interaction, the interface has to

Figure 6. The Steiner clinic in The Hague.

Figure 7. The Campo Volantin footbridge in Bilbao by Santiago Calatrava.

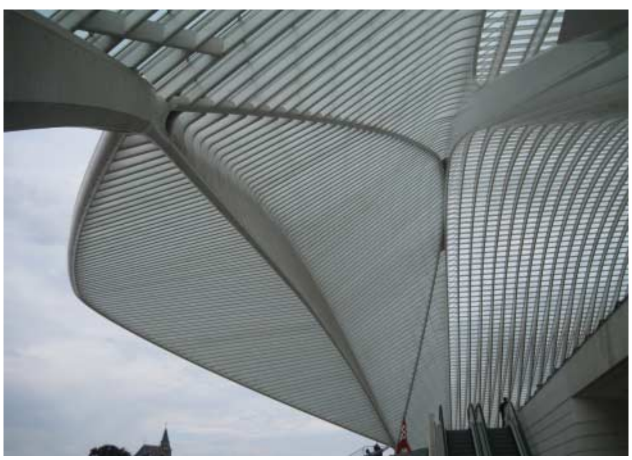

Figure 8. The roof structure of Calatrava's Guillemins train station in Liège, Belgium.

be rooted at the lowest levels of the technology. Designing appropriate interfaces, therefore, requires deep knowledge and understanding of both the natural and the technical environment, not just matching the technology with user but actually creating anthropomorphic resonances.

The concept of resonance has been explored in human–computer interaction (HCI), for instance, by Caroline Hummels and co-workers (2003, 2007) applied to the product design. It is a key concept in J. J. Gibson's ecological approach to perception, where objects and other elements in the environment resonate (or 'tune in') with the implicit or explicit expectations, needs or wishes of the individual perceiver (Gibson, 1979).

In this paper, I want to illustrate several aspects of the design approach of organic user interfaces, with examples of application domains ranging from the intimate scale of electronic musical and video instruments to the architectural scale of interactive buildings, to large-scale video projections addressing the urban and landscape environments. New design opportunities for organic interfaces are explored through the notion of dynamic forms of active haptic feedback, and 3D modelling and manufacturing techniques that lead to the emergence of individual interfaces.

2. ELECTRONIC MUSICAL INSTRUMENTS

Practitioners in electronic music have always been concerned with developing new instrument forms to fully explore the possibilities of their new electronic medium. From early examples such as the Theremin in the 1920s (and still popular as an electronic instrument form) to new digital interfaces, musicians, technologists and designers have attempted to develop new types of instruments (Paradiso, 1997).

In musical instrument design, although there are anthropomorphic elements in some traditional instrument forms, the design is largely determined by the nature of the sound-producing principles. Traditional musical instruments shape the movements of the player, guiding and constraining at the same time. Electronic musical instrument design gives vastly more freedom (and confusion!) in exploring a morphology responding to human factors. These explorations and developments, accelerated by the introduction of the Musical Instrument Digital Interface (MIDI) protocol in the mid-1980s, are more recently organized in the community of NIME (New Interfaces for Musical Expression) with yearly international conferences since 2001.

Working with various composers and performers of live electronic music from the late 1980s to the mid-1990s and beyond, the author has explored many ways of creating new forms to fit the player. These were often wearables, such as gloves (Laetitia Sonami, Walter Fabeck), belt and shoes (Marie Goyette) or small keyboard and sensor contraptions worn on the player's hands (Michel Waisvisz), some examples of which can be seen in Fig. 9 and are described in a recent publication (Bongers, 2007).

Designing interfaces so close to the human body poses specific challenges. Technology and technical design tools often

Figure 9. Several electronic musical instruments.

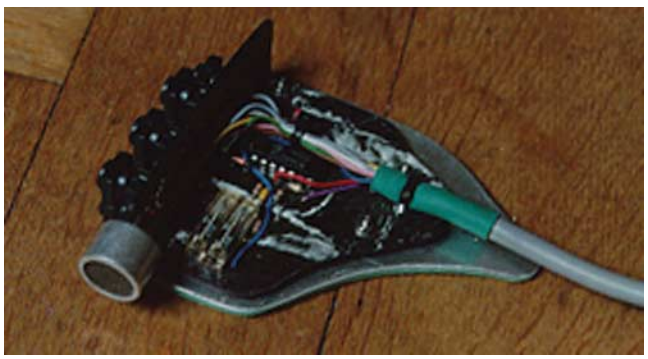

Figure 10. Curved shape of an electronic circuit in a musical instrument.

tend towards the square, sharp edges, static and symmetrical shapes. The human body is very different, round, pliable, curved and constantly moving. While the human endoskeletal system can be described in mechanical terms in the sense of motion (Degrees of Freedom, range, strength), the muscles and outer tissue are more flexible in shape while the movements of the mouth (lips, tongue) are not limited by a mechanical structure.

To adopt the hard and rectangular technology to the human form and movement, a number of techniques had to be developed and applied. Because most of the electronic circuits were custom designed and often hand made, it was possible to shape them in curved (Fig. 10) and bent shapes (Fig. 11). Flexible circuit boards can be applied only in larger volume designs, but it is possible to bend the fibreglass/epoxy material circuit boards. The technique I developed to permanently bend circuit boards is by heating the material (with a heat gun) and quickly cooling (using cold spray) for it to keep the curved shape

Figure 11. Bent circuit board for a wearable musical instrument.

