How we talk(ed) about it

Ways of speaking about computational architecture

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How We Talk(ed) About It: Ways of Speaking About Computational Architecture

Abstract

If we understand architecture as a three-part system formed by the building, its image, or drawings and images describing buildings, and the critical discourse around architecture, then the texts or ways of speaking about computational architecture play a key role in understanding the field and its development. By analysing a corpus of around 4.6 million words from texts written between 2005 and 2020 that form a part of critical discourse in the field, this paper aims to map ways of speaking about computational architecture. This contributes to architectural theory and might help gain a better understanding of the evolution of the field. Findings show that computational architecture is surrounded by a specific way of speaking, hybridised with words from fields such as biology, neuroscience, arts and humanities, and engineering. While some topics such as 'sustainability' or 'biology' come up consistently in the discourse, others, such as 'people' or 'human', have periods when they are more and less popular. The paper tracks and documents trends and illuminates patterns and concludes by presenting a map of periodic and recurring topics in ways of speaking about computation in architecture over the last 15 years, discusses them within a larger context and highlights open research questions.

Keywords: architectural design, computational architecture, digital construction, natural language processing, digital architecture.

As computation is retooling most fields (1), over the past 30 years, the avant-garde in architecture has been connected to the heavy use of technology. The digitalisation that architectural design has been going through has had an impact on the profession's conceptual agenda, design, and materialisation. Repurposing software tools built for other industries and using them for architecture has created star practices such as Gehry Partners with CATIA (2), and Zaha Hadid Architects with Maya (3). Moreover, some architects from the younger generation have started to code as they discover that there is a lack of tools for specific tasks, or that existing tools are inadequate or insufficient (4), (5), (6), (7), (8). As new tools are developed, so are new ways of thinking, writing, designing, and doing. The logic of tools feeds back into the mentality of the operators (9), (10) as design is always affected by the choice of tools (11), (12), (13), (14).

All this has produced many terms referring to architectural projects that make extensive use of digital technologies such as: ‘digital architecture’, ‘parametric architecture’, ‘computational architecture’, ‘algorithmic’, ‘generative architecture’, and ‘advanced architecture’. These terms are explained and discussed extensively in architectural texts.

Menges and Ahquist (15) define computational architecture as the explicit use of scripting and/or programming in the design and/or the fabrication phase. According to Leach (16), algorithmic architecture involves the use of programming languages and/or paradigms. One definition for parametric architecture is that it implies working through software interfaces that allow relational design: virtual objects contain interconnected features and changing one feature will change the others automatically (16). In this case, the designer produces objects as well as the relationships between objects. The debate around what parametric, computational, algorithmic, and digital architecture mean (17) is ongoing. As has been shown in (18), all these terms have been used ambiguously, inconsistently, and interchangeably.

In this article, computational architecture is used as an umbrella term to discuss architecture shaped by technological advancements, and this includes digital, parametric, algorithmic, and parametric architecture. The term ‘computational’ is used instead of digital or digitalisation because the focus is on early adopters of advanced technologies for architectural design and not on how software applications designed for architecture are being implemented across the discipline. Therefore, this study deals with the early phases of the digitalisation of architecture.

Hensel identified a series of problems that computational architecture faces: fragmented discourse, exhausted idiosyncrasy, redundant form-function dialectic, and shallow ecological and sustainability approaches. However, most importantly, contemporary discourse does not reflect on the larger context in which computational architecture exists (19). Similarly, Cash (20) makes a compelling case on the poor state of theory and meta-theory building in design research in general.

Forty (21) describes architecture as a three-part system formed by *the building*, *its image* (drawings and photographic representations), and its accompanying *critical discourse*. Modernist architecture was not only a new style of building, but also a new way of talking about architecture, ‘instantly recognizable by a distinct vocabulary’ (21). By studying how architects write, Medway explains how much of writing is done to

motivate action, stating that ‘architects finish a sentence with a sketch’ (22). Furthermore, according to Damron (23), sketches are illuminated by sentences, as writing is part of the doing. Language then becomes an integral part of architecture (24), (21), (22), (23). Therefore, mapping and investigating the vocabulary of computational architecture becomes important for understanding the practice in general, for building theory and meta-theory for architecture, and for reflecting on the larger context in which the field evolves.

This paper investigates how computation is changing architecture by studying writings about architecture and is guided by the following research questions:

RQ1: What is the language of computational architecture?

RQ2: Does this language change over time and in what ways?

This study aims to add to the body of work that investigates the digital turns in architecture (9), (25),. In order to answer these questions, a corpus linguistics representative for computational architecture was built. This corpus contains texts written over a 15-year period between 2005 and 2020 from two sources: the journal Architectural Design and the eVolo skyscraper competition.

The rest of the paper is structured as follows: after related work is presented in Section 1, the tools, methods, and research framework for investigating the research questions are introduced in Section 2, and the findings are presented in Section 3. Finally, in Section 4, the main topics found in the corpus and surrounding computational architecture are discussed, and a conceptual map of the topics surrounding computational architecture over time is presented.

1. Analysing Ways of Speaking in Architecture

The term ways of speaking is sometimes used to refer to the discourse a certain community creates (26), (27), (28). The ways of speaking of an academic community help to build discipline-specific knowledge and establish its cultural identity (29), (28). In ‘*Words and Buildings’*, (21) argues that the ways of speaking of modernist architects were integral in helping them frame their vision, while (30) goes so far as to say that modernist architecture was ‘more basically, a body of documents defining modernism and interpreting those buildings’. In *‘The Words Between the Spaces: Buildings and Language’,* (31) read the history of architecture through the development of architectural texts discussing the role of language in producing buildings. In (23),

Markus argues that ‘the use of language should be investigated in design simply because language is involved at every stage’.

It is generally accepted that architecture has a specific vocabulary (32), (33), yet little work has been done on analysing ways of speaking in computational architecture. (18) study a corpus of texts trying to find unified definitions for parametric, generative, and algorithmic design. (34) and (35) both collect and analyse corpuses of texts about architecture in general and report findings related to the particularities of these texts: architecture has a specific vocabulary impregnated by topics which come from connected fields, the language is technical and often metaphorical, and new words are created ‘with ease’.

2. Materials and Methods

To analyse the ways of speaking about computational architecture, a corpus linguistics in English, built to be representative of the subfield, was created. This corpus, ComPara, is different from previous work by (34) and (35) in two ways. First, ComPara looks at a specific area of architecture, namely computational architecture. Second, ComPara covers the period between 2005 and 2020. This section describes the design, collection, and analysis methods for ComPara. After selecting relevant sources, data was extracted and analysed quantitatively to extract the main topics and trends in the text. The data were then assessed qualitatively. The analysis of ComPara represents a corpus-based interpretative study.

2.1. Selection of relevant sources - criteria for corpus design

The first step in building a corpus is to select relevant sources. (34) uses three criteria in designing her corpus - *representativeness, accessibility* and *contemporariness*. Representative sources are those that are relevant in describing the professional discourse of architecture. Accessible sources are those that are available for professionals and those that can be found and placed in a digital database. Contemporariness refers to up-to-date sources.

