Basic Body Plans for Soft Modular Pneubotics in Architecture

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Osnovni tjelesni nacrti za mekane modularne pneubotske konstrukcije u arhitekturi
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FIG. 1 Conceptual 3D rendering of basic body plans: From upper left to lower right: BPA; BPB1,2,3; BPC1,2,3 and BPD

SL. 1. Konceptualni prostorni prikaz osnovnih tjelesnih nacrta: Odozgo lijevo prema dolje desno: tip A; tip B1,2,3; tip C1,2,3 i tip D
Basic Body Plans for Soft Modular Pneubotics in Architecture

Osnovni tjelesni nacrti za mekane modularne pneubotske konstrukcije u arhitekturi

This article introduces a theoretical model for the design of pneubotic structures that can be constructed and actuated by using the modular unit volume element. Through analysis of construction of soft robots, pneumatically adaptable and responsive structures and art installations, a set of four basic body plans is proposed, as abstract expressions that form a base for the design of soft modular pneubotics in architecture.
INTRODUCTION

UVOD

Biomimetic pneubotic structures in architecture are pneumatically responsive and adaptable structures still in early development that follow the development of soft robots. Unlike the more widely spread hard robots, whose parts are made of rigid materials and whose movements are mechanical, soft robots are made of elastic materials that mimic the structure and movement of soft body organisms. Soft pneubotics can be regarded as a recent invention, although some examples of soft pneumatic automata existed before the digital era and some hard air-run automata also existed in the 19th century. The majority of recent pneubotics in architecture mostly use linear pneumatic actuators, be it hard air cylinders or soft artificial muscles, and less often volume elements to actuate the structure. Their morphodynamics range from very fast movements and drastic transformation like those in Tower 2 structure from Hyperbody Group to smaller changes like the ones used in the adaptable 375 m² pavilion for temporary exhibitions Airtecture form Festo tested in Germany. Less often are those structures soft in both their key segments – their construction and actuation elements. With all their components and performance, pneubotic structures often appear as artificial bodies similar to living beings.

The idea of a “body” is already present in the field of soft robotics, as well as in art installations and adaptive and responsive architecture. It is often used to describe a part or a whole structure. Lipson Hod for instance, in his research on evolutionary technics of developing robotic controllers, uses the terms morphology – for physical structure, and controller, for a “separate unit that governs the behaviour of the morphology”, in control theory also called plant and the control, to describe the body and the brains of robots. In computer sciences, terms borrowed from biology like genotype and phenotype are often used to describe the generative procedure and resulting finite digital representation respectively. Karl Sims uses directed graphs (genotypes) to generate bodies of virtual creatures (phenotypes) as “a hierarchy of articulated three-dimensional rigid parts”. He also uses anthropomorphic terms like “body”, “leg segment” or “limb segment”, or else “brain” to describe the structure and logics of evolving virtual creatures in simulated physical environments. On the topic of new problems regarding design of soft robots, Iida and Laschi suggest novel approaches to complex simulations of soft robotic bodies and sensory-motor processes allowing for body-control co-optimisation. The research in architectural robotics is thus conducted on the level of the body and of computer control – as a sort of artificial intelligence of the structure.

Although soft robots are more complex to simulate, they are in fact less complex (and cheaper) to produce and easier to interact with users and the environment, due to their softness and (body/material) compliance which makes them less prone to damage and less likely to hurt users unlike hard robots. Marchese, Önal and Rus use the term continuum body to describe parts of a fish robot that has actuation part constructed as one continuous element with built-in “spine” and expandable sides with embedded pneumatic network, instead of a series of parts typical for hard robot structures.

Many other authors also use the expression “soft body” when describing soft robotic structure. Wever even calls a pneumatic cushion of otherwise nonrobotic tensairity structures “a pneumatic body”. Describing classical robotic bodies, some authors use expression like “robots having hard body plan”, further differentiating soft from hard robots.