(parts and wiring are added afterwards). This way the circuit board parts of the instruments were shaped to fit the human form optimally (and often painted or laminated for aesthetic reasons). This technique can also be used with printed circuit boards (before adding the electronic components).

Owing to the tremendous range of movement of the fingers and limbs, the wiring had to accommodate the movement by being slack and guided by loose fixations. The stress on the soldered connections of the wires can become quite strong, and the wires were therefore sewn onto the circuit boards past the soldering, around the insulation. These instruments after all were intended for repeated performances on stage, requiring a high level of reliability.

The Lady's Glove musical instrument developed with Laetitia Sonami brought all these techniques together, as the most complex physical musical anthropomorphic interface developed by the author, as pictured in Fig. 12. It has bent and shaped printed circuits and free-moving wires that were very thin, flexible and strong (Teflon cover). The sensors are

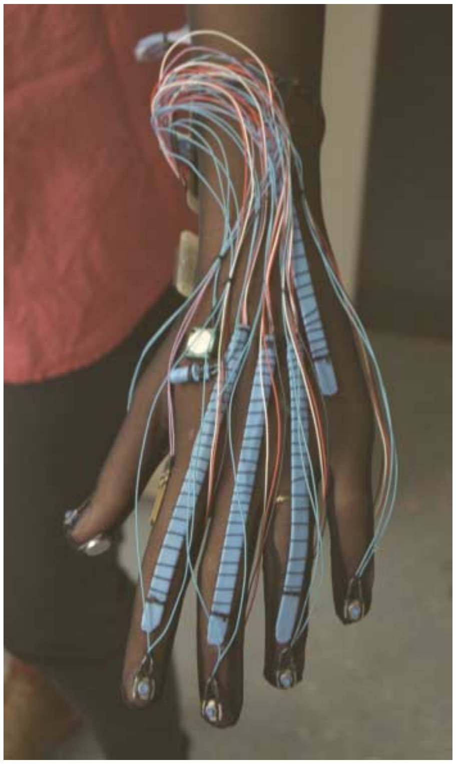

Figure 12. The Lady's Glove instrument of Laetita Sonami.

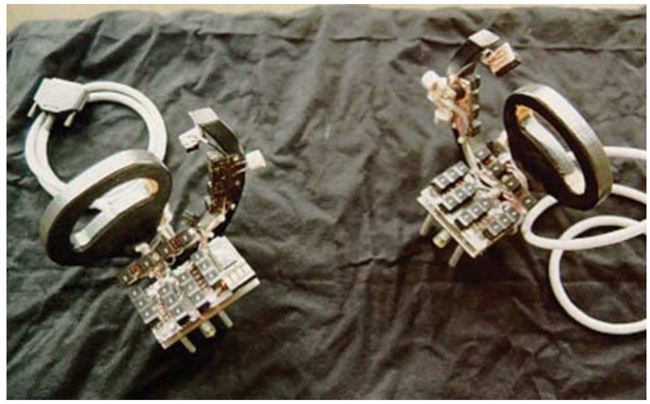

Figure 13. A pair of The Hands instrument of Michel Waisvisz.

sewn onto a lycra glove (custom made for the artist's hand) that holds everything in the right place. The correct placement of the sensors to match both the intricate and the gross movements of the hand was achieved by sewing the sensors and wiring on with the artist's hand inside, a labour-intensive but necessary procedure.

The Hands, the instruments developed by musical interface pioneer the late Michel Waisvisz (Krefeld 1990; Waisvisz, 1985), are an interesting case study of a search for the optimal anthropomorphic resonance. Unlike the gloves and other wearable instruments, this interface always relied on a rigid frame to carry sensors, actuators and electronics. Working with the electronics and fine-mechanical engineers in the STEIM workshop during the 1980s, Michel iteratively developed many versions of the instrument, experimenting with both form and function. Initially aluminium was used for the frame, later wood. These materials were shaped and/or bent to fit the hands of the player. Around the time I joined the team in 1987, a rough form had emerged from all the experiments in a shape resembling a hand-scale scrap-yard version of an Iron Man fist, bearing the traces of many recent additions and removals. Only a few additions were made by me, switches around the thumbs of both left and right hands, and by then not only the form but also the functionality had largely been established. This 'design' was then used as basis for designing an adjustable set for the University of Music in Basel (Switzerland), with the intention that the instrument could be played by a variety of people, so the placement of the controls was adaptable to different player's hands as can be seen in the bottom left image of Fig. 9.

The next version was designed in the early 1990s, using a wooden frame that Michel created himself based on his own hand (see Fig. 13), with the electronics built by the author at the Institute of Sonology in The Hague, in such a way that all controls would be placed in the same place as the original aluminium versions (which retired to the musical instrument collection of the Gemeentemuseum in The Hague (Kyrova, 2002, p.171–174)).

These examples illustrate the necessary flexibility in shapes and adjustments of intimate interfaces; however, they remain rather personal and only accessible/usable for a small group of people. The instruments were effectively hand crafted, custom built and, therefore, too expensive as solutions for mainstream application. Using a modular approach, as developed in projects described in later sections of this paper, and eventually combined with recent 3D CAD modelling tools and rapid prototyping techniques a form of 'mass customized' individual anthropomorphic interfaces may be developed.