Two sources that fit the three criteria were selected: the journal Architectural Design (AD), and winners and honourable mentions of the eVolo Skyscraper Competition. AD and eVolo were chosen because they both specifically deal with

technological innovations in relation to architecture. Established in 1930, AD is widely considered to be at the forefront of architectural thought. Over the last three decades, AD has also featured many articles about technology and architecture to such an extent that Mario Carpo states that 'Not all things related to computational design have been published in AD, but a large part of them have' (25). On the other hand, eVolo's *About* section describes the journal as 'focused on technological advances in architecture and design' (36). The eVolo Skyscraper Competition is arguably one of the most popular of its kind worldwide, with around 1200 yearly submissions from over 150 countries (37). This is why AD and eVolo are representative of computational architecture. The period between 2005 and 2020 was chosen because of the accessibility of digital texts from this time. For AD, only issues starting in 2005 are available digitally on the journal's page (38), while the first edition of the eVolo Skyscraper Competition was released in 2006.

2.2. Collecting the data and size of ComPara

The following inputs from the period between 01/2005 and 12/2020 were collected from AD for use in the corpus: (a) all issue titles, (b) the titles of all 1795 articles from each issue, (c) the text of these articles, and (d) keywords associated with the *Introduction* article. This forms a corpus of around 4.5 million words. The keywords were collected from the *Information* section next to the article on the journal's webpage. It seems that they are generated automatically using a language processing algorithm, but details of the algorithm are inaccessible to external users. Keywords represent 'words which are statistically characteristic of a text' (39).

Data from 2006 to 2020 were obtained from eVolo using the following bases: (a) titles of all winning and honourable mentioned projects and (b) the descriptions (abstracts) submitted by authors for these projects. This forms a corpus of around 100,000 words.

The current total size of ComPara is around 4.6 million words and forms a special purpose medium-sized corpus (34).

2.3. Tools for processing ComPara

The study presented here is corpus-driven (40), meaning there were no pre-assumptions or hypotheses before the analysis was conducted.

The analysis of ComPara was done in two stages. First, the corpus was analysed quantitatively with the use of natural language processing (NLP) tools. Next, a qualitative analysis of the results that emerged from the quantitative analysis was carried out.

An array of NLP tools exists, with each tool implementing different algorithms derived from statistical techniques for topic modelling (41), (42), or (43). In this study, two browser-based text analysis applications were used, namely Voyant Tools (44) and Infranodus (45). These applications implemented well-known algorithms, such as the Latent Dirichlet Association (42), (41), as well as proprietary algorithms.

Voyant Tools includes a large collection of tools. The ones used here are *Summary, Trends, Phrases* and *Cirrus*. Using *Cirrus*, word clouds were created to display words that were dimensioned based on their frequency in a text (46), (47). Common connection words and punctuation are excluded. Word clouds are useful for seeing key terms in a text and have been successfully used as tools for the preliminary analysis of texts (48). However, in classical word clouds, all connections between words are lost.

Infranodus is an NLP tool that transforms pieces of text into contextual word clouds (49). Infranodus is based on a text network analysis algorithm, similar to the Latent Dirichlet Association (but described as better), that represents any text as a network and identifies the most influential words in a discourse based on terms' co-occurrence. An algorithm is applied to identify different topical clusters, which represent the main topics in the text as well as the relations between them (45). Thus, contextual word clouds represent the most common words in a text, the connections between the words, and topics, which are words that appear next to each other in text, but not with the other words.

2.4. Data analysis

The data in ComPara contains *titles, keywords*, and *prose text*. These different data types were analysed using two different approaches. Keywords are words without a context, and titles are only short sentences. As a result, contextual word clouds would either not be created or the connections between words would be too weak to produce meaningful results. The titles and keywords were transformed into word clouds to address this while the prose text was directly transformed into contextual word clouds.

Word clouds were created from titles and keywords from AD and titles from eVolo. These clouds were then printed out. After a period of becoming familiar with the data, the clouds were coded all together in initial subsets using an emerging coding approach (50). Then, these emergent codes went through a period of analysis, where Voyant tools' *Trends* and *Phrases* were used to query the data for different keywords that were traced back to their original contexts. This ensured that the meaning in context was understood correctly and helped in the production of the final list of codes. The generated list was used to code all word clouds. Afterwards, the codes were affinity diagrammed (51) until a final theme structure was created.

The prose text from AD articles and eVolo project descriptions was transformed into contextual word clouds and main topical groups, and the most influential elements were generated automatically using Infranodus NLP.

3. Findings: Architectural Design

Issue titles, article titles, article text, and the *Introduction* keywords from entries between 2005 and 2020 were retrieved from AD. The titles and keywords were transformed into word clouds and categorised under six main themes that emerged after affinity diagramming: (a) profession-specific terms, (b) places, (c) time periods and currents in art and architectural history, (d) technology, (e) sustainability, and (f) mathematics, physics, and biology. The texts in the articles were transformed into contextual word clouds, and the topical clusters and most influential elements from each issue are presented.

3.1. Data from AD issue titles (2005–2020)

Fig. 1 shows the word cloud made from the titles of the 96 AD issues. These are discussed below under the six main themes.

Profession-related terms include: 'architecture', 'design', 'space', 'cities', 'urbanism', 'urban', 'buildings', 'research', 'space', 'landscape', 'city', 'site/non-site', 'housing', 'megastructure', 'pavilion', 'territory', 'local', and 'hyperlocal'. 'Rural' and words related to it such as 'countryside' or 'pastoralism' are a lot less frequent compared to words related to 'urban'.

References to ***places*** in AD's issue titles include 'Europe' (2006), 'India' and 'Italy' (2007), 'China' (2008, 2018), 'Turkey' (2010), 'Latin America' (2011), 'Iran' (2012), 'London' (2012), 'UAE' and 'the Gulf' (2015), and 'Brazil' (2016).

Words related to ***time periods*** that stand out are ‘contemporary’, ‘21st century’, ‘2050’, ‘now’, ‘1970s’, ‘1960s’, ‘age’, and ‘third age’. ‘Future’ is a lot more frequent in the titles than the term ‘past’. Words related to current affairs in art or architectural history are ‘radical post-modernism’ (2011); ‘new structuralism’ (2010), which refers to a symbiosis between design, engineering and architectural technologies; ‘parametricism 2.0’; ‘surrealism’ (2018); and ‘avant-garde’ (2019). By 2019, two new ‘posts’ had replaced the post-modern of 2012, namely ‘post-digital’ and ‘post-Anthropocene’.

