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Research

The Grammar of Movement: A Step Towards a Corporeal Architecture

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Abstract. This research uses shape grammars as the basis of a computational tool to explore the relationship between the human body in motion and space, aiming to develop further knowledge about cognition and architecture. Artistic and scientific tools and methods already used to develop these concepts are being studied in order to create a new tool that will help us to understand, through simulation, how the body mediated through architecture can influence human cognitive response and thus behaviour. The goal is a methodology for the design of a "corporeal architecture" that can create a naturally immersive environment in which the ability of its geometry and physical properties to conduct or induce body movements in space for specific purposes can generate experience. Also discussed is the potential of the tool proposed for the study of the human body in movement as a generative strategy in architecture. In describing the parameters and criteria chosen to develop our software, we exemplify briefly how a shape grammar, as a system of rules, can be used to generate sequences of actions, establishing the idea that human behaviour in space can be composed as choreography and provide a means of considering architectural space not only in terms of shape but particularly in terms of life.

The human body, existential space and (virtual) reality

Cyberspace is a very relevant aspect of human interaction today, both for leisure and professional purposes. Most people use email and web-based communication or the new social networks to contact friends, family, partners, clients or employees. These media have also begun to be used for political campaigns and other important areas of public life due to their powers of persuasion and immersion in the minds of users. Human-machine interfaces, such as the Nintendo Wii™ video game console which allows the whole body to move, are developing rapidly but, in general, most of them require repetitive, mechanical and passive body postures, over-stressing the body as a whole. The result is that many people are starting to suffer from health problems such as obesity, poor eyesight, muscular and skeletal disorders or even insomnia and depression.

The problem of the mechanisation of the human body and the loss of individuality was already being discussed in the arts at the beginning of the last century. One example

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is Charlie Chaplin's *Modern Times* which, with characteristic humour, warns against the mechanisation and systematisation of life, and extremely repetitive tasks in labour and leisure activities and even for survival (fig. 1). The film's main character, the "Little Tramp" is shown in a series of comical but paradoxically tragic sketches in which technology is seen as so aggressive and oppressive that he cannot cope with it and ends up having a nervous breakdown, losing his job and wandering homeless in the streets.

Fig. 1. Worker feeding machine. Still from Charlie Chaplin's *Modern Times* (1936)

Given the historical and ethical fact that the timeless role of architecture is to create metaphors of human existence as a way of building and supporting ourselves in the world, what can be concluded, with regard to architecture as art and technology, from the growing activity in cyberspace which forms part of contemporary social interaction? Can this growing activity in virtual worlds be a true indicator of architecture's failure as an immersive system, leading to the search for other experiences in parallel universes as a result of collective dissatisfaction with the built world? For Juhani Pallasmaa,

> The dehumanization of contemporary architecture and cities can be understood as a consequence of a neglect of the body and the senses […] an imbalance in our sensory system, [with] today's growing experiences of alienation and loneliness related to a certain kind of pathology of the senses [Pallasmaa 2005: 16-19].

Pallasmaa emphasises this beyond architecture by stating that contemporary culture is heading towards a terrifying de-sensualisation and de-eroticisation of human relationships in reality. Thus, virtual reality interaction may be demanding a paradigm shift in architecture, forcing it to reconnect with the human being and human emotions by providing stimulating interaction with the physical environment, including built forms, other humans and animals. A "corporeal architecture" that aims to connect with the dweller by triggering his senses, would stimulate his mind and body holistically and provide a naturally immersive environment, offering balance and a sense of well being.

Steps towards a corporeal architecture

> *To think about architecture is to think in another way* […] *is to accept chaos* [and] *live it with the feet*
>
> Bruno Queysanne [1987: 95-98]

One of our approaches to this problem described was to try to understand what kind of means and what type of knowledge of the human body the new media uses to enable it to absorb people for so long. Recent technological progress has allowed many sciences related to the new media to develop very fast, due to their use of computation, programming and artificial intelligence, namely tools that allow complex ecologies to be understood and reproduced through algorithms. These have influenced the latest developments in mind and brain studies, such as cognitive psychology, the physiology of the human body (mind) and the latest discoveries in the neurosciences, such as emotional intelligence, mirror neurons theory and the "embodied mind" paradigm [Silvério Marques 1990: 159-187].

In architecture, the use of these tools could open up the path proposed by Christopher Alexander in the article "A City is not a tree" [1965], in the sense that they could allow for the "artificial" reproduction and simulation of what he calls "natural" cities. Some strategies already use new media to study behavioural phenomena on an urban scale by means of simulation and cross referencing large amounts of data. One example is Space Syntax, based on Hillier's "The Social Logic of Space" [1996]. The application of a generational model with this purpose can be very useful since it offers an understanding of the essential conditions that ensure efficient architecture in terms of human behaviour, Alexander's "natural" approach.

Bearing these concepts in mind, and working within a broad frame of reference that includes the philosophy of action, psychology, anatomy, phenomenology, semiotics, shape grammars and media studies, we have been constructing a body of knowledge on the perception of the human body, which is still disaggregated, and are trying to understand how architecture can incorporate this in order to become more appealing to the senses and have a greater impact on memory. This could involve subjective experience and also appeal to collective memory, whilst reflecting natural human gestures to protect the body, the source of architecture's archetypes. We call such architecture, "a corporeal architecture".

Hopefully, a corporeal architecture will reflect the elementary characteristics that have allowed human beings to group together to form social bonds and cities – what Cabral de Mello [2007] calls "architectural deep structure or genotype",[1] namely the mechanisms underlying the creation of artefacts, tools and architecture, the most complex example, as an essential extension of the human body (fig. 2).