THE THEORETICAL CONTEXT OF A “BODY”

Teorijski kontekst „tiJela”

The French philosopher Gilles Deleuze describes a “body” through terms of longitude and latitude. It can be anything that has these properties. A body “[...] can be an animal, a body of sounds, a mind or an idea; it
can be a linguistic corpus, a social body, a collectivity. We call longitude of a body the set relations [...] that is between unformed elements. We call latitude the set of affects that occupy a body at each moment, that is, the intensive states of an anonymous force. The longitudes and latitudes together consist Nature [...] which is always variable and is constantly being altered, composed and re-composed [...].13 Regarding modularity and reconfigurability, Hod Lipson states: “Reconfigurable robots are composed of modules that can be connected, disconnected and rearranged in various topologies to create machines with variable body plans. Self-reconfigurable robots are able to rearrange their own morphology, and thus adapt in physical reality.”14

Applied to architectural structures, the longitudes of their bodies are their material, structural and geometric properties, while their latitudes are their physical, static, dynamic, user-induced or other influences. Dynamically adaptable structures thus expand their longitudes to a greater span of properties like motion, physical properties, changing geometries and disposition of elements in order to better relate to their latitudes, their capacities being actualised more frequently. Structural body as a machine or a swarm of machines is a structure that can produce an effect of change in its longitude in accordance to the change in its latitudes, but can also exist in relation to much greater latitudes. Compared to a notion of society and networks, Deleuze and Guattari connect “[...] large-scale networks with the networks in the body, and between bodies, so that we start to see things like temperament and identity as emergent properties that are products of the machines immanent in the initial conditions”.15

Kaas Oosterhuis and associates, in a trans-disciplinary research project Hyperbody, expand the idea of a body to a hyperbody, i.e., a body that contains a computer code. Hyperbody is thus an informationally permuted body – a robotic structure capable of executing the code and reacting within longitudes and latitudes of the field of its possibilities. In this manner, the new term can describe complex relations within the structure and within the context. Citing the research group Hyperbody, Gruber relays that “Hyperbodies are pro-active building bodies acting in a changing environment”16, and Bier explains: “A hyperbody is to architecture what hypertext is to literature. [...] A single computer is worthless in many ways. [...] An isolated building has no importance whatsoever. Only by virtue of its relations to its users and other built bodies, buildings literally build up meanings in our lives. I see hyperbodies as the ultimate form of relational building bodies.”17

Structure thus becomes “living formation” that reacts and learns, and, if networked with other bodies, it can exchange information in response to their latitudinal “experiences”. Thus, a meta structure can be created that encompasses experiences of all its individual structural bodies.

A BODY PLAN

MANUEL DELANDA

Manuel DeLanda states: “Deleuze uses the term ‘abstract diagram’ (or ‘virtual multiplicity’) to refer to entities like the vertebrate body plan, but his concept also includes the ‘body plans’ of non-organic entities like clouds or mountains”.18 He also explains that body plan does not contain details about the numbers and shape of elements, for instance proportions and shape of limbs of vertebrates, in order to cover a wide spectrum of possible combinations of measurable parameters of their forms.19 In the context of parametric design, DeLanda says that extensities of a body (which represent longitudes of a body) are represented as a procedure of its designing (procedural programming of its formation, i.e., a body plan, a genotype), and parametric intensities that determine its shape and thus represent the latitudes of a body – a phenotype. Body plan is, therefore, a parametric shell, emptied of its parametric intensities, whereas the body is the totality of latitudes and longitudes that give it shape. When intensities are changing, the structure is polymorphic and when the intensities are changing, the structure is morphodynamic. In computational design techniques, a structural body can be virtually morphodynamic during the design process, but the assessment whether the structure will be morphodynamic after the construction has finished depends on the capacity of the structure for changing its intensities in its lifetime. A body is generated through a procedural instruction. As a genetic means it is also used to form the geometry of soft robots, as a diagram of robotic elements that can be combined into specific sets optimised for certain purposes. Further on, exploring the space of possibilities, optimal forms of complex body plans of pneumatic structures can be generated, all based on combinations and permutations of established basic body plans.