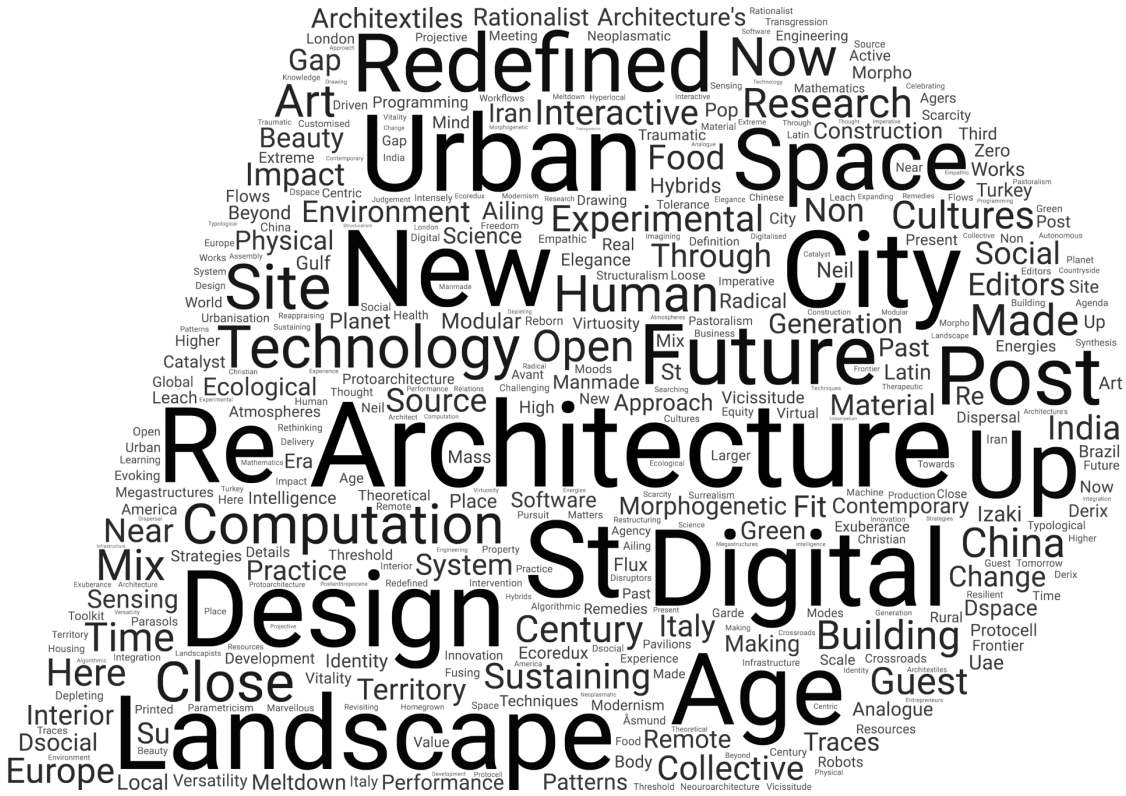

Fig. 1 – Word cloud of all words, scaled according to frequency, forming the 96 issue titles of AD (01/2005 – 12/2020). 550 total words and 293 unique words.

Words relating to ***technology*** were abundant in AD’s issue titles, and they include the following terms: ‘digital’, ‘computation’, ‘interactive’, ‘software’, ‘robots’, ‘open-source’, ‘machine’, ‘virtual’, ‘robots’, ‘algorithmic’, ‘programming’, and ‘3D printed’.

Then, there are words related to ***sustainability*** such as ‘sustainable’, ‘ecology’, ‘food’, ‘ecological’, ‘sustaining’, ‘scarcity’, ‘green’, ‘ailing planet’, ‘depleting’, ‘resources’, ‘environment(s)’, ‘post-traumatic’, ‘ecoredux’, and ‘resilient’. It is

interesting to note that the word ‘sustainable’ is less frequent than either ‘digital’ or ‘computation’ in AD issue titles.

References to the field of ***mathematics*** include ‘mathematics’ and ‘4D space’. References to ***physics*** include ‘morphogenetic’, ‘morpho-physical’, ‘vicissitude’, and ‘flows’, while references to ***biology*** include ‘protocell’ and ‘neo-plasmatic’.

3.2. Data from AD article titles (2005–2020)

The titles of the 1795 AD articles are made up of 12,929 words with 4,146 unique words. The most frequent words in the titles are ‘architecture’ (199), ‘design’ (194), ‘new’ (97), ‘urban’ (90) and ‘city’ (86). The word clouds from the article titles are relatively similar to the word cloud made from the issue titles, as each issue called for articles fitting these themes. However, analysing the titles year by year reveals an interesting progression, which is also visible in the analysis of the texts of these articles. This will be discussed in succeeding subsections. Word clouds of article titles year by year are available at (52).

3.3.Keywords associated with the AD Introduction (2005-2020)

There are 13,835 keywords with 5,961 unique words associated with the *Introduction* of each of the 96 AD issues, and the most frequent keywords are ‘architecture’ (166), ‘university’ (85), ‘architects’ (75), ‘design’ (70) and ‘new’ (63). Fig. 2 illustrates the 500 most frequent keywords scaled according to their frequency and loosely grouped in the six thematic clusters.

Profession-related terms such as ‘architecture’, ‘design’, ‘house’, and ‘building’ lie at the centre. The most mentioned architectural functions are ‘museum’, ‘pavilion’ and ‘residential project’. Other common functions are ‘hotel’, ‘campus’, ‘office’, ‘airport’, ‘station’, ‘hospital’, ‘library’, ‘arena’, ‘hall’, and ‘square’.

Names of ***places*** sit at the lower right corner placed on a map that paints a polarised picture. The USA, Europe, China, Japan, and Australia are relatively well represented, while Latin America is only represented due to mentions of Mexico and Columbia. No African country, city, or place make the top 500 keywords. Zooming in and looking into the keywords year by year, we see that Africa appears twice in the keywords, once in 2015 and once in 2017. In comparison, China is mentioned 21 times, while London has 50 mentions, some in every year between 2006 and 2020. Europe is only represented by a few places or institutions. London and the Bartlett dominate the

representation, with mentions of the Architectural Association (AA) and its Design Research Laboratory (DRL), the RIBA, and the Serpentine. Next comes the Venice Biennale, followed by Paris, the Pompidou, and France. Then there are some mentions of German places and institutions: Berlin and Stuttgart with the Institute for Computational Design (ICD). Finally, Switzerland and Zurich, Vienna, the Netherlands and Barcelona-Spain are the least frequently mentioned places. Eastern Europe, Northern Europe, and Russia are not mentioned at all. Istanbul is mentioned a few times, while the Middle East is only represented through Abu Dhabi, Beirut and the Gulf. Mumbai is mentioned, although only a few times, followed by Singapore and Hong Kong, as well as China with Beijing, Shanghai, and Shenzhen. The rest of Asia is only mentioned through Japan. Even the word ‘west’ is more frequently mentioned and is consequently larger on the representation than the word ‘east’.