Fig. 2. Still from Stanley Kubrick's *2001: A Space Odyssey* (1969). A step in human evolution, the invention of the tool, using body movement

Some archetypical traces of a grammar of movements

To Vitruvius, the human body was the source of all geometry. As a man of his time, Vitruvius followed the Pythagorean tradition and considered nature the source of all knowledge, transcribed in the form of the perfect number, ten. To Vitruvius, the human body is nature's prime work, incorporating the only creature with ten fingers, and the ability to think, create and manufacture objects. The Vitruvian man does not move to produce geometry, "flat on his back and passive, he is *made* to produce it. The active agents, as Vitruvius tells it, are the compass and the set square. At once a metaphysical

proposition and a ritual formula, Vitruvian man is also and above all the architect's template" [McEwen 2003: 181]. So, the Vitruvian man can be made to produce a circle, and a sphere, since to the Stoics, in the words of Cicero, as quoted by McEwen, they alone "possess the property of absolute uniformity in all their parts", "no other shape can maintain the uniform motion and regular disposition of heavenly bodies" [Cicero, *De natura deorum* 2.47, 2.48 quoted in McEwen 2003: 160].

Being static in itself, the "architect's template" is a tool that represents the canon of human body proportions, and its use generates motion in space. The results produced are meaningful through the action of the architect and the culture to which he belongs.

Leonardo da Vinci rediscovered the Vitruvian man in the Renaissance and created its most famous descriptive drawing in which Man is not static at all, but standing and in motion. Leonardo called this system a Canon of Proportions in which sixteen possible positions for the human body are systematized in the same drawing, generated by variations on two main positions overlapped and inscribed within the cosmological symbols of the circle and the set square. It must be no coincidence either that Leonardo's Canon of Proportions (fig. 3) depicts sixteen actions. As quoted by McEwen [2003: 50-51], Vitruvius says in *De arquitectura* that "the Romans recognized both 6 and 10 as perfect numbers and combined them to make the supremely perfect number 16, finding the rationale for this in the foot, which had sixteen fingers", thus 16, the number 4 squared, was in McEwen's words "the agent and evidence of Roman order and also represented the Etruscan division of the sky into four (two squared) cardinal signs [2003: 51].

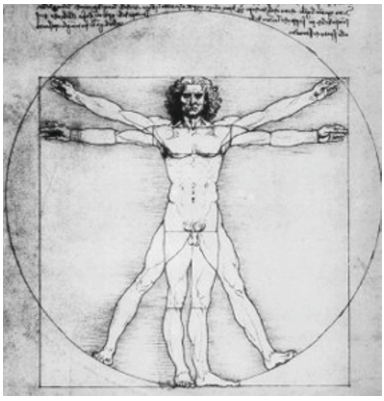


Fig. 3. The Canon of Proportions, Leonardo da Vinci's depiction of the Vitruvian Man, c. 1487. Gallerie dell'Accademia, Venice

Leonardo's interpretation of the Vitruvian man is standing, following the Roman theology of the feet. According to McEwen,

> Arrian, writing in the second century A.D., tells the following story about the arrival of Alexander the Great in India:
>
> *Some Indian sophists, the story goes, were found by Alexander in the open air in a meadow, where they used to have their disputations; when they saw Alexander and his army, they did nothing than beat with their feet on the ground they stood on. When Alexander enquired through interpreters what their action meant, they replied: "King Alexander, each man possesses no more of this earth than the patch we stand on"* [McEwen 2003: 52].

This story gives some meaning to the similarities found between both Vitruvius's description, Leonardo's representation of the cosmological Man and the Hindu archetypical depiction of Shiva as Nataraja, the Lord of Dancers. The visual image of Nataraja achieved canonical form in the bronzes cast during the Chola dynasty in the tenth century A.D. and are often said to be the supreme statement of Hindu art (fig. 4).

Fig. 4. Shiva as Nataraja, canonic depiction from the tenth century A.D.

Shiva as Nataraja is the arch-yogi of the gods and the system is a representation of the dance that generated yoga, which in Sanskrit means union of body, soul and cosmos. It depicts the four-armed body of Shiva, each arm representing the four cardinal directions and therefore, a square. Through its choreography, the balance between the motion of the limbs represents the whirling of time and the immobility of the serene expression on his face; the paradox between Eternity and Time. The ring of fire and light, the circle that circumscribes the body, represents the entire universe in cyclic rhythm and in union through motion. The gestures (*mudras*) and objects in each of Shiva's hands represent the beating pulse and the sound that makes Shiva dance, the first element of the universe and the most pervasive. In Hindu mythology this sound generated the first grammar of Sanskrit, which Shiva transmitted to Panini, the great Sanskrit grammarian, and the first verse of his grammar is called the Shiva Sutra [Goel 2001]. The 'grammar' of movements encoded in the Nataraja depiction of Shiva was transmitted from generation to generation, extending into many symbolic gestures and actions related to spirituality, dance and religion. These yoga postures provide a link to some of the most primitive traditions of reverence to nature, being based on elementary and symbolic geometrical shapes such as the triangle, square, pentagon and hexagon, and embedded in the matrix of our collective subconscious. In eastern culture, Yoga is believed to have a very powerful psychophysiological effect on the individual, expanding his consciousness and improving his overall health and longevity.

The human body in motion as geometrical source and spatial generator

The geometrical proposition of the human body had much focus in the German and the Russian avant-gardes of the twenties, especially at the Bauhaus, where life drawing had always been part of the school's curriculum. Most Bauhaus' Meisters such as Feininger, Itten, Klee, Schlemmer, Kuhr, and later on, Joost Schmidt held this course successively, according to individual focuses. For example Itten concentrated his studies on expressiveness giving focus to the rhythmical coordination of the body limbs and the body structure as a whole, while Klee was interested in the representation of the tectonics

of the human body through linear drawings, where the articulations necessary to movement were emphasized as dots.