When designing musical instruments, one becomes aware of the importance of effort. Making things easier and effortless is not always desirable, often when certain (not only musical) parameters are interacted with by player, he or she benefits from having something to work against or guiding a movement or finding a location. These cues and guidance come from the seams, the gaps and the frictions an interface can display. With the current omnipresence of touch screens this discussion is more relevant than ever. The notion of effort will be discussed in more detail later in Section 7.

3. LIQUID ARCHITECTURE

From the intimate scale of musical instruments, it is interesting to look at examples on the much larger scale of anthropomorphic resonances in interactive architecture.

Recent developments, which can be seen as a response to traditional 'square' architecture, are driven by the possibilities of CAD tools and the notion of parametric design (Burry and Burry, 2010). Using the computer as a design tool, particularly with a well-established link with manufacturing and building practices, can lead to a freedom of form that was not easily achievable before. From the mid-1990s, pioneers such as Markos Novak, Zaha Hadid, Decoi, Frank Gehry, and Greg Lynn started to propose and eventually build architectural forms that were later also described as 'liquid architecture' (Novak, 1991; de Solà-Morales, 1998), hypersurface architecture (Perrella, 1999) or hybrid space (Zellner, 1999). Perhaps, due to their strong relationship with water, Dutch architects have always been very present in the movement (Jormakka, 2002). An early example of liquid architecture was the (appropriately themed) Water Pavilion (Schwartz, 1997). This pavilion consisted of two parts that were designed by architects Lars Spuybroek (NOX) (Spuybroek, 2004) (Fresh Water part) and Kas Oosterhuis (ONL) (Salt Water part), and was related to the massive Delta Works project that has served to regulate the water levels of The Netherlands including the areas that are below-sea-level. Both buildings of the Water Pavilion have a fluid shape indeed, and even though apparently the most fluid shape was drawn by hand originally, computers played a big role in the design and carrying out of the construction. For the opening in 1997, the buildings were filled with an interactive interior of a spatial sound composition, projections, moving water, ambient lights and fog, for which I designed and implemented the sensors and part of the interactive systems, some of which can be seen in Fig. 14. I have worked with both architects on several projects since, but want to focus for the context of this paper on the work of Kas Oosterhuis. Within the field of liquid architecture he is one of the few who are not satisfied with finishing with a 'frozen' liquid form and going beyond the static form by creating a real-time interactive architecture (Oosterhuis, 2002, 2003). Oosterhuis is also the chair of the interactive architecture research group and Masters programme called Hyperbody at the TU Delft (the Netherlands), and in this environment we have developed a number of actually moving structures using pneumatic systems, as discussed in the context of Organic User Interfaces in a recent publication (Oosterhuis and Biloria, 2008). Conceptually, it is actually a small step from parametric CAD software, to parametric manufacturing and a real-time parametric building. Practically, however, many new technologies and approaches need to be developed to make this feasible. Using powerful pneumatic 'muscles', several actually moving structures have been designed and presented that have the ability to organically interact with human inhabitants on the architectural scale. In these structures, every muscle becomes a real-world moving part of the 3D parametric wireframe model, interacting with its environment through the sensor system that I have developed (in the first project, six discs with three sensors each, following human motion, proximity and touch, as shown in Fig. 15) (Bongers, 2004b). The aim of this research is to create a real-time moving architecture, yet to be implemented on the full scale. Projects so far have included a smaller dynamic space, moving towers, walls and façades. The moving walls, shown in Fig. 16, are interesting as they could potentially be used as dynamically reshaped projection surfaces, forming an organic display on a large scale.

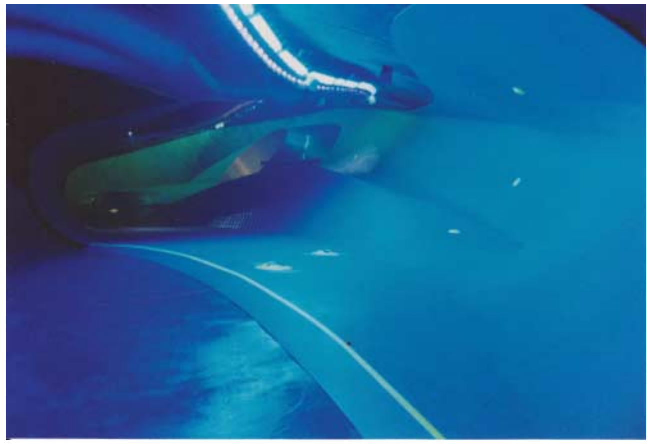

Figure 14. The inside of the Water Pavilion (Fresh Water part) with projections and sensors visible.

Figure 15. The first Muscle structure, and a muscle sensor disc.

The pneumatic muscles are only able to perform a contraction, the expansion is usually achieved by some form of a spring-like structure (such as the pressure of a bubble structure, girdled by the muscles, see Fig. 15) but an antagonistic muscle pair as in the human body can be applied as well. Further inspiration from the human body can come from the way the movement and tensions of the human muscles are sensed due to the mechanoreceptors in joints, tendons and the muscles themselves. The pneumatic muscles have no such system, and these need to be incorporated in the mechanical structures designed in order to achieve better controlled movements.