AIM, METHOD AND MATERIALS

This article focuses on the possibilities of constructing pneumatic architectures that could be constructed and at the same time actuated through the use of a modular volume unit elements. In order to make a system

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1 This work is based on the research results from the PhD dissertation: Biomimetic Pneumatics in Architecture: Research Model for Modular Structures by Davor Andric, completed in 2017 at the University of Zagreb, Faculty of Architecture, under supervision of Karin Sersen and Josip Galic, and on subsequent research done by the authors.
2 Bier et al., 2012
3 Kronenburg, 2003. The pavilion can be packed in a standard container and transported to another location. The main structure consists of eighteen pneumatic beams on “Y” shape pneumatic columns. The active stability system uses tensile pneumatic ties like artificial muscles that counteract the effects of changing outside actions on structure thus allowing for active load distribution management of the structure.
4 Lipson, 2006
5 Sims, 1994
6 Sims, 1994
7 Iida, Laschi, 2011
8 Dickinson, according to: Rus, Tolley, 2015
9 This kind of network or embedded pneumatic network is sometimes also called pneuNet.
10 Marchese, Onal, Rus, 2014
11 Wever, 2008
12 Ilievski, Mazzeo, Shepherd, Chen, Whitesides, 2011
14 Lipson, 2006
15 Ballantyne, 2007: 32
17 Oosterhuis, 2012: 16
18 DeLanda, 2002
19 DeLanda, 2002
for constructing a plethora of such actively adaptable pneubotic structures, an idea of a basic body plan is used to extract basic functional schemas of soft robots, of interactive art and architecture, in order to make a library of elements to generate simple and complex pneubotic structures in architectural design. The goal is to find a set of basic body plans that can be used to construct concrete pneubotic structures of architectural scale by using one single element that could be mass produced but could manifest itself differently according to its local situation within the structure.20

Based on the previously discussed theoretical context, a model for classification of soft robots and soft structures in art and architecture is set up to produce a set of basic body plans for constructing concrete modular soft adaptable structures in architecture. The basic modular element that this research proposes and examines is a soft expanding cube that can generate form and actuate a soft body. The shape of the cube is selected as a basic geometrical unit that enables addition in all three spatial dimensions. A soft cube can also be further folded into other geometrical shapes in order to achieve specific functionality like local rotation or bending etc., within basic body plans.

A basic body plan here is an expression used to describe the structural logic of soft robotic part reduced to its most abstract level. These basic body parts having basic body plans can, further on, form complex bodies with complex body plans. To enable translation of movement from small soft robots to elements of architectural scale, basic body plans are formulated in terms that can best describe construction and transformation properties of a body part. Examples from the field of contemporary soft robotics and adaptable structures in art and architecture are here sorted according to the manner in which they get modified and transformed through inflation of their pneumatic elements.

Examples from the field of contemporary soft robotics and adaptable structures in art and architecture are here sorted according to the manner in which they get modified and transformed through inflation of their pneumatic elements. Basic body plans are corroborated through concrete cases and shown in a summary table (Table I) and in conceptual 3D rendering (Fig. 1).

**Basic body plan type A** – The first and most simple detected basic body plan is a single element or a group of single elements that are not directly connected to each other. It can be represented by the expression: \( \text{BPA} = n \cdot \text{UE} \). It is important to note that these expressions are not mathematical formulae but short codes instead. In this case it states: (Basic) Body Plan \( A = n \) (a number of) Unit Elements.

Art installation Bubbles by Foxlin Studio follows this main body plan. It is a pneumatic installation comprised of large pneumatic volumes in space that can deflate or inflate reacting to visitors, by opening or closing the spaces between pneumatic bodies.21 Another case enacting this body plan is the Inflatable bubble stabilizer by Takuya Onishi.22 It is a system of pneumatic elements that can be inserted into structures damaged in earthquakes to provide temporary stability through inflation. Some similar structural stabilizing bodies are being researched by the Air Dشن company in Japan to form an actively responsive system of earthquake building insulation. Pneumatic devices inserted between foundations and the house adaptively inflate according to the type and intensity of the earthquake thus insulating the structure from the ground in an optimal manner.23 Bio-Kinesis by Kim Minwoo and Jo Sunghye, on the other hand, is an interactive soft kinetic media skin or rather art installation consisting of an array of biomimetic pneumatics that react to the presence of people.24 Each unit is made of a hard surface onto which a soft body is mounted. Each body works independently of each other and does not influence others’ geometry.