Oskar Schlemmer, first hired as Master of Form at the Bauhaus theatre workshop in 1923, based his course on "Man" (1926/27) on the study of Dürer's system of proportion, Leonardo's Canon of Proportions and the golden section. He included in the course curriculum the study of human biology and chemistry, the stages of growth from gestation to maturity and also notions of psychology and philosophy. Schlemmer developed systems to study the mechanics and kinetics of the human body through notation and staged diagrams of movement in space (fig. 7).

Fig. 5. Schlemmer and the Bauhaus's theatre group on the school's stage

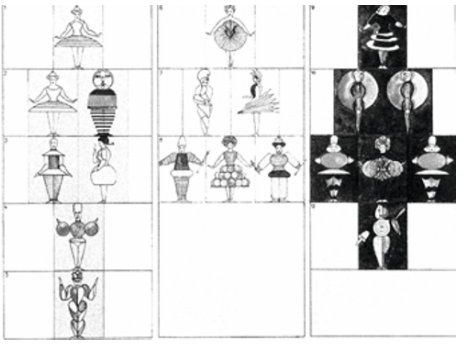


Fig. 6. Schlemmer's designs for the Triadic Ballet, 1922 and 1926

These studies were the basis for his choreographies, culminating in the 'Triadic Ballet', his most famous piece (figs. 5 and 6). In his diary of July 5, 1926, Schlemmer explains why his ballet was given the name Triadic,

> Because three is a dominant number, in which the unitary 'self' and his opposed dualist are suppressed, starting the collective … After that comes five, then seven and so on. The ballet should be understood as a dance of the triad, the switch from one with two, then three. … Further, the triad is shape, colour, space; the three dimensions of space, height, width and depth; the fundamental shapes, sphere, cube and pyramid; the fundamental colours, red, blue and yellow. A triad of dance, costume and music [Schlemmer 1987: 88, translated from the Spanish version by the authors].

According to Pythagorean thinking, the number three was the number that embraced the totality of existence and mathematically originated the possibility of palpable extent. For Plato three was the number of the soul and for Aristotle, it was a beginning, a middle and an end [Le Corbusier 1954: 65-71].

To Schlemmer, space was the unifying element in architecture and the common denominator of the many interests amongst the Bauhaus staff. According to Goldberg, "what characterized the 1920's discussion on space was the notion of *Raumempfindung,* or "felt volume", and it was to this "sensation of space" that Schlemmer attributed the origins of each of his dance productions" [Goldberg 2006: 104] (fig. 8). Schlemmer's system was based on place geometry, coordinating simple elements such as the straight line, the diagonal, the circle and the curve. According to this theory, "a stereometry of space evolves, by the moving vertical line of the dancing figure" [Goldberg 2006: 104].

This stereometry could be 'felt' if space was imagined as being filled with a soft malleable substance in which the figures of the sequence of the dancer's movements hardened as negative form.

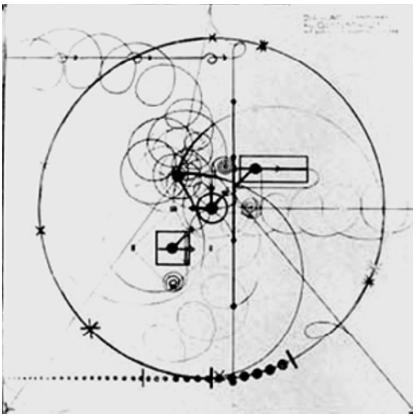


Fig. 7. Schlemmer's diagram for "Gesture Dance", 1926

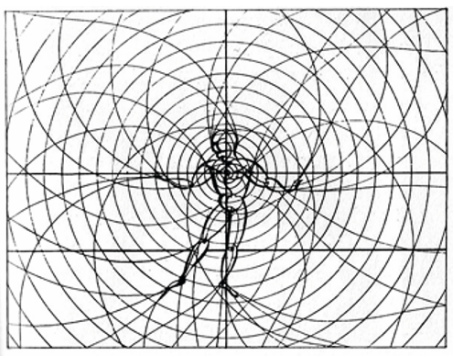


Fig. 8. Oskar Schlemmer, drawing from *Mensch und Kunstfigur*, 1925

These abstract theories were illustrated in 1927 by Schlemmer and his students, at the Bauhaus stage in a dance called 'Dance in space (Delineation of Space with Figure)'. The square surface of the stage floor was divided into bisecting axes and diagonals, circumscribed by a circle and afterwards taut wire was run across the empty stage, defining the 'felt volume' diagram of the cubic stage space (fig. 9). A multiple exposure photograph of this performance by Lux Feininger gives us an image that resembles a living performance of a standing Vitruvian man in motion, generating volume with his body in the void of space (fig. 10). As a self-confessed admirer of classical philosophy, from which he drew support for his aesthetics and ethics according to the mythological opposition between Dionysus and Apollo, it is most likely that Schlemmer devised his "Mathematical Gesture Dance" using this phenomenological approach to Vitruvius's canonic tradition.