Figure 16. Interactive moving walls at Hyperbody at the TU Delft.

Figure 17. A selection of physical interaction modules, in use in the Protospace multi-user parametric design environment.

Figure 18. The steel structure of the iWeb building at TU Delft.

At the same time, another research project was carried out, which looked into interaction styles for parametric design environments. Currently, in its third incarnation, the Protospace lab is a research space where the group develops and applies new technologies (Bongers, 2012c; Hubers, 2005). The challenge was to create a multi-user, 3D interaction environment where mixed teams consisting of architects, designers, engineers, managers etc. could fluidly collaborate on the parametric design process. The number of parameters to be interacted within even a simple architectural structure is several hundreds, interlinked and simultaneously operating. Our approach was to develop a modular interaction structure where every part of the interaction would have its own most suitable physical interface and representation techniques, to be chosen freely by the users. Figure 17 shows a number of these physical modules and part of the parametric design environment. The system was also capable of gesture and speech recognition, pitch tracking (of sound input) and 2D movement tracking (using active optical 'beacons'), and spatial sound feedback on multiple speakers and individual microphones and headsets. This project informed the research and development of theoretical models of multimodal interface design (Bongers and van der Veer, 2007).

Another relevant aspect of Kas Oosterhuis' work is the development of a file-to-factory approach, enabling each part of the structure to be custom fabricated in a unique shape without increasing the costs in comparison with mass production. A good example is the iWeb building which housed the second version of Protospace. Each of the steel parts has an individual unique shape as can be seen in Fig. 18 and, when assembled correctly, the round and fluid form of the pavilion emerges. It is located on the TU Delft campus and used to be in front of the old Architecture Faculty building which unfortunately got destroyed in a big fire in 2008. The iWeb building is still there but cannot be used at the moment. The pneumatic muscle system itself was lost in this fire, as were most of the modular interaction systems described above, with the first Protospace, which was inside the Architecture building.

Recent moving architecture structures by the Hyperbody research group have utilized linear motors, which are heavier but have the advantage of sensing systems that report the motor's position.

4. VIDEO-ORGAN

The Video-Organ was designed and developed together with composer and artist Yolande Harris as a modular instrument for the live performance of audiovisual material (Bongers and Harris, 2002). The individual modules of the system, or instrumentalists, were all designed with a particular musical or videographic manipulation in mind, as well as following ergonomic considerations. An example of an organic element was the Squeezamin module shown in Fig. 19, consisting of foam with proximity sensors embedded, covered in material

Figure 19. The Squeezamin, a Video-Organ instrument for sound manipulation.

Figure 20. Anthropomorphic individual hand instrument shapes.

Figure 21. Video-Organ performance with projection on shaped surface.

(wool) sewn in the same shape as the foam. Squeezing the object resulted in four parameters of a sound process individually or collectively manipulated by the player.

The design of the modules was approached from the anthropomorphic characteristics of the human body in shape and movement. The project helped to refine an earlier developed taxonomy of movement characteristics for input devices (Bongers, 2000) into a design space with the dimensions of (movement) range, haptic feedback and precision of tracking of each human movement component (degree of freedom, DoF). This design space takes the human properties as a basis for a technical development of input devices. The Squeezamin, for instance, had two rotational DoFs (pitch and roll, each with a range of ±45°) and one lateral DoF (along the Z axis, and a range of 26 mm), derived from four infrared analogue proximity sensors. The haptic feedback was passive, from the compression of the foam.

Further form studies were undertaken using clay, which was moulded in anthropomorphic and individual shapes affording a firm grip as shown in Fig. 20. The clay models could contain electronics and sensors, or by using a 3D scanner put into a CAD modelling programme to be further manipulated and printed in a different material. This is a technique that we are currently exploring for medical applications, as described in Section 8.

Another organic element of the project is how the video projections in the performances deliberately avoided the square frame of a projection screen, seeking a dialogue between interactive video and the projection surface. And the example is the use of an ornamented wall as a projection surface, on the back wall of a church, in the concert at the NIME conference in Dublin in 2002 as shown in Fig. 21.

5. VIDEOWALKS

Taking the notion of projecting on non-orthogonal surfaces and unframing the video image as discussed in Section 4 further, the VideoWalker project started as a mobile investigation in organic moving image placement.

The two main aims of the project were (i) to ‘liberate the projector’ and (ii) to research video projection as an expressive human output modality. A portable instrument was developed in 2003 in Barcelona and used in performances there and in Maastricht in The Netherlands in 2004 and 2005, and further developed since 2009 in Sydney. The player holds the projector with sensors and interface mounted, carrying a battery, speaker and a computer in a backpack, which enables to project sounds and images anywhere in the surroundings. It led to structured

Figure 22. VideoWalk about portable projections on buildings.

performances in a festival in Sydney in 2009, the SEAM Spatial Phrases Symposium, responding to the aim of this festival to bring together architecture, dance and cinema. As a ‘spatial phrase’, it took the audience for a walk and following the unfolding audiovisual spatial composition for ∼25 min. A repertoire of video material was prepared to enable the player to project on the buildings and other urban elements, surfaces and trees, responding, enhancing, contrasting in colour, shape, movement and semantic content of the material to the characteristics of the environment as can be seen in Fig. 22. During several site visits before the event, experiments with the behaviour of the projected image were conducted, and the actual piece developed during rehearsals on the site under similar lighting conditions as the final performances (dusk). During these rehearsals, as a player I was able to familiarize myself with the image distortions and effects of the projections. Often using a round shape as an image mask made the projection much more blend in with the environment much better than the square. The size of the image was scalable in real time, in addition to the influence of the angle and distance of projection surface on the shape of the resulting image. The background and experiences of the project are presented in more detail in a recent journal paper (Bongers, 2012a).