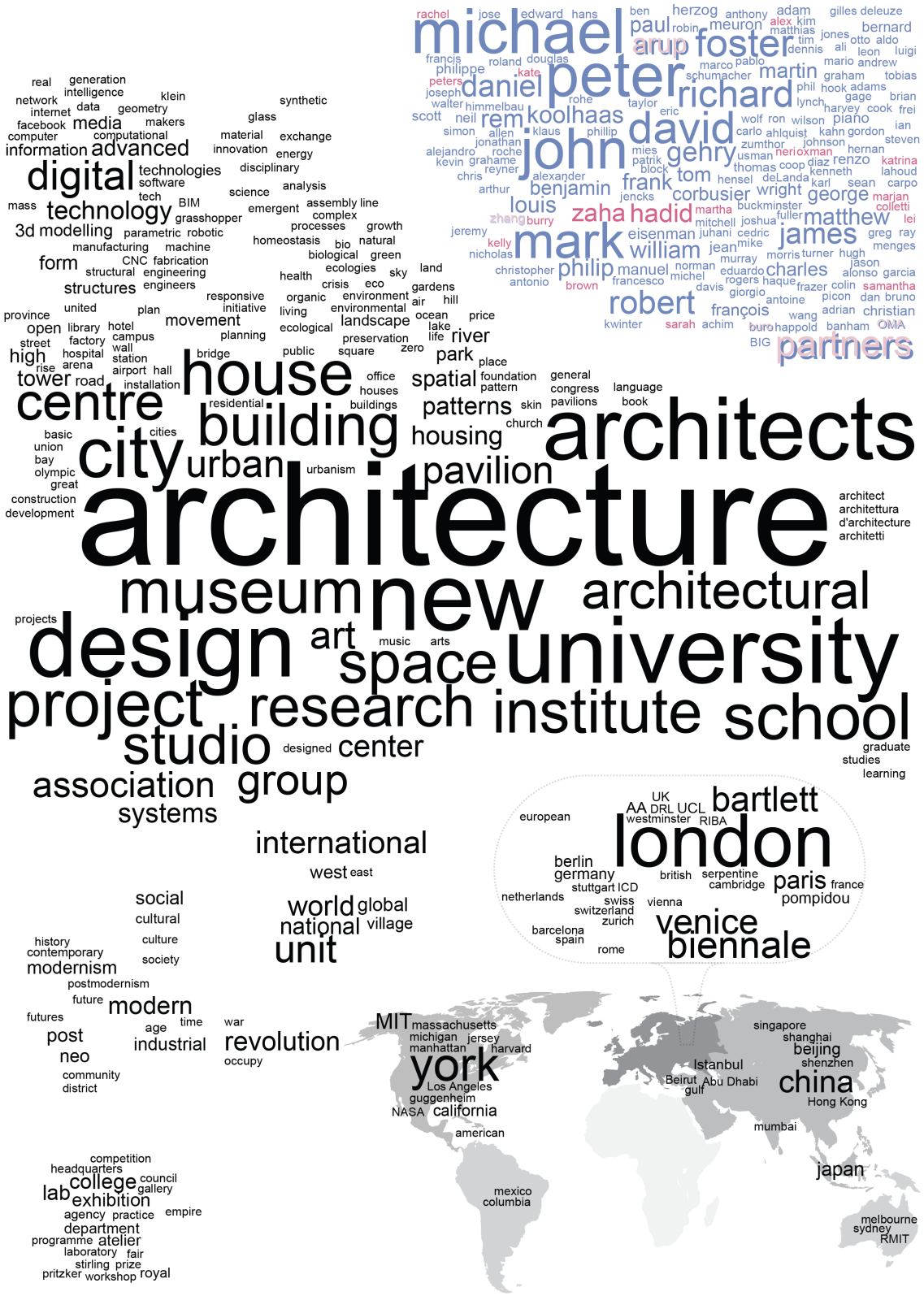

Fig. 2 – Word cloud showing 500 most used keywords associated with the *Introduction* in the 96 issues of AD (01/2005 – 12/2020) scaled according to frequency and grouped based on thematic clusters. There are 13,835 keywords with 5,961 unique words.

Words related to ***periods*** in art and architecture are 'modernism' and 'post-modernism', 'future(s)', 'history', 'contemporary', and 'functionalism'. The term 'industrial revolution' is found in the keywords in 2009, 2015, and 2017–2020. The word 'gothic' is mentioned three times in the keywords (2013, 2016, 2018); in contrast, 'baroque' is only mentioned once, in 2011. The word 'new' is a lot more prevalent than the word 'old' throughout the years.

Color-coding the ***names of people*** (upper right corner in Fig. 2) shows a male-dominated scene apart from some notable exceptions such as Zaha Hadid, Neri Oxman, and Jane Burry. Names of practices such as OMA or Arup are double coloured while 'BIG' and 'Happold' from 'Buro Happold' are left blue because the names of the practices are of male architects. Both place and name analysis pictures look a lot more diverse when zooming in to the keywords year by year. Looking at the names mentioned in AD's *Introduction* keywords year by year, philosophers include materialists such as Deleuze, Deleuze-Guattari, and DeLanda. 'Deleuze' is a keyword in 2006, 2009, 2012, and 2014, 'Guattari' in 2009, 2012, 2014, while 'body without organs' is mentioned in 2008. 'DeLanda' is a keyword in 2009, 2012, 2015 and 2016. These three are the most popular philosophers whose names are included in the corpus. Next come the words 'deconstructivist' (2007, 2009, 2014) and 'Derrida', which were mentioned in 2009. Third, and more recently, Tim Morton was mentioned in 2012, then Harman (2016, 2019) and Heidegger (2019). Other philosophers include Kant (2014, 2019), Foucault (2006, 2008, 2012), Lefebvre (2009, 2012, 2013), and Merleau-Ponty (2012, 2019). Edward Soja (2011–2012), Roland Barthes (2009, 2016), Žižek in 2010, McLuhan (2006, 2012) and Latour (2006, 2014) are also mentioned. Scientists mentioned include Wolfram (2016), Freud (2008, 2016), and Darwin (2009, 2012, 2019). John Ruskin (2009, 2019), Heinrich Wöflin (2016), Arthur Danto (2009), and Duchamp (2009, 2013, 2019) are some of the included art historians. Finally, among architects, Rem Koolhaas and Le Corbusier are the most popular. They were part of keywords in 11 out of the 16 years. Gregg Lynn is mentioned six times (2006, 2007, 2009, 2014, 2015, 2020), Bucky Fuller is mentioned six times (2006, 2008, 2010, 2011, 2012, 2015) as well, and Frei Otto is mentioned seven times (2006–2010, 2015–2016).

The upper left corner of Fig. 2 has grouped together terms which have to do with ***technology*** such as 'digital', 'technology', 'computational', 'media', 'network', and 'internet'. Software families ('BIM'), programming languages ('grasshopper'), and manufacturing technologies ('CNC' and 'robotic fabrication') were mentioned as well.

The interest in engineering is also seen in the frequency of ‘Arup’ as a keyword between 2010 and 2012. This keyword comes back in the periods of 2014–2015 and 2017–2018, albeit less frequently.

Words related to ***sustainability*** placed around the top centre of Fig. 2 include ‘ecologies’, ‘green’, ‘environmental’, and ‘homeostasis’.

Finally, there are words related to ***mathematics, physics, and biology***. ‘Geometry’ appeared six times in 2010 and 2011. There are few words that can be connected to physics, and they include ‘air’, ‘energy’, ‘sky’, and ‘physics’. Words which can be connected to biology include ‘bio’, ‘biological’, ‘growth’, ‘natural’, ‘organic’, and ‘life’.