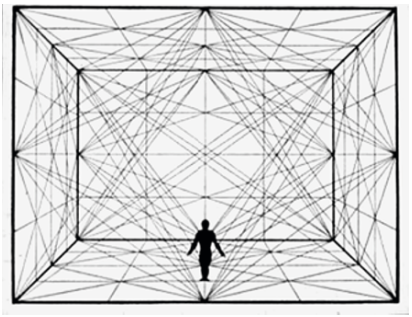


Fig. 9. Schlemmer's drawing for "Figure in Space with Plane Geometry and Spatial Delineations", 1927

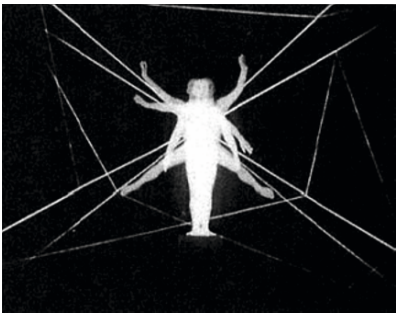


Fig. 10. "Dance in Space (Delineation of Space with Figure)", multiple exposure photograph by Lux Feininger, Bauhaus Stage demonstration, 1927

Praise of the Pythagorean tradition continued with Le Corbusier and the Modulor (1948-1955), considering Mathematics "the majestic substructure conceived by Man to

grant him comprehension of the universe" [Le Corbusier 1954: 71]. The Modulor (fig. 11) was devised as a measuring tool that systematizes the mathematical wisdom of the Pythagorean Triad and Duality and the Fibonacci sequence, and its creator hoped that it could relocate architecture in relation to the human scale, as it was based on the systems of the proportions of the human body, the Golden section and the Vitruvian man. To Le Corbusier, it would be a tuned measuring instrument which, combined with the technical resources of his time, "could make the good easy and the bad difficult" [Le Corbusier 1954: 58], facing the challenges and the growing complexity of the machine age.

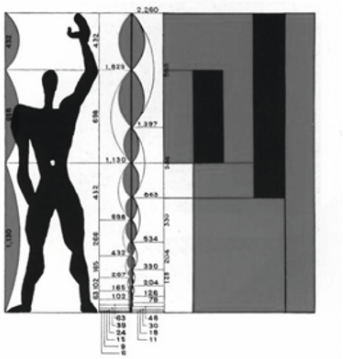


Fig. 11. "The Modulor", Le Corbusier, (1948-1955)

Le Corbusier wanted to express in his work the belief that "only the architect can strike the balance between man and his environment (man = psycho-physiology; his environment = the universe: nature and cosmos)" [1954: 111], a rather holistic view that also recalls humanist thinking. Paradoxically, being the creator of a system of rules that recalls many Renaissance authors such as Alberti, who considered the eye as the supreme organ of perception, Le Corbusier states in his final considerations in the Modulor, "I have stayed within the realm of concrete things, within the field of human psycho-physiology. I have concerned myself only with objects falling under the jurisdiction of the eye [1954: 184].

Le Corbusier's suspicion of the Renaissance architects was based on his understanding of their architecture as more a product of subjective and individual spiritual quests than a commitment to a social or universal philosophy. Ironically, his overall understanding of the "Universal Man" as an inflexible *tabula rasa* that scorned cultural, genre and emotional differences would be the cause of the Modulor's decline, when it became seen as a static, closed and abstract representation of Man. In Pallasmaa's words,

> The modernist idiom has not generally been able to penetrate the surface of popular taste and values, [it] has housed the intellect and the eye, but it has left the body and the other senses, as well as our memories, imagination and dreams, homeless [Pallasmaa 2005: 19].

Regardless of this, it should be noted that twenty-five years before designing the Modulor, in *L'Esprit Nouveau* Le Corbusier expressed the need for rules in architecture based both on scientific knowledge and art and experiment, a scientific aesthetics that combined reason and intuition. This would be based on his studies of cubist painting and sculpture and the musical concept of harmonics, applied to architecture in pursuit of the "fourth dimension, the moment of boundless freedom brought about by an

exceptionally happy consonance of the plastic means applied in a work of art" [Le Corbusier 1954: 29-32] he key to aesthetic emotion being a function of architectural space. Even though the Modulor, as a system of rules, was not complex enough to deal with the challenges of its time, reducing them exclusively to a problem of proportion, its use was intended to open up the path for the architect to work with more assurance, letting intuition flow and making art easier. It can therefore be said with some assurance that if Le Corbusier had had at his disposal the computational means and knowledge available today, the Modulor would probably have produced very different results, encompassing many more parameters and criteria and opening up the path to a more individualized, subjective and "corporeal" architecture.

A New Tool: Genera(c)tiveHumanoidLifeForm: the simulation of simple movements to generate complex shapes / spatial relations with the dynamics of the human body

> *We should start from the elemental. What does this mean? That we start from the plane, the line, the simple surface and that we start from the simple composition of surfaces, using the body*
>
> Oskar Schlemmer, diary entry, May 1929 [1987: 112; our translation]

After Le Corbusier's failed attempt to definitively fill the gap between the human body and architecture, there has been a great deal of criticism but little else has been done to solve the problem in an operative manner. In industrial design, especially in human machine interfaces or in prosthetics, there have been considerable developments that have led towards a kind of "body-tailored" design in which the fundamental concepts developed are flexibility, responsiveness and intuitive use, resulting in more intelligent and corporeal designs. This has been made possible due to recent developments in mind and brain theory and the new digital technologies that allow all kinds of information, including biomechanical processes such as movement, to be translated into a mathematical or programming language.

These tools have been extensively developed in cinema in the so-called computer generated images (CGI) or animations, in which characters are animated as digital puppets and the actor's job is to fill them with life, using his emotions, with all his physical expressions being transposed remotely to the puppet using motion capture hardware interfaces connected to his body in specific places. This information is interpreted by software that translates the information and generates algorithms to animate the puppet, character or avatar. Such algorithms are becoming increasingly complex and more accurate at an astonishing speed. Computer generated animations can mimic body language so faithfully that they can already establish the same kind of empathy or *attunement* that a good actor can create with his public, using his own body. Digital animation also allows the creation of all sorts of objects and geometries, through parametric design and the use of topological geometries, surpassing Euclidian limitations. This allows for the simulation and rendering of zero gravity and underwater environments and also different weather or lighting conditions.