**Basic body plan type B** – The analysis of registered cases has resulted in recognition and definition of the basic body plan B, which describes structures with directly connected pneumatic elements. The research registered three specific subtypes B1, B2 and B3.

**Basic body plan type B1** – The first basic body plan of type B is a linear series of connected pneumatic elements. This basic body plan can be written as \( \text{BBPB1} = x \cdot \text{UE} \), since it only has one spatial dimension.

Hartz, Bögle and Schlaich proposed in their paper a pneumatic roof and facade systems that can telescopically shrink and expand depending on the air pressure within the air cushions.25 This can be most succintly expressed by basic body plan type B1. Further on, Responsive Structure is another research project in architectural application of this soft structure mechanism, through which Amin Sadeghi and Mehran Gharleghi and colleagues

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20 Modular pneubotic element represents a series of identical products, which fits into industrial paradigm of mass production, but thanks to different rates of inflating it becomes similar to but different from other elements in use, which altogether fits into post-industrial paradigm of mass production of differences.

21 ‘Bubbles’
22 Onishi, 2004
23 Sakamoto, 2008
24 Park, Kim, 2016
25 Hartz, Bögle, Schlaich, 2009
26 ‘Studio Integrate: Responsive Structures LDF’
27 Sumovski, 1893
28 Cobo Arévalo, 2014
29 ‘Formeta’
30 ‘Pneumatic structure Archives’
31 ‘Bubbles’; Onishi, 2004; Sakamoto, 2008; ‘Bio-kinesis’
32 Hartz et al., 2009; Sumovski, 1893; ‘Studio Integrate: Responsive Structures LDF’
33 Cobo Arévalo, 2014; ‘Formeta’
34 ‘Pneumatic structure Archives’; Coney et al., 2013
35 Correll et al., 2010; Shepherd et al., 2011; Sun, Song, & Paik, 2013; Shepherd et al., 2013
36 Marchese, Önal, et al., 2014; Marchese, Katzschmann et al., 2014; Iliievski et al., 2011; Martinez et al., 2013
37 ‘Robotics: Soft Hands’; Tarczewski, 2005
38 Albert et al., 2013; ‘Amorphobotwork: Sixteen birds’
from London studio Integrate explore possibilities of designing, manufacturing and construction of light modular adaptable pneumatic structures. By inflating the series of smaller cushions, a pneumatic actuating element contracts, causing the connected main element (a series of bigger cushions) to bend, thus achieving lifting to allow for ventilation of space and penetration of light.\textsuperscript{26} Another, older example of this type is a series of tubular elements connected linearly in order to make a self-erecting \textit{bridge over a precipice} proposed in 1893 by J. A. Sumovski. A series of tubes is inflated, at the start all but the first one; and after inflating the first one the structure is then lifted.\textsuperscript{27}

**Basic body plan type B2** – These are all soft bodies sharing a basic body plan: BPB2 = xy \cdot UE. This means that the unit elements are connected to each other and arranged into planar structures.

*Prototype of a varying morphology beam* from 1970 by José Miguel de Prada Poole\textsuperscript{28} is just such a structure made of a series of interconnected pneumatic cushions staged into two rows. The beam changes its curvature depending on the intensities of pressure in individual cushions, and the offset of rows by half the cushion makes the change in curvature even more intense. *Pneumatic Envelope* by Rick Sole\textsuperscript{29}, further on, is a surface structure made of pneumatic cushions with a layer of light blocking material. Inflating individual cells results in setting the light-blocking lamina apart so that the light can pass through the structure. The envelope thus becomes an adaptive skin regulating insolation in relationship to interior needs and outside conditions. Inflation of one cushion pulls the surrounding cushions to itself, since inflation reduces the size of the cushions in the system plane, but that influence is not severe and does not compromise the functioning of the system.

**Basic body plan type B3** – This basic body plan is a three-dimensional version of the same basic body plan, so the expression for it is: BPB3 = xyz \cdot UE.