As a spin-off, an audience instrument was created for a pop-up gallery project in a Sydney laneway in 2010. The projector was fitted with sensors that influenced the projected image to change according to the physical movements of the audience member playing with it. For instance, the dynamic distortion of the image, a video projected moving up a very tall and narrow white wall, was balanced by a dynamic change in the software playing the image, compensating for the decrease in the projected size due to the increase in distance by enlarging the image controlled by the sensor at the same time. This way the instrument was organically responding to the player’s movements.

6. FACETS

A range of kaleidoscopic interactive video-projection installations have been developed to explore the use of rich physical and embedded interfaces. The image material consists of pre-recorded video material, and live camera input. All video is treated in software to mirror the image along the X and the Y axes of the screen, creating the basic quadrants, which are then further manipulated through rotations and zooming (magnifying and particularly multiplying) effects, linked to sensors in the objects that the audience can play with. Because all rotations are different and all motions and movements of the players (as picked up by the sensors) create endless variations of the image, like an optical kaleidoscope.

In several versions in curated public exhibitions and presentations, the projections varied in scale, number and shape. For instance, as part of the Art Light exhibition in Sydney in 2009, the projection surface was a custom-made screen consisting of gauze of 12 × 3 m, so that the spectator could see both the projected image and the real world behind it. This view of the palm trees in the venue’s garden conceptually linked to the choice of image material, video footage of flows and movements in nature. On another occasion, five separately controlled (by the audience) round kaleidoscopic videos were projected onto the curved ceiling of a museum, organically distorting the image into a new shape as can be seen in Fig. 23. This range of video installations is presented and discussed in more detail in a recent journal paper (Bongers, 2012b).

The main purpose of the project is to investigate anthropomorphic resonances through the design and development of new, intuitive, sensitive and often organic interfaces. The choice of wood as a basic material for the interfaces reflects several conceptual considerations and in this context I mainly want to emphasize the organic nature of the material and shapes. The wood forms a nice contrast with the electronic circuit boards embedded in it. It is also a good example of a design that responds to the notion of effort, which was discussed earlier in the context of musical expression and is represented in the ‘haptic feedback’ dimension of the Design Space as presented in Section 4 about the Video Organ (and discussed further in the Section 7 on the active shape). The motion sensors used (Phidget accelerometers) are square circuit boards of 30 × 30 mm, with a weight of only a few grams and this is not a good match with the drastic visual changes in the projected image. It was found that by mounting the sensor on a wooden block of a few hundred grams and about 10 × 6 cm, in size, the mapping between movement of the interface and movement of the projection became more in balance. The blocks are shown in Fig. 24. The balance between movement and weight has to do with the amount of effort needed to create the visual response, and as such it is a good example of the notion of ‘making things easier’ is not to be approached in a simplistic manner. There is information embedded in the physical response to the effort that the user has to put

Figure 23. Five interactive round video-projections on the curved roof of the Powerhouse Museum in Sydney.

Figure 24. Some of the Facets wooden interaction modules.

in, which is vital for the articulation of the movement. This is a recurring realization when dealing with proposals for free-moving gestural controllers, from the earliest experiences with the Theremin musical instrument to the present day WiiMote and Kinect game controllers.

These video projects deliberately avoid the more integrated but also totally fixed placement of the video-mapping approach, as can be seen in the fascinating work by groups such as Superbien, Urban Screen and The Electric Canvas, as

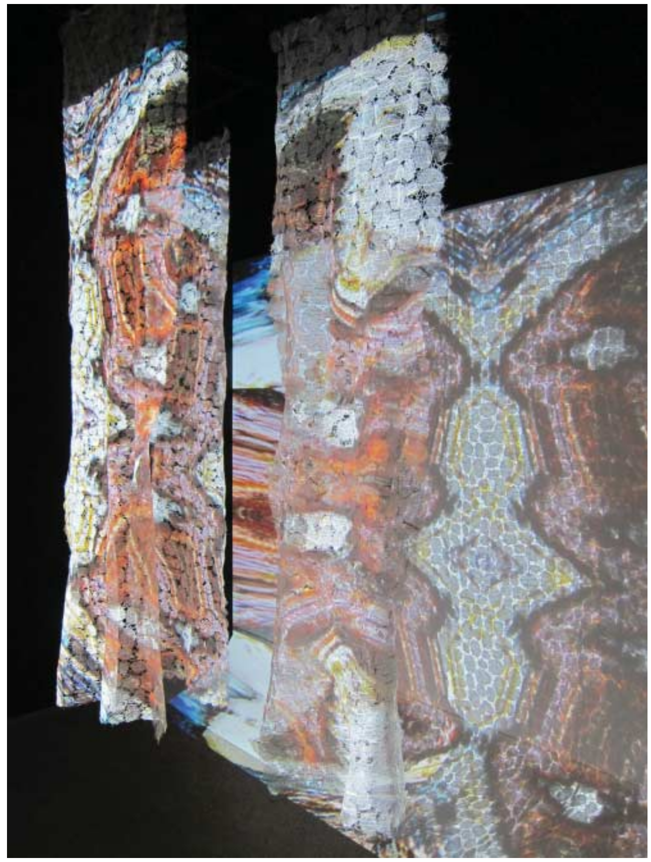

Figure 25. Interactive lace panels with video projections, the InterLace piece in the Love Lace exhibition.