In architectural design, digital modelling and rapid prototyping, tools are gradually replacing analogical design systems, but there is still no single tool that links the psychophysiological characteristics of dwellers and architectural space together as parameters or rules in the generation/simulation of personalised designs which are body-tailored, empathic and therefore "corporeal". Dweller performance and behaviour in space is usually the ultimate architectural test, only possible after construction and

generally involving a great deal of uncertainty. Although the use of such tools will not, in themselves, allow for greater individuation of the user's in-space dwelling or generation, they can certainly help to increase the level of complexity and surpass the generic limitation of other systems such as the Modulor by encompassing rules and parameters that simulate complex bodies and situations.

This current investigation has been trying to develop such a tool and we have started to write an algebraic synthesis of the human body, hoping to transfer the biomechanical process of movement into digital information in a way similar to the method used in artificial life studies and robotics. We wish to open up the view of the canonic Vitruvius tradition by enlarging the universe of the human body types considered, which will allow for the simulation of a greater number of different actions and, consequently, spatial relationships and situations. In our program it is possible to choose different types of body, due to the careful introduction of the values that were chosen as parameters to be inserted in the programming code, resulting in: Male, Female, Child, OverAveragePerson and UnderAveragePerson (fig. 12).

In writing the body of the character in the programming language, the "Genera(c)tiveHumanoidLifeForm", it was necessary to find a way to draw a synthesis of simple geometric shapes that could be used to simplify a human body, bearing in mind that the model drawn must offer as much freedom of movement as possible in order to simulate human motion adequately. The model is a replica of the articulated models usually used in drawing classes (fig. 13). At present, its simple "body" is divided into various main segments, followed by an anatomical simplification of the limbs, so that each section corresponds to a drawing function written in AutoLISP code.

The geometry used in the Humanoid puppet is a set of elementary shapes with a substructure that is represented by drawing: a "circle" for "connectors and head"; and a "rectangle" for "straight limbs", so that the former are responsible for the rotation of the latter, just as the mechanisms of a real human body function.

Each of these functions is a drawing operation defined by three set parameters: insertion point by coordinates (x and y), width of the shoulders (width) and height of the body (height). The parameter percentages have been introduced by approximation to the proportions between limbs, so that they can be manipulated to draw as many variations of "body types" as possible.

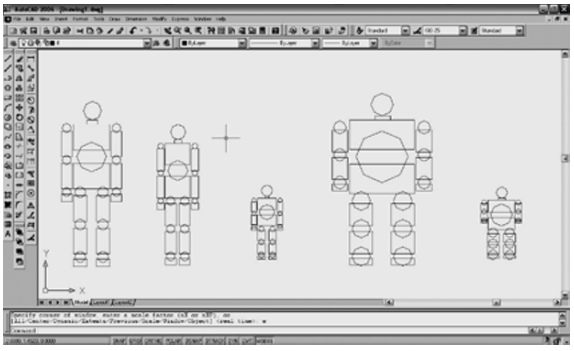


Fig. 12. Output of "Genera(c)tiveHumanoidLifeForm" AutoLISP code: Male, Female, Child, OverAveragePerson and UnderAveragePerson. Image by M. Piedade Ferreira

Fig. 13. Humanoid drawing model used as a reference for digital parametric puppet

By studying the motion of the human body in space, we are trying understand how the human being, as an organism with specific psychophysiological characteristics and an innate capacity for interaction and spatial definition, generates space through movement and gives shape to his habitat "in the same way a bird shapes its nest, with the movements of its body" [Bachelard 2005: 113]. While simulating spatial generation through movement and body language, we hope to find the expression of the architectural genotype and phenotype, the matrix or source of a natural and corporeal architecture based on instinctive human gestures of protecting the body, many of which are universal and the basis of architectural archetypes. To achieve these simulations, at a more advanced stage the program will animate avatars to work as responsive agents in the generation of architectural space, and algorithms will be developed to interpret their movements while performing activities connected with future experiences of the spaces they ought to generate. These algorithms will determine how such space will be generated in terms of shape: in some cases the interpretation will be literal and the form of these spaces a direct transcription of avatar movements whereas in other cases, the interpretation will be more refined and the shape of the spaces generated will only bear a vague relation to these movements.

At this stage, the program that has been developed is a literal interpretation of the avatar's movements and generates animations, or choreographies, by recursion of instructions or transformation rules, in this case, rotation and copy. Shapes and spatial relations are generated by rotating the limbs and the sequential copying of each of the results. The overlapping of the program's output was chosen as an analogy to the Futurist synthesis used to study movement and simultaneity, a technique also developed in film both by the Russian Constructivists such as Popova and Vertov, and the Italian Futurists such as Balla (figs. 14 and 15) and Boccioni (fig. 16). Boccioni's work is a particularly good example of how form might be generated by an interpretation of human movement.

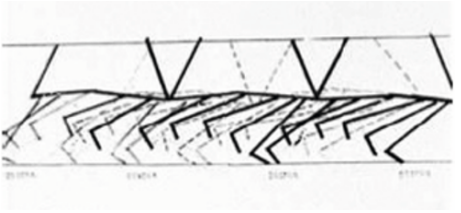


Fig. 14. Giacomo Balla's technical study for *Girl Running on a Balcony*, 1912

Fig. 15. Balla's *Dynamism of a Dog on a Leash*, 1912. Albright-Knox Art Gallery, Buffalo, New York

Fig. 16. Umberto Boccioni's *Forme uniche della continuità nello spazio* (1913, Milano, Civico Museo d'Arte Contemporanea) explores the plastic continuity of the movement of the human body in space

Eadweard Muybridge's work is another important reference in our work. Muybridge was considered by many to be the father of cinema and a pioneer in the study of animal locomotion, using a self developed photographic multiple exposure system called the "Zoopraxiscope" [Zoö + Gr. praxis a doing, an acting (from to do) + scope.] that allowed images to be projected sequentially onto a screen, thus generating animations. Our idea is to create software that facilitates the composition of complex choreographic movements and subsequently the generation of architectural space from such choreographies using algorithms to interpret movement forms and translate them into architectural space. Muybridge's work may be used to depict the functioning of our program. The first step in our software is to animate an avatar to simulate a human moving through space: a person entering home and hanging her coat on a rack, an acrobatic dance performed by someone in a disco listening to his favorite music, or the jump of an Olympic athlete in a stadium. The second step is to use an algorithm to interpret this movement according to some relevant criteria and obtain, for instance, a sequence similar to Muybridge's "Animal Locomotion," Plate 165 (Jumping and pole vaulting) (fig. 17, top). This intermediate output might then be used to generate form using the algorithm to overlap image stills from the sequence (fig. 17, bottom).