According to this principle functions the pneumatic installation *Dynamat* by Mark Fisher and Simon Conolly from 1971. It is a structure made of an array of interconnected square pneumatic cushions arranged in tree layers, which changes shape depending on which cushions are inflated or deflated. Its movements were pre-programmed by means of a sound recording that dictated inflation and deflation of parts of structure producing different concave or convex forms of its double layered surface.\textsuperscript{30} On the other hand, *Evolving soft robots with multiple materials* by Cheney, MacCrudy, Clune and Lipson are

<table>
<thead>
<tr>
<th>Type, expression and graphical scheme</th>
<th>Cases: sketches and names</th>
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<tr>
<td>A (unit element) BPA = n \cdot UE</td>
<td>Bubbles; Inflatable bubble stabilizer; Air-floating-type base isolation device; Bio-Kinesis\textsuperscript{31}</td>
</tr>
<tr>
<td>B1 (linear series) BPB1 = x \cdot UE</td>
<td>Pneumatic structures in motion; Bridge over a precipice; Responsive structure\textsuperscript{32}</td>
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<td>B2 (planar series) BPB2 = xy \cdot UE</td>
<td>Prototype of a varying morphology beam; Pneumatic Envelope\textsuperscript{33}</td>
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<tr>
<td>B3 (spatial series) BPB3 = xyz \cdot UE</td>
<td>Dynamat; Evolving soft robots with multiple materials\textsuperscript{34}</td>
</tr>
<tr>
<td>C1 (flexible side + expandable side) BPC1 = FS + ES</td>
<td>Chain structure soft robot; Multigait soft robot; Multi-chamber bending actuator prototype; Self healing soft robots resilient to puncture\textsuperscript{35}</td>
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<tr>
<td>C2 (flexible middle + expandable sides) BPC2 = FM + n \cdot ES</td>
<td>Autonomous soft robotic fish; 2D robotic manipulator; Soft robotic compliant grippers; Robotic tentacles with three-dimensional mobility\textsuperscript{36}</td>
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<tr>
<td>C3 (membrane + expandable core) BPC3 = EM + FS</td>
<td>Soft Fingers; Deployable inflated bridge\textsuperscript{37}</td>
</tr>
<tr>
<td>D (hard parts + expandable part) BPD = HP + EP</td>
<td>Soft robotic arm; Sixteen birds\textsuperscript{38}</td>
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virtual soft robots made of several different types of materials in three-dimensional shapes. Individual voxels\(^{39}\) can contract, expand or else be inert soft or inert rigid. By various placement of voxels and their actuation, a plethora of soft robots with different locomotion can be generated.\(^{40}\)

**Basic body plan type C** – The following main basic body plan is that of type C, as a combination of flexible and expandable parts, which can be developed in three basic subtypes: C1, C2 and C3.

**Basic body plan type C1** – This basic body plan is perhaps the most important because it enables the construction of linear and planar soft bodies that bend. They achieve this quality through their construction that consists of sides that bend and sides that expand. The structure can be of same material with different thicknesses or a composite of two or more materials. Basic expression describing these bodies is: BPC1 = FS + ES.\(^{41}\)

Soft robots with this type of basic body plan are often made of a series of modular elements that use bending, for example a chain structure soft robot made of 6 bending segments to achieve locomotion (crawling in this specific case).\(^{42}\) Hence these robots’ body can be written as CBP = 6 ∙ BPC1, CBP meaning complex body plan.\(^{43}\) Other robots can have still more complex design like a multigait soft robot with a central body and 4 segments connected to it like four limbs, and which is then capable of crawling and undulating with complex and sophisticated movements.\(^{44}\) These robots’ complex body plan consists of one middle segment and 4 limbs attached to it, i.e., CBP = BPC1 + 4 ∙ BPC1.\(^{45}\)

**Basic body plan type C2** – This basic body plan has a flexible middle with expandable sides. It hence has the ability of producing bending to either side of the body. If the sides are arranged in different directions, a more intricate spatial bending can be achieved. The expression is BPC2 = FM + n ∙ ES.\(^{46}\) Most of the soft robotic examples have two, some three sides that expand, but it is possible to have more.