experienced in light festivals such as Glow (Eindhoven, the Netherlands) and Vivid (Sydney). The Facets pieces deliberately try to integrate the distortions of the images by the surfaces (shaping, colouring, enhancing). The VideoWalks can be seen as the live performative version of this, exploring and improvising structured by preparations. My exploration of video as a medium for live performance started with the Video-Organ, inspired not only by the many performative uses of video such as VJing, but mainly by the much more sophisticated state of discussions in the field of music where the relationship between composition and performance/improvisation has been researched for decades.

A further development of the approach of projecting on non-orthogonal and unframed materials is the InterLace piece, a collaborative work with textile designer and artist Cecilia Heffer (Ward, 2011). The final work consists of three lace panels (~170 × 40 cm each) hung vertically floating in space, with kaleidoscopic video projections influenced by sensors embedded in the lace. Instead of a flat projection, now a spatial light composition is achieved augmenting the patterns of the lace material by the projection and shadows cast on the wall behind it as can be seen in Fig. 25. The video image material comes from the same landscape elements as the shapes of the lace material, pebbles and patterns found in the South Australian landscape. Light sensors embedded in the material create ever-changing feedback loops augmenting the gentle motions of the video, further influenced by the deliberate or implicit audience movements. A visitor can cast a shadow from, for instance, their hand over the sensitive spots of the material, thus creating personal influences on the resulting patterns. These responses are subtle and slow on purpose, following the notion that gestural control allows sensitive relative movements but not precise articulations as discussed before.

7. THE DYNAMIC FORM: ACTIVE HAPTIC FEEDBACK

The examples discussed so far were mostly limited to the static form, as designed to match the human form, with passive dynamic elements (movement generated from the human body). With active dynamic technology, it is possible to change the shape, orientation and other physical properties of the interface in real time, or 'form follows flow' (Vertegaal and Poupyrev, 2008). Motors, solenoids, pneumatics, shape memory alloys (SMAs) and other dynamic technologies enable the creation of forms that can actively respond to, and resonate with, the human form and movement. The Hyperbody architectural structures as discussed in Section 3 are examples of such systems. In HCI, the field of Haptic Interaction is concerned with the research and design of interfaces that use dynamic forms (Buxton, 1987). In musical instrument research, it was soon realized that it was important to present properties of the sound processes that were manipulated through active haptic feedback (Chafe and O'Modhrain, 1996). My own experiments in this area mainly concerned vibrotactile feedback (using tiny loudspeakers) and some work with motors, SMAs and solenoids (Bongers, 1998). Applying and extending (or subverting) technologies from the field of Virtual Reality (VR, popular in the early 1990s) for musical and other interaction purposes was successful though limited.

Commercial applications are rare, after many failed products from companies such as Logitech (for instance, a force feedback mouse, and the iFeel mouse with vibrating element). Philips Research Laboratories in Eindhoven had developed a sophisticated tool, the Force Feedback Trackball, which was one of the reasons for me to join the team in 1996. This tool was mainly used for research into haptic perception (Keyson and Houtsma, 1995), and later for the exploration of new interaction styles (Bongers *et al.*, 1998; Engel *et al.*, 1994) and never became a commercially available product. The only widely available haptic feedback tool is the Sensable Phantom series of mechanical linkage devices, which have a 6 DoF movement and orientation input and 3 (or 6) DoF force (and torque) output. The difference between the devices in the series are the movement range, force/torque delivered and number of DoF actuated. As demonstrated by Sensable and other manufacturers' 3D CAD software, it becomes possible to 'feel' around 3D virtual shapes that could change in real-time. While this is a high-quality device and software, the limitation is that there is only point of contact. To make convincing anthropomorphic resonances, it is necessary to support multiple points of contact. When touching an (virtual) object or shape with the hand, at least all five fingertips make contact.

To be able to resist the pressing of the fingertips (the index and middle fingers can easily exert over 20 N of force), strong actuators (and mechanical support structures) are needed, which inevitably leads to higher weight and clunky contraptions. SMAs may be used, or new materials such as electroactive polymers may be promising but the force of these materials is limited (Mazzone *et al.*, 2003).

Vibrotactile actuators, such as the ones used in earlier work on virtual textures (Bongers, 2004a), require much less energy and may be used for suggesting shapes, leading and guiding of movement with subtle cues. As noted in Section 2 on musical instruments, to respond to the important need for effort on the user's part as a form of guidance, stronger cues are most effective but small electromagnetic actuators can play an important role here.