The tool we are designing, therefore, will ultimately be used as a dynamic stage set, where parametric avatars or puppets are commanded by the designer and used as flexible templates in the generation of space, producing geometry by their motions, recorded on geometrical surfaces that will be codified in a mathematical language. The quality of the result will depend on the criteria adopted by the designer when choosing characters for the bodies and composing their movements in space. The designer will be working as a director or puppeteer on a customized stage where the characters will perform actions according to his rules or criteria and, by printing the resulting shapes by rapid prototyping, the result will be a "corporeal" materialization of a virtually generated sequence of actions. Rees' work "Putto 8 2.2.2.2" (fig. 18) is useful in illustrating this idea. His work shows the process of using rapid prototyping for making physical form from shapes created by simulating body movement. Rees used software to compose

humanoid shapes that were then digitally fabricated, but the process of composing such shapes was not automated. This process was, therefore, time-consuming and the complexity of the composed shapes limited. Our work draws inspiration from his works but it goes one step further by automating the process of generating such shapes. Our idea is to create shape grammar-based software that eases the composition of complex choreographic movements by interpolating between choreographic postures defined as key steps in a movement sequence.

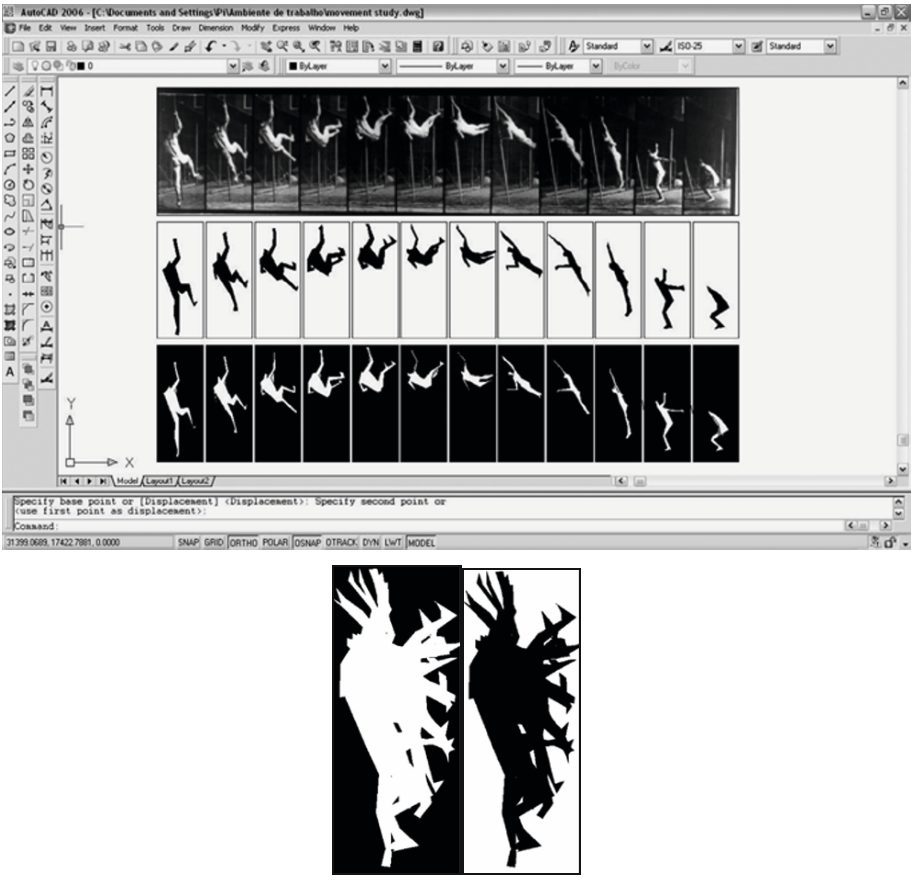


Fig. 17. Simulation of the form generation process in the "Genera(c)tiveHumanoidLifeForm" under development. Eadweard Muybridge's "Animal Locomotion," Plate 165 (Jumping and pole vaulting) of 1887 (top) illustrates a possible intermediate output of this program. Image stills in the sequence are then overlapped to obtain two different results (bottom). Images by M. Piedade Ferreira

Fig. 18. Michael Rees's "Putto 8 2.2.2.2, 2003", explores through digital modelling and rapid prototyping the virtual and material composition of (im)possible bodies. Source: http://home.earthlink.net/~dadaloplop/michael_rees.html. Reproduced by permission of the artist

The Grammar of Movement – Rules for a performance machine

> *Since the art of the actor is the art of plastic forms in the space of a stage, he must study the mechanics of his body* [and] *train this material so that it is capable of executing instantaneously those tasks which are dictated externally*
>
> Meyerhold, The Actor and Bio-Mechanics
> [Campbell, Lynton et al. 1971: 80]

In 1909, Marinetti's first Futurist manifesto was published in Russia, providing Russian artists with a powerful weapon against the art forms of the past. Futurist ideals were adapted to support a cultural revolution that started with Mayakovsky's 1912 quasi-futurist manifesto "A Slap in the Face of Public Taste" and generated many artistic movements that would grow in the twenties, such as Suprematism, Rayonism and Constructivism, the latter seen as an ethical proclamation of a social and political revolution that would have a major influence on the development of the aesthetics of the Modern Movement, especially Le Corbusier's architecture. Constructivist artists believed that to surpass academism in the arts, speculative activities such as painting should be abandoned and artists should use real space and real materials in performances of what they called "production art".