**Basic body plan type C3** – This basic body plan is a sort of an inverse basic body plan C2, meaning it has expandable middle with flexible sides. Hence the expression for this basic body plan is BPC3 = EM + FS. Sides can be different in their properties: one can be more flexible than the other, only in tension or more rigid etc.

For instance, *Printable Fingers* are soft robotic structures with 3D printed outer cage that has one flexible and one accordion-like expandable side and inner soft balloon-like tube. Expansion of the tube causes the stretching of accordion-like side which causes the finger to bend.\(^{53}\) *Tensairity* structures, further on, although not designed as robotic, have the same basic body plan: upper more rigid compression side, inner pneumatic cushion, and lower tension side. The case of *Deployable inflatable bridge concept* by Tarczewski represents a structure composed of cushions of various thickness between an upper compression and lower tension layers.\(^{54}\)

**Basic body plan type D** – Basic body plan type D is a basic body plan that consists of a pneumatic actuator mounted on elements of stable form (quasi hard parts) in a way that produces rotation or bending. Expression for this basic body plan can be: BPD = HP + EP.\(^{55}\) Soft actuator can operate by expansion or by contraction (which is actually an effect of expansion in other dimensions).

Soft robotic arms like some of those created at Otherlab are made of pneumatic parts of constant pressure and form, and pressure actuator chambers that move those parts.\(^{56}\)

Pneumatic art installation *Sixteen Birds*, on the other hand, is made of interactive “birds” that are each made of long inflated conical wings and a cushion in the middle. Birds wave their wings when cushion expands and changes the angle between two wings.\(^{57}\)
**DISCUSSION AND CONCLUSION**

**Diskusija i zaključak**

The model presented here, based on the idea of a basic body plan, is one possible way to analyse the phenomenon of soft movement in nature in its capacity for application in the design of pneubotic structures in architecture. It represents a level of abstraction needed to transcode the structure of soft bodies from nature into another field of application. In this regard, since a certain level of abstraction was already needed to transcode the logic from nature into the field of soft robotics (and in some cases into art and architecture), this same abstraction is in some way encoded in their body plans. A body plan that encodes the functional diagram of a natural model should encapsulate the transformation capacity of the natural model into targeted structure. In this way this model is biomimetic.

Body plans that were detected in this analysis should not be considered the only ones, but rather the most obvious and appropriate to be reconstructed using volumetric modular elements. In case of linear actuation elements, like soft muscles for example, a set of different body plans might need to be established.

Examples for some body plans registered here are much more frequent than others. This might be regarded as an indicator of possible distribution of basic body plans among pneubotic structures that could be used in architecture. For instance, the most frequent cases that could be found in soft robotics are among robots of body plans type C and D, since their primary transformation effect is achieved through bending, while body plans type A and B have fewer examples because they need more expansion elements to produce similar results. Of course, this should not be taken as a rule, since architectural structures have problems of different nature from those of soft robots and maybe a body plan that is less “successful” in the field of soft robotics might be quite efficacious in the aspect of architectural application.

Applied to the design of architectural structures, body plans detected here, containing only the information about the type of parts and how they are connected but not their parametric values, can generate multiple structural forms. Therefore, they are virtually polymorph, and the specific instances of their multiplicities represent their actualities that can change according to the inflation of specific parts they are generated from. The inflatability of their pneubotic elements gives them the ability of actualizing their different virtualities in real time through dynamic changes of their form; they are not only virtually but also actually morphodynamic.

Combining multiple basic body plans should produce complex pneubotic structural bodies that inherit their characteristics from basic body plans they consist of. – It is the addition of parts that causes the multiplication of effects allowing for the emergence of new properties and behaviours. The question how a body plan can contain transformation capacities of a body and how they can manifest within a complex body is an intricate topic for further research that could be carried out using this model.