3.5. Data from the text of AD articles (2005-2020)

The texts forming the 1795 AD articles are made up of 4,544,090 words and 92,963 unique words. The most frequent words are ‘design’ (19,892), ‘architecture’ (16,915), ‘new’ (16,701), ‘building’ (10,528) and ‘city’ (9,668). Fig. 3–7 shows the main topical clusters and most influential elements in each AD issue. These were retrieved from the contextual word clouds generated using the Infranodus NLP tool.

Most of the topics shown are ***profession-specific*** words, such as ‘architecture’, ‘design’, ‘building’ or ‘city’. The words ‘form’ and ‘system’ (marked in italics in Fig. 3–7) often come up either in the main topical groups or as the most influential elements. References to ***places*** make up the main topical groups sometimes, and they corelate to the AD issue titles, article titles, and *Introduction* keywords. Sometimes the words ‘local’ and ‘hyperlocal’ are significant topics. ***‘Time’*** comes up eight times in topical clusters, sometimes appearing close to the word ‘space’ (see Fig. 4: 2008-4, Fig. 5: 2013-5). ‘Future’ comes up three times.

Words that have to do with ***technology*** are coloured purple, and they are relatively evenly distributed throughout the years and include ‘virtual’, ‘software’, ‘parametric’, ‘robotic’, and ‘BIM’. ‘Artificial intelligence’ comes up 145 times in the texts, and most mentions are in 2019–2020.

Words that could be connected to ***sustainability*** are coloured blue. These include ‘environment’, ‘scarcity’, ‘resource’, and ‘sustainability’.

Words that can be associated with ***biology*** are coloured in dark blue and include ‘protocell’, ‘biomimicry’, and ‘DNA’. In 2019, some references to neuroscience were made (see Fig. 7: 2019-5). Topics about ***mathematics*** include ‘geometry’ and

'mathematic', and these were concentrated in 2011. Words that can relate to ***physics*** include references to outer space exploration, such as 'Moon' and 'Mars', but also 'flow' and 'energy'.

2005-1	2005-2	2005-3
Main topical groups:	Main topical groups:	Main topical groups:
16%: space time environment	21%: design architecture project	16%: street market people
13%: *system* create *form*	18%: city research university	15%: restaurant shop small
12%: architect designed designer	14%: architect housing social	13%: city garden farm
11%: wall made floor	12%: building build energy	12%: urban local building
Most influential elements:	Most influential elements:	Most influential elements:
space house technology design	**urban architecture design space**	**food space city street**
2005-4	**2005-5**	**2005-6**
Main topical groups:	Main topical groups:	Main topical groups:
20%: building making drawing	15%: design project urban	16%: building block development
14%: material construction site	14%: city architect york	14%: city model world
14%: spike made test	13%: house street view	12%: space area public
13%: design process *form*	13%: architecture art park	12%: data time local
Most influential elements:	Most influential elements:	Most influential elements:
design architecture building drawing	**building city community**	**city building virtual area design**
2006-1	**2006-2**	**2006-3**
Main topical groups:	Main topical groups:	Main topical groups:
22%: project house space	21%: *system* material structure	23%: architecture architect country
16%: building *system form*	16%: design process base	15%: building space area
15%: architecture design urban	16%: surface space roof	13%: house street private
10%: city centre big	13%: model digital component	11%: city centre riga
Most influential elements:	Most influential elements:	Most influential elements:
design architecture building urban	***system* design material**	**building architecture architect**
2006-4	**2006-5**	**2006-6**
Main topical groups:	Main topical groups:	Main topical groups:
24%: design *form system*	25%: design *form* practice	23%: building structure surface
20%: architecture software code	22%: information software technology	21%: textile architecture design
17%: surface cell step	11%: network intelligence collective	14%: project architect city
9%: project work lalvani	8%: *system* model material	11%: museum art DRD
Most influential elements:	Most influential elements:	Most influential elements:
design structure set rule software	**design *system* network *form***	**textile design building structure**
2007-1	**2007-2**	**2007-3**
Main topical groups:	Main topical groups:	Main topical groups:
19%: elegance elegant aesthetic	27%: landscape urban design	27%: project space create
17%: *form* project surface	26%: city park area	20%: architecture design work
17%: architecture design process	13%: create garden space	14%: building office complete
14 %: building art landscape	7%: long high square	11%: art university yale
Most influential elements:	Most influential elements:	Most influential elements:
elegance architecture design	**landscape city urban**	**architecture italian building art**
2007-4	**2007-5**	**2007-6**
Main topical groups:	Main topical groups:	Main topical groups:
21%: design interactive architecture	27%: building *form* space	16%: architecture city work
15%: visitor museum building	21%: architecture architect rationalist	14%: building house site
14%: work people body	13%: work unger design	12%: space area designed
11%: floor square house	9%: project urban housing	12%: architect mumbai studio
Most influential elements:	Most influential elements:	Most influential elements:
interactive art work architecture space public	**architecture building rationalist**	**building architect space**

Fig. 3

2008-1	2008-2	2008-3
Main topical groups:	Main topical groups:	Main topical groups:
24%: urban *form* development	19%: material *system* structural	17%: interior space atmosphere
16%: project centre large	16%: environment morphology relationship	15%: room wall scale
14%: space public create	15%: design process performance	15%: design architecture project
11%: city area build	14%: structure *form* force	14%: house time designed
Most influential elements:	Most influential elements:	Most influential elements:
urban space city	**material *form* surface**	**space interior design air**
2008-4	2008-5	2008-6
Main topical groups:	Main topical groups:	Main topical groups:
23%: space time *form*	24%: city chinse planning	22%: design *system* structure
23%: architecture design work	17%: china urban development	15%: body cell human
14%: wall construction meter	17%: buidling design architecture	14%: architect water make
12%: model physical scale	7%: policy economic reform	11%: project part tissue
Most influential elements:	Most influential elements:	Most influential elements:
design architecture space	**city china urban**	**project living design cell**
2009-1	2009-2	2009-3
Main topical groups:	Main topical groups:	Main topical groups:
27%: design architect architectural	20%: *form system* material	21%: architecture design energy
27%: architecture art building	18%: building model BIM	17%: air *system* light
7%: paul english chu	16%: design construction project	13%: building environment interior
7%: brown venturi scott	15%: architecture create engineering	11%: wall organization spatial
Most influential elements:	Most influential elements:	Most influential elements:
architecture design architect art	**design building model**	**architecture design air energy space**
2009-4	2009-5	2009-6
Main topical groups:	Main topical groups:	Main topical groups:
28%: urban city *form*	27%: design space urban	29%: pattern design architecture
18%: design project architectural	16%: city future ballard	21%: *system* building structure
13%: space spatial public	13%: world experiece make	11%: city university york
12%: architectural research urbanism	11%: place large centre	7%: architect group MIT
Most influential elements:	Most influential elements:	Most influential elements:
design urban architecture	**city building urban design**	**pattern design *system* architect**
2010-1	2010-2	2010-3
Main topical groups:	Main topical groups:	Main topical groups:
21%: city building istambul	23%: form *system* spatial	22%: architecture nature design
17%: project urban space	16%: design architectural digital	15%: urban space *form*
14%: architecture architect year	13%: project space exuberant	15%: city *system* material
9%: part level floor	9%: building level high	10%: site context local
Most influential elements:	*Most influential elements:*	*Most influential elements:*
city design istambul	**design architecture digital building *form***	**design architecture city urban**
2010-4	2010-5	2010-6
Main topical groups:	Main topical groups:	Main topical groups:
28%: design model architectural	26%: space urban *system*	18%: environment *system* world
14%: shell top isler	17%: city project beirut	16%: building design architecture
13%: material digital architecture	17%: architecture studio rice	13%: material ecological future
12%: *form* structure surface	15%: site opposite east	9%: project space opposite
Most influential elements:	*Most influential elements:*	*Most influential elements:*
design *form* architect material	**city urban space**	**material building design ecological city architecture**