This kind of non-conventional theatre combined many kinds of performance arts such as circus arts, puppetry or music hall, and the movement of the human body was studied with actors on stage, using methods and practices such as the eurhythmics of Emile Jacques-Dalcroze, the eukinetics of Rudolf von Laban and Meyerhold's Bio-Mechanics. Meyerhold would become, in 1921, the Director of the State Higher Theatre Workshop in Moscow, where he developed bio-mechanics as a system of rules for actors, based on physical discipline and self-awareness. This allowed for a new dynamic style of theatre and, in the words of Meyerhold, the actor could base his art on scientific principles, transforming the entire creative act into a conscious process which would help him use his body's means of expression correctly to arouse the emotions of the spectator,

inducing him to share his performance [Campbell, Lynton et al. 1971: 60-81]. "The Magnanimous Cuckold" (fig. 19), 1922, was Meyerhold's first staged Constructivist performance, in which the actors were carefully placed and conducted by the director in a rhythmic production. The stage set was designed by Popova and consisted of a set of interconnected apparatus operating as a dynamic extension of the actors' movements in space.

Fig. 19. Stage set for Meyerhold's "The Magnanimous Cuckold" designed by Liubov Popva, 1922

Merging the actor with the scenography was also one of the intentions of the Futurists, who wanted to make a synthesis of sound, scene and gesture to create a psychological synchronism in the soul of the spectator, compressing into a few minutes of improvisation innumerable situations, sensibilities, ideas, sensations, facts and symbols (see [Goldberg 2006: 26]). The Futurists also outlined rules for the movement of human bodies on stage, advising the actor to gesticulate geometrically, in a draughtsman-like topological manner, synthetically creating cubes, cones, spirals and ellipses in mid-air. To explore these concepts, many futurist artists constructed and performed with "Übermarionettes" or life-sized puppets whose geometry would allow the idea of a dynamic sensation made eternal through mechanization to be explored.

Although these concepts were developed to create a sense of "gripping" or immersing the spectator in the actor's performance, it is possible to establish an analogy between this kind of experience and an architectural space serving as a dwelling that is generated by a kind of actor, in this case, the tool we are developing, a humanoid puppet in a flexible digital setting. In other words, if the movements and expressions of an actor on stage or film can arouse the emotions of the spectator and if these movements can be translated into a material architectural space, the dweller may sense the actions and emotions that generated the space.

Following Meyerhold's scientific methodology, in order to achieve a performance, or a space, that can "grip" the spectator or the dweller, it is necessary to establish a system of rules that govern the actor's body language as a communication tool. According to Schlemmer's performance theory, these rules must be considered decisive in the transformation of space through the action of the human body: the rule of the circumscribing cubit space; the functional laws of the human body in its reaction in space, the rules of human locomotion in space and the metaphysical forms of expression. Leonardo da Vinci, in his treatise *On Painting*, presents a set of rules that allow for the appropriate depiction of the human body so that the postures of the characters in the paintings represent motion in their bodies and especially in their minds (see [Kemp 1989: 120, 144-146]).

As previously stated, in a further phase our tool will allow the action and reaction of dwellers, as responsive avatars in digitally constructed environments, to be simulated. In this case, the shape of the architectural spaces will be intentionally manipulated by the user to create a certain psychophysiological impact. This can be achieved by changes in light, colour, texture or sound and by placing the architectural elements in ways that will make the user follow certain paths in certain rhythms, similar to the method used by Meyerhold in the setting of "The Magnificent Cuckold". By "composing" the dweller's movements in space, bearing in mind that he is always constructing an individual and subjective experience, we hope to achieve a synthesis of sensory stimulation that will immerse him in architectural space on a subliminal or subconscious level. With this approach, we are trying to test through behaviour simulations whether it is possible to establish a calculated body/mind game with the dweller that works in the same way as film or computer game experiences, and to see if this methodology can be useful in generating designs that can provide the potential for individuation and a more corporeal experience of architectural space.

In this sense, our first operational approach to shape grammars aims for an understanding of how the dynamics of the human body codified by rules can be used as a tool to generate architectural space and thus corporeal experience. We hope that the systematic use of rules will help us understand what is required to reproduce the human body in motion and also how to generate sequences of actions and architectural space by simple or combined motions that have a specific impact on the human body in a holistic sense.

In the grammar of movement that is being developed, one or more shape rules enabling the body to move from one position to another correspond to each figure. The starting position is the static position of a standing human and this brief set of rules can be used to generate choreographies. This language will be extended to encompass other figures, thereby enlarging the universe of actions. Subsequently, it will be possible to define several sublanguages, for instance one for dance, another for yoga, another for common daily tasks and so on, bearing in mind that these languages are subsets of the language of human movement. Our simulation tool will be developed according to the rules or set parameters codified by the rules in the grammar.

In the grammar developed so far, the chosen movements are yoga postures, namely a set of yoga postures due to their anthropological value as some of the most primitive expressions of human consciousness of the cosmos and also their psychophysiological impact on the human body. They have also been chosen for their symbolic elemental geometry and their capacity to generate complex choreographies by allowing a great variety of combinations of elements and coherent results from random or chosen rules. We will now present a simple rule description, and give some examples of generated designs, or choreographies, describing different levels of complexity. Twelve rules have been developed so far, and the grammar is a composed grammar in order to achieve a more extensive description of the transformations which occur. Each rule presents two views on each side, a front view on the left and a side view on the right (fig. 20).