8. INDIVIDUAL INTERFACES

Working with industrial design students in our faculty, several recent projects have explored 3D printing as a means to create highly individualized interface shapes. Starting from a basic, minimum shape housing the electronics and sensors, it is now possible to adjust the design along a number of parameters to suit individual needs. It is even possible to design an personalized organic shape based on the individual components down to the separate circuit boards, sensors etc., as can be seen in Fig. 26. This gives a great freedom in design, when the design students and practitioners take the effort of learning about the workings and characteristics of the separate circuits and elements. This is a radical approach that brings product design closer to electronics design, and applied in several design educational institutes around the world. For instance, at the Industrial Design department at the TU Eindhoven in the Netherlands, the students in a self-directed (competency-based) learning studio environment learn to work with electronics and programming right from the beginning, and train in general user-centred design techniques.

The material of an average 3D printer is an off-white plastic (ABS) although other colours are possible too. These Fused Deposition Modelling machines use an additive material approach, a process of building up the model in layers (typically of 0.25 mm thick) from an extruded melted plastic material. The price and maintenance of 3D printers of any volume is still relatively high, so only institutes and companies can afford them; however, many 'printing on demand'-type

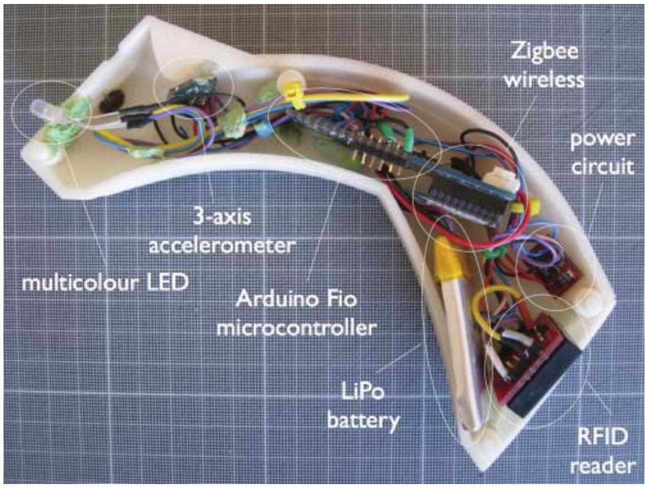

Figure 26. An individual interface for physical rehabilitation applications.

companies bring the possibilities of these techniques closer to the everyday design practice. One of those companies is Shapeways, a Philips spin-off, which also acts as a shop front, comparable with the model of (paper) printing on demand publisher Lulu. Companies such as Shapeways can also print in different materials, using, for instance, laser sintering techniques, including nylon, stainless steel and silver. In fact it is possible to use the same 3D printing process for creating the shapes as well as part of the electronic circuits. New structures become possible too, by printing moving elements inside other moving parts, leading to whole kinetic structures printed in one go, which were impossible to build like this before.

The possibility of creating individual interfaces is particularly relevant in medical situations where the variation in needs and characteristics of practices are extremely varied. When we studied, for instance, physical rehabilitation therapies, we found that solutions and therapies were custom made for each patient and for each session. This was explored in a recent project involving 'interactivated rehabilitation', which aims to enhance the necessarily repetitive actions of a patient in therapy with multimodal feedback and guidance (Bongers and Smith, 2010). Using video, games and music, it become possible to create a more rewarding, entertaining and stimulating environment (Duckworth and Wilson, 2010). Movement, dexterity, sensitivity and muscle strength are often impaired in these situations in a variety of ways, which calls for individually designed interfaces. Our current research reflects earlier projects in that the rehabilitation interfaces are approached in a modular way. The therapist can put together a certain exercise by assembling the appropriate modules, which are all interactive and together forming a flexible eco-system of interface elements.

9. DISCUSSION AND CONCLUSION

After the somewhat nostalgic response of the Arts & Crafts movement to the industrialization, and the more integrative and innovative response of the Bauhaus movement which effectively developed the notion of industrial design (Hochman, 1997; Whitford, 1984), we now have arrived in a time where a new balance between craft and industry is emerging. With the new techniques and technologies of CAD software, 3D printing, it becomes possible to design and produce highly individualized organic shapes and products. There is a tendency from mass production to mass customization, as it has been called by, for instance, John Heskett, a leading figure in Industrial Design thinking (Heskett, 2002). This means that design practice, user needs and manufacturing are all brought closer together. Products and devices can organically grow to suit individual needs, developments and changes driven by individual users, even when their needs change the device can organically change as well. Combining this freedom of form, with the dynamic form of haptic feedback (in addition to the already established flexibility of visual and auditory displays), interfaces that really suit the user and develop along with people's lives become possible. People have an innate need to individualize, but total freedom can be bewildering. The design practice in response is shifting to include a more service-oriented, guiding attitude where people themselves are in charge of the way they interface with technology. This is the shift from the prevailing elite designers attitude (rooted in modernism) of stipulating how things they design, from software to products to buildings, are going to be used.

These recent technical developments have an influence on the whole design and research process, as shown in Section 8. Rather than treating the 3D printed shape as a prototype that attempts to resemble the final shape for mass production (when, for instance, injection moulding techniques are used) as much as possible as is done in traditional industrial design practices, we use the 3D print as a sophisticated 'technical probe' and form proposal rather than a normal prototype. It is a prototype as a research technique, intended to learn about user behaviours and expectations, as an iteration in the design process of creating organic interfaces. Figure 27 shows such a probe-prototype.