Fig. 4

2011-1	2011-2	2011-3
Main topical groups:	Main topical groups:	Main topical groups:
22%: type architecture *form*	21%: protocell architecture technology	23%: urban project community
19%: urban building architectural	20%: *system* living chemical	17%: city informal area
19%: city development idea	19%: material structure building	15%: public space building
8%: space public office	11%: environment soil hylozoic	10%: latin architecture architect
Most influential elements:	Most influential elements:	Most influential elements:
city urban type	**protocell architecture material**	**city urban public**
2011-4	2011-5	2011-6
Main topical groups:	Main topical groups:	Main topical groups:
17%: mathematic design geometry	18%: building house facade	16%: building system energy
14%: space *form* structure	12%: project housing context	14%: design research project
11%: figure contemporary structural	11%: art work street	12%: environmental simulation base
11%: point line scale	11%: architectural *form* space	12%: group modelling biomimicry
Most influential elements:	Most influential elements:	Most influential elements:
surface design line space figure geometry mathematic point	**architecture post modern**	**design building research**
2012-1	2012-2	2012-3
Main topical groups:	Main topical groups:	Main topical groups:
23%: development regneration urban	26%: *system* structure elment	17%: building garden project
14%: area east line	18%: material *form* behaviour	15%: architecture iran iranian
11%: city centre stratford	17%: design process base	15%: isfahan house build
11%: place building high	15%: research university ICD	14%: material mirmiran complex
Most influential elements:	Most influential elements:	Most influential elements:
site city urban regeneration	**material design *system***	**architecture iranian iran**
2012-4	2012-5	2012-6
Main topical groups:	Main topical groups:	Main topical groups:
15%: building food local	21%: city architecture project	16%: place space identity
14%: design urban project	16%: urban china condition	15%: architect ARUP studio
13%: scarcity space resource	16%: house housing traditional	12%: architecture university award
11%: architect term sustainability	13%: building infrastructure space	12%: city urban form
Most influential elements:	Most influential elements:	Most influential elements:
design city urban *system*	**city urban architecture *form***	**architecture architect school work**
2013-1	2013-2	2013-3
Main topical groups:	Main topical groups:	Main topical groups:
35%: architecture design innovation	22%: building model geometry	35%: city nature landscape
9%: university life science	20%: design project process	11%: digital painting site
9%: project art space	11%: digital modelling foster	10%: architecture design process
8%: roche mark guest	9%: *form* energy user	8%: image son titman
Most influential elements:	Most influential elements:	Most influential elements:
architecture design innovation	**design parametric computer model**	**architecture city design nature image**
2013-4	2013-5	2013-6
Main topical groups:	Main topical groups:	Main topical groups:
20%: city *system* form	23%: drawing architectural image	19%: architecture transgression time
17%: urban design process	16%: project space time	17%: space urban public
14%: building space social	13%: architecture design university	12%: building site structure
13%: network flow energy	13%: city building idea	11%: work project architect
Most influential elements:	Most influential elements:	Most influential elements:
city urban *system* flow	**drawing architectural architecture**	**architecture space urban city**

Fig. 5

2014-1	2014-2	2014-3
Main topical groups:	Main topical groups:	Main topical groups:
17%: design building process	17%: space living social	17%: robot construction building
17%: space data build	17%: housing building community	15%: fabrication architecture digital
16%: material *form* surface	16%: design ageing project	15%: design research architectural
13%: point scale model	13%: home resident people	14%: robotic *system* potential
Most influential elements:	Most influential elements:	Most influential elements:
design material architecture technology	**design space ageing architecture**	**fabrication design robotic architecture process construction ETH**
2014-4	2014-5	2014-6
Main topical groups:	Main topical groups:	Main topical groups:
19%: detail architecture design	22%: design architectural *system*	24%: space architecture station
17%: material *system form*	17%: space building *form*	22%: moon earth mars
11%: DNA pattern dynamic	12%: architecture university centre	11%: technology construction building
11%: project research cyborg	11%: spatial experience pattern	9%: laboratory image
Most influential elements:	Most influential elements:	Most influential elements:
detail design architecture	**space design spatial**	**space NASA architecture *system***
2015-1	2015-2	2015-3
Main topical groups:	Main topical groups:	Main topical groups:
21%: building development urban	32%: design local building	18%: structure create building
12%: museum national bahrain	13%: space wall house	17%: architecture design studio
10%: world tower center	11%: work studio landscape	15%: space project public
9%: project qatar doha	10%: architecture school oslo	14%: architect build art
Most influential elements:	Most influential elements:	Most influential elements:
city dubai gulf museum building UA	**architecture design local**	**city architcture space design pop**
2015-4	2015-5	2015-6
Main topical groups:	Main topical groups:	Main topical groups:
17%: city future today	22%: structure structural fibre	25%: design architecture urbanism
16%: world building social	20%: material *system form*	19%: urban *form* model
14%: design human architect	18%: design computational institute	13%: project development housing
13%: water project infrastructure	12%: research pavillion group	12%: city building scale
Most influential elements:	Most influential elements:	Most influential elements:
city future design world urban	**design material research structure**	**design urban city mass**
2016-1	2016-2	2016-3
Main topical groups:	Main topical groups:	Main topical groups:
27%: time building architecture	23%: design architectural process	21%: city brazil building
21%: design project process	20%: social *form* urban	17%: urban project design
16%: landscape human condition	18%: material structure *system*	13%: public area park
9%: space public year	13%: research project work	7%: cultural square office
Most influential elements:	Most influential elements:	Most influential elements:
time design building drawing	**design architecture material**	**city urban public brazilian**
2016-4	2016-5	2016-6
Main topical groups:	Main topical groups:	Main topical groups:
21%: village town house	21%: design digital technology	21%: architecture mood digital
19%: rural urban design	15%: architect designer information	17%: object space *form*
17%: city social modern	13%: project game developed	15%: human time scale
15%: landscape territory industrial	12%: architectural practice work	14%: design architectural project
Most influential elements:	Most influential elements:	Most influential elements:
rural urban city village	**design architectural digital patent**	**architecture mood architectural**