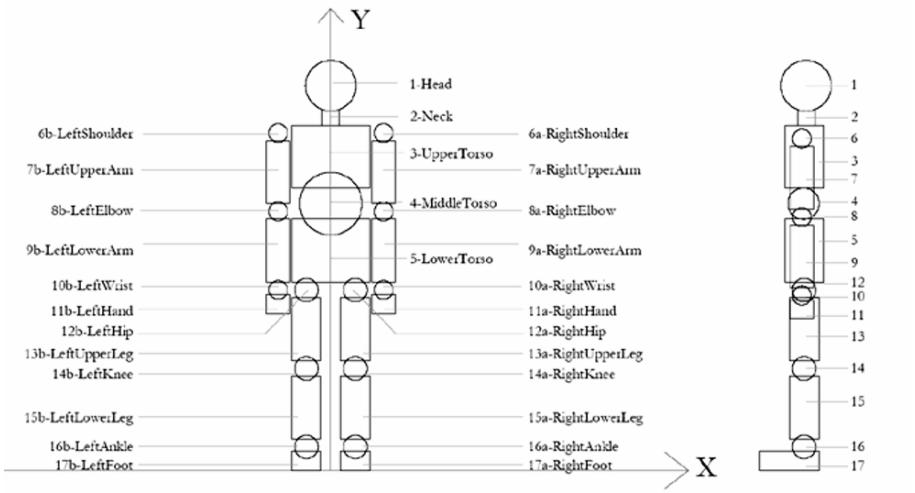
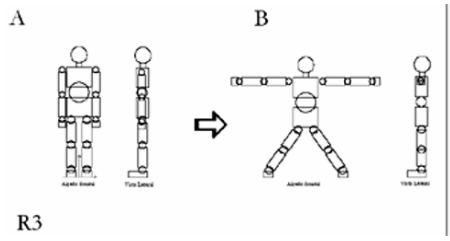
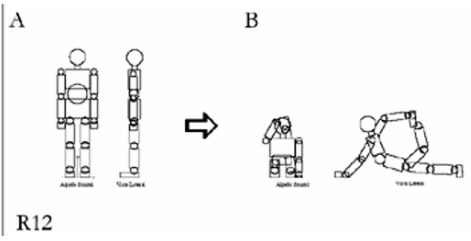


Fig. 20. Grammar of Movement Initial Shape. Image by M. Piedade Ferreira

The initial shape is an output of the Genera(c)tiveHumanoidLifeForm program, a parametric humanoid based on the human body's system of proportions. To facilitate the application of the rules for each geometrical shape that composes the "body" each one was identified by a number, as shown in the diagrams in fig. 21. Each rule moves a set of these "body" parts following a proper procedure. Consider, for instance, Rule R3 in fig. 22. To rotate the right arm centring on the shoulder until it becomes parallel to the ground, one of the movements included in this rule, the procedure is as follows: with centre in 6a, rotate 90° the "body" shapes 6a ; 7a ; 8a ; 9a ; 10a ; 11a. This rule also moves the left arm and the two legs using similar procedures. Another rule, R12, is shown in fig. 23. These rules encode a vocabulary of choreographic postures and can be used to introduce them in a chosen sequence on strategic points in space, thereby defining a specific choreography. Fig. 23 shows an example of a choreography obtained by random application of the rules. The set of all possible choreographies that can be generated from the rules form a language of choreographic designs. Future work will be concerned with two aspects. The first is to impose restrictions on the rule application sequence thereby creating higher level rules that can be used to define sublanguages. The other is to write rules to interpolate between postures and originate movement.





Figs. 21 (left) and 22 (right). Examples of Rules R3 and R12, respectively.
Images by M. Piedade Ferreira

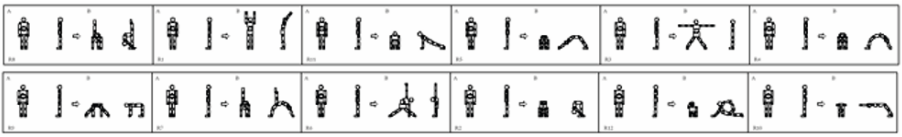


Fig. 23. Choreography generated by random application of the rules.
Images by M. Piedade Ferreira

Final considerations

The work described in this paper aims to demonstrate our efforts to gather a consistent body of knowledge on what may be the decisive parameters needed to start to develop a design methodology which, by using a carefully selected system of rules and tools capable of encompassing a large amount of complex parameters, can generate objects that allow for a more intuitive, intelligent and emotional interaction between them and dwellers. Our aim is that this "corporeal" view of architecture will be able to operate in a prophylactic or therapeutic way capable of confronting some of the adversities generated by the impact of today's technology on the human body, by stimulating its sensory system holistically. We have also tried to demonstrate how the incorporation, from an historical and critical standpoint, of other systems and methodologies, technological, artistic or scientific for example, can be very useful in the development of a new tool, since they have already opened up the path required for the work but have stopped, due to a lack of means or simply due to changes in technological, cultural or political conditions. In addition, this research has allowed us to reflect on the importance of a structured and reasonably reliable system of rules or criteria that can support the use of such tools, such as the simulator we are trying to develop, bearing in mind that, as Le Corbusier pointed out in "*Des yeux qui ne voient pas*", a tuned instrument is not enough to generate harmony, it is necessary to use standards, "… the product of logic, of analysis and painstaking study; they are evolved on the basis of a problem well stated. In the final analysis, however, a standard is established by experimentation" [Le Corbusier 1954: 33].

Notes

1. Cabral De Mello's thesis *A Arquitectura Dita / Anamorfose & Projecto* [2007] adapts to architecture the equivalent concept coined by Saumjan [1965].

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