This model is expected to find application in more fields of research: 1) in the field of architectural theory this model opens prospects for rethinking the ideas of bionic and parametric design, idea of a structural body, body plan, polymorphism, embedding, encapsulation, inheritance, virtuality, soft and interactive architectures etc.; 2) in the field of architectural structures this model could be applied in the design of lightweight, mobile, temporary structures that can actively adapt or react to changes thus protecting users or augmenting some aspects of their environment; 3) in the field of bionic design, apart from the detection of body plans and translating natural structures into architectural field, the model could be used for the development of parametric morphogenetic tools for designing soft adaptive structures; 4) in the field of robotics this model is suitable for research of sensors, control procedures of soft pneubotic morphologies, as well as research of emergent patterns of behaviour in swarm robotics and artificial intelligence. And finally, the represented model also opens up the field for development of other forms of modular pneubotic elements and group of elements for achieving other levels of complexity and efficiency of soft bodies in architecture, as well as the development of metrics for human-robotic interaction and digitally driven architectures.

[Written in English by the authors]


SOURCES

IZVORI

INTERNET SOURCES


Osnovni tjelesni nacrti za mekane modularne pneubske konstrukcije u arhitekturi

Biomimetičke pneubske konstrukcije u arhitekturi recentna su pojava u ranoj etapi razvoja koja prati razvoj mekih robota. Meki roboti, zahvaljujući konstrukciji od rastežljivih materijala, često opažaju konstrukciju i pokrete živih bica. Vecina suvremenih pneubskih konstrukcija u arhitekturi koristi linearan pokrećak andele poput mekih mjesa ili tvarnih klipova, a njihova se morfodinamitekost krece od jasnog i brzih pokreta te promjena oblika poput konstrukcija Tower 2 grupe Hyperbody, do manje izraženih poput onih pneumskog prilagodljivog paviljona Airtractive tvrtke Festo. Pneubske konstrukcije često ostavljaju dojam kao da su živa meka tijela. Pojam tijela u mekoj robotici je uvirezen i često se koristi pojmovi poput tijela i možak da bi se opisala konstrukcija robota i softver za njihovo upravljanje, kao i neki zoomorfni i antropomorfni nazivi poput ud, noga, trup i dr. Dakođer, koriste se pojmovi suosjeteni iz biologije, kao što su genotyp i fenotyp za postupak nastanka nekog oblika, odnosno njegove specifične izvedenice. Opisujući klasična robotska tijela, neki autori dodatno naglašavaju razliku u odnosu na meke robe koristeći pojmove poput tvrdi roboti ili roboti tvrdog tjelesnog nacrt. Pojam tjelesnog nacrt, nadovezujući se na pojma tijela kako su ga uspostavili Gilles Deleuze i Felix Guattari, arhitektonske prilagodljive konstrukcije u arhitekturi, često imaju jedinstven volumenski element kao gradbeno-pokrećak jedinice. Idea osnovnoga tjelesnog nacrt koristena je u kontekstu funkcionalne analize konstrukcije i pokreta mekih tijela da bi se dobio set osnovnih tjelesnih nacrta iz kojih je moguce konstruirati konkretna pneubska konstrukcije arhitektonskog mjerila u arhitekturi. U ovome istraživanju razmatrana je mogućnost kontruiranja pneubskih konstrukcija u arhitekturi koristeći jedinstveni volumenski element kao gradbeno-pokrećak jedinice. Očekivana primjena ovoga modela pokriva više polja i relevantna je, između ostalog: 1) u polju arhitektonske teorije – u pogledu razmatranja o idejama bioničkog i parametarskog projektiranja, arhitektonskih tijela, tjelesnog nacrta, ugrađivanja i nasljeđivanja svojstava, virtualnosti i aktualizaciona, mekoj i interaktivnoj arhitekturi i dr.; 2) u polju arhitektonske konstrukcija – projektiranje laganih, prijenosnih, privremenih, prilagodljivih i aktivno reagirajućih konstrukcija; 3) u polju bioničkog oblikovanja – razvoju parametarskih morfogenetičkih postupaka za projektiranje prilagodljivih konstrukcija; 4) u polju robotike – razvoju osjetilnih i pokrećakih postupaka mekih konstrukcija, kao i izvrsavanju uzoraka ponašanja robota, robotickih rojeva i umjetne inteligencije; 5) drugim mogućnostima razvoja modularnih pneubskih elemenata i sklopa složenih i učinkovitih konstrukcijskih tijela, kao i metrika ljudska-robotitske interakcije i razvoja drugih oblika digitalno pogonjenih konstrukcija u arhitekturi.