Fig. 6

2017-1	2017-2	2017-3
Main topical groups:	Main topical groups:	Main topical groups:
17%: urban project design	19%: space patient care	19%: design workflow process
15%: local community shared	13%: health environment wellbeing	15%: building information BIM
13%: social platform technology	12%: design architecture healthcare	13%: architect work structural
9%: hyperlocal data create	12%: hospital building designed	12%: project space large
Most influential elements:	Most influential elements:	Most influential elements:
city media urban social	**design hospital health building**	**design building project process**
2017-4	2017-5	2017-6
Main topical groups:	Main topical groups:	Main topical groups:
17%: city high urban	26%: building space office	16%: printed material create
14%: space program create	11%: carbon high future	14%: design printing digital
11%: water level sky	11%: design system architect	12%: architect designer shoe
11%: *system* ade series	9%: build housing house	12%: body architecture *form*
Most influential elements:	Most influential elements:	Most influential elements:
water tower city *system* space high production produce	**building design space city**	**design printed architecture**
2018-1	2018-2	2018-3
Main topical groups:	Main topical groups:	Main topical groups:
14%: energy *system* site	27%: architectural drawing space	17%: building space work
14%: design simulation build	15%: surrealist project world	15%: architecture social practice
13%: building performance time	12%: image poetic point	15%: architect freedom project
13%: solar facade roof	9%: architecture surrealism breton	14%: image charles son
Most influential elements:	Most influential elements:	Most influential elements:
building energy design house	**architecture architectural surrealist**	**architecture architect public**
2018-4	2018-5	2018-6
Main topical groups:	Main topical groups:	Main topical groups:
23%: housing unit project	17%: project local community	26%: space structure traditional
14%: design urban community	15%: design urban process	17%: architecture architect chinese
12%: public space create	15%: public work space	17%: design architectural practice
11%: architect social work	13%: practice architecture architectural	15%: natural university lighting
Most influential elements:	Most influential elements:	Most influential elements:
housing public design urban	**practice public architecture**	**design architecture chinese**
2019-1	2019-2	2019-3
Main topical groups:	Main topical groups:	Main topical groups:
23%: human machine space	29%: discrete digital project	19%: research practice architectural
17%: landscape architecture infrastructure	16%: design computational process	17%: design building project
14%: technology car autonomous	13%: architecture retsin gilles	13%: space office public
10%: amazon data centre	11%: london architect university	10%: architecture london school
Most influential elements:	Most influential elements:	Most influential elements:
human machine landscape	**discrete design digital architecture**	**research design practice**
2019-4	2019-5	2019-6
Main topical groups:	Main topical groups:	Main topical groups:
18%: work architect superstudio	28%: beauty aesthetic building	28%: architect work identity
17%: project architectural drawing	19%: design architectural space	23%: architecture building world
13%: world space time	15%: art create brain	9%: practice project architectural
13%: architecture art chicago	14%: architecture base urban	7%: big photo peter
Most influential elements:	Most influential elements:	Most influential elements:
architecture project avant garde work architectural superstudio	**architecture beauty design art**	**architect architecture design**

Fig. 7

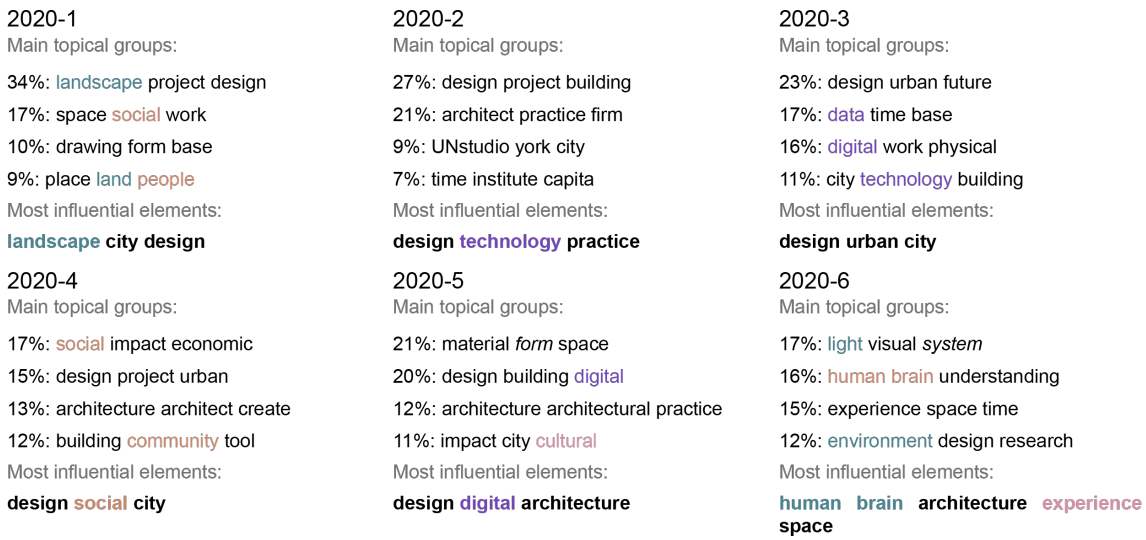

Fig. 3, 4, 5, 6, 7, 8 – texts making up the 1795 AD articles between 2005-2020. Main topical groups and most influential elements as analysed using the Infranodus NLP. The topics are presented for each AD issue, year by year. The texts total 4,544,090 words and 92,963 unique words.

Lastly, words which can be associated with ***human*** are coloured in orange and they include 'social', 'community', 'human', and 'people'. It is interesting that not a single word that could be connected to humans was part of the most used topics between 2009 and 2013. However, they have been frequently used in the last three to four years (see 2016 through 2020 in Fig. 5-7). The word 'human' itself appears a total of 4006 times in the texts of the AD articles, but it is used significantly more often in 2014, 2019, and 2020.

4. Findings: eVolo Skyscraper Competition (2006–2020)

There are 42 winning projects and 307 honourable mentions in the eVolo Skyscraper competition between 2006 and 2020, which in total form 349 projects. Some of these projects have been described and categorised in detail over the years in (53), (54) and (37). Below, the topics forming the titles of eVolo projects are presented under the same main themes used for AD. The abstracts describing the projects were transformed into contextual word clouds. The main topical clusters and the most influential elements from these contextual word clouds are presented year by year.

4.1. Data from the titles of eVolo winning projects and honourable mentions (2006–2020)

Fig. 9 shows the words forming all titles of the winning projects and honourable mentions of the eVolo skyscraper competition between 2006 and 2020.

Terms connected to ***architecture***, and more specifically to high rises, such as 'vertical', 'tower', 'skyscraper', 'city', 'urban', and 'structure' stand out at first glance. Architectural functions that have high frequencies are 'airport', 'bridge', and strangely, 'pyramid'.