By developing flexible and organic solutions, designers are handing over some of the freedom to the users, who can personalize and customise their interfaces. Organic interfaces can develop over time through their use(rs), matching the stage of development achieved with the tool, artefact and/or medium. An organic interface should allow for growing and evolving with the user. This includes 'wear and tear', reflecting the way the interface is used resulting in a dynamically developing sense of guiding and applying.

With the examples in this paper, I have tried to illustrate a technological approach towards the soft, rounded, organic, replacing the square, edgy, sharp, hard and inflexible. Advances in microcontroller circuits, particularly the Arduino

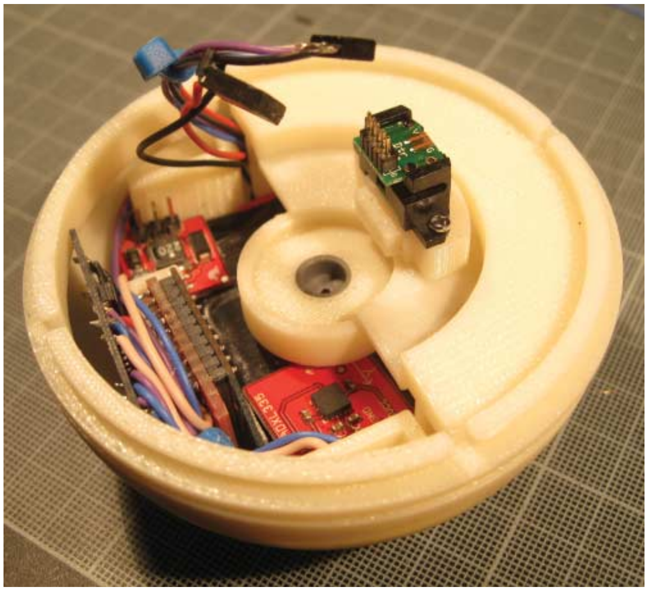

Figure 27. Custom iTunes physical interface for research purposes.

Figure 29. Foundling, (2008), sculpture by Patricia Piccinini.

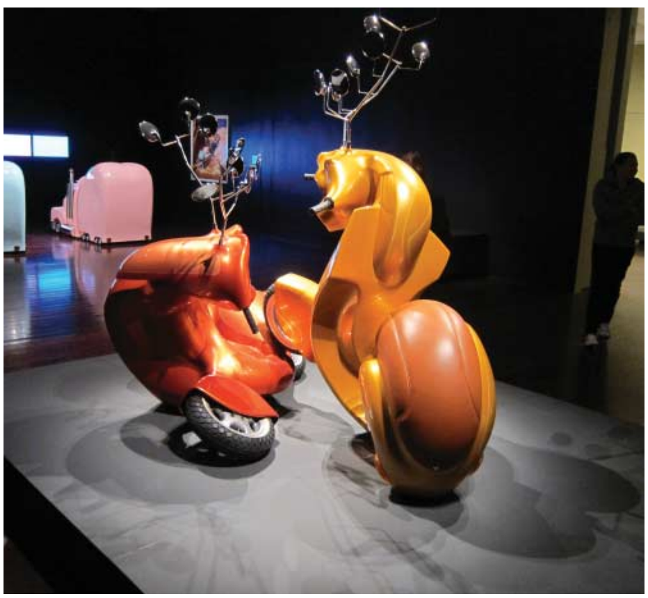

Figure 28. The Stags (2008), sculpture by Patricia Piccinini.

developments, have made it much easier to embed interactive behaviours into products and objects. Extended from this platform is the Lilypad range of interactive textile technologies, including the round and purple (instead of square and green) circuit boards, giving easy access to the development of a wide variety of wearable technologies (Buechley *et al.*, 2008).

Over the last decade we have seen an increasing attention to physical interaction in the field of HCI. This is a natural development from the earlier stages of the field which had more emphasis on the software and the cognitive psychology, and bringing back the physical and craft notion into HCI (McCullough, 1996), also reflected in the success of the yearly conference on Tangible and Embedded Interaction (TEI). This supports the notion of anthropomorphic resonance, through better matched physical interfaces.

The work of Australian artist Patricia Piccinini elaborates the relationship between organic and technological through a range of fascinating sculptures (Messenger, 2011). What is interesting is the dualistic approach of making the technical more organic and the familiar organic strange. For instance, some sculptures show technical artefacts altered to an anthropomorphic presence, such as two mopeds in a loving embrace as can be seen in Fig. 28, while other sculptures show realistic looking unreal animals or human-like creatures as can be seen in Fig. 29. In a similar vein, technology is envisioned in an organic form by the director David Cronenberg in his film Existenz from 1999. The characters in the film enter a computer game world by connecting to a machine, similarly to the process in the Matrix movies or William Gibson's vision of 'jacking in to cyberspace'. However, where these mainstream examples always depict technology as cold and hard, contrasting with the human flesh, Cronenberg shows 'pods' that look more like glowing jellyfish, with an umbilical cord-like of cable that gets connected to the player's own 'bio-port'. Who knows, maybe one day our technology will be as 'organic' as envisioned in this movie … .

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All the photos in this article are by the author in the case of personal projects (except for Fig. 21 which is a still from

a video by Sergi Jorda), the other photographs are taken on location of the actual buildings or objects. I am grateful for the architects and artists whose work I found inspiring and respectfully represent here.

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