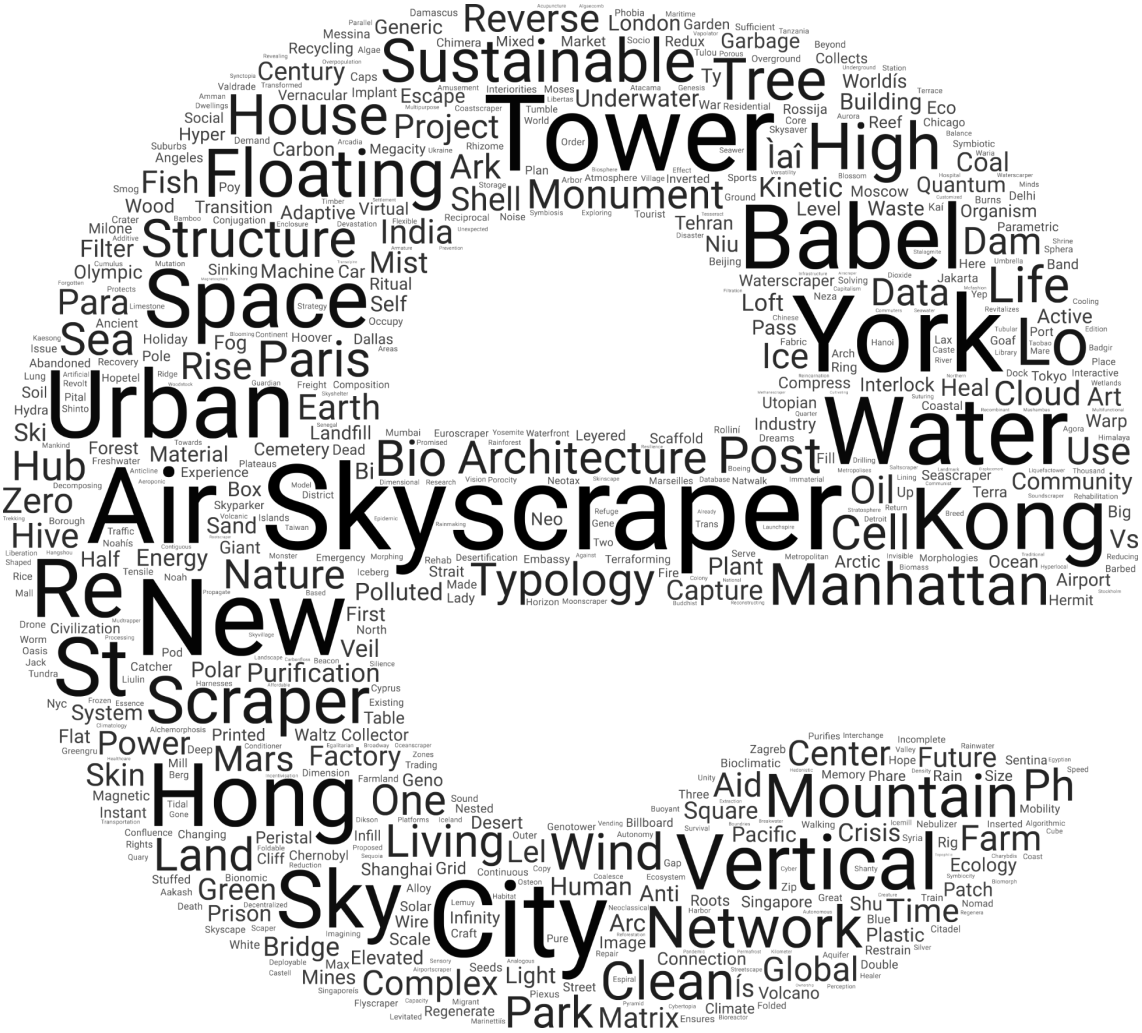

Fig. 9 – Word cloud of all words, dimensioned according to frequency, in titles of winning projects and honourable mentions for the eVolo skyscraper competition (2006–2020). 1,483 total words, 753 unique words.

The names of ***places*** of high density, such as New York, Hong Kong, Paris, London, India, and Shanghai, have high frequencies. But 'Babel' is used as often as

these real places and appears as part of titles six times in total (twice in 2012 and 2014, and once in both 2016 and 2017). Babel is connected to a skyscraper under perpetual construction (The New Tower of Babel (55)), a home built at almost any height with the help of aerostatic construction (House of Babel (56)), an ecological structure designed as a scientific facility and tourist attraction for the desert (Sand Babel (57)), a massive collage of cultural symbols (Taiwan Babel Tower (58)), and a memorial for workers in the building industry (The Scaffold of Babel (59)). A series of projects look at outer space as a place to build human habitats. The word 'Mars' appears relatively frequently in the titles: twice in 2013 and once in 2017. 'Moon' is also part of titles with the Moonscraper in 2011 (60), while 'stratosphere' is mentioned in 2013 (61). Generally, these projects describe concepts of terraforming that would save humanity in the face of overpopulation, depleting resources, and the negative effects of climate change.

On the other hand, maps of geographies that produced successful eVolo submissions can be found in (52) but also under (53), (54), and (37). For the winning submissions, the 42 projects came from 16 countries. When looking at the countries of both winning projects and honourable mentions, 48 countries are represented, but the distribution is uneven. The United States is clearly dominating (88 projects), with China (51 project) second, the United Kingdom (41 projects) third, France (26 projects) fourth, South Korea fifth (19 projects), and Poland (11 projects) and Russia (11 projects) sixth. Africa is almost off the map, with only two honourable mentions from Egypt, while South America is only represented by Chile (3 projects), Peru (one project), and Venezuela (one project).

The most referenced ***period*** in eVolo's titles is the 21st century. The term "future" also appeared frequently and was used to refer to the year 2016 (for an entry in 2010) and to more distant ones such as 2100 or 3015. The only reference to the past that comes up in eVolo titles is 'the 70s'.

When it comes to ***names***, the prevalence of 'Babel' is complemented by other Christian religious references such as 'Noah' and 'Moses' (in the context of depicting apocalyptic scenarios). An honourable mention from 2011 called Rhizome Tower: A Thousand Underground Plateaus (62) makes the influence of both Deleuze and Guattari explicitly present in the titles of eVolo projects.

References to ***technology*** include words such as 'machine', 'algorithmic' and 'parametric', '3d printed', 'drone', and 'data'.

While direct technology references are not as common in the eVolo titles as they are in AD, there are more words that can be connected with ***sustainability*** in eVolo. For example, the terms 'ecology', 'climate', 'sustainable', 'living', 'earth', 'clean', 'pollution', and 'recycling' frequently appear in eVolo titles.

There are no direct references to ***mathematics*** in the project titles. However, references to ***biology*** are ample and include 'geno-tower', 'bioclimatic', 'peristal living', 'cell', 'geno-matrix', 'bio-city', 'bionomic', 'bio-pyramid', 'bio-habitat', and 'biomorph'. ***Physics*** is also referenced, although less often than biology. For example, the word 'quantum' is part of titles with 'Quantum City' in 2007 (63) and 'Quantum Skyscraper' in 2013 (64).

4.5. Data from eVolo abstracts of winning projects and honourable mentions (2006–2020)

The abstracts of winning projects and honourable mentions in the eVolo skyscraper competition between 2006 and 2020 have 96,016 words and 9,988 unique words. The most frequently used words are 'city' (482 mentions), 'building' (371 mentions), 'new' (360 mentions), 'water' (322 mentions) and 'structure' (298 mentions). Fig. 10 presents the most influential topics and elements in the eVolo abstracts year by year between 2006 and 2020.

Among the most common topics in the abstracts are ***profession-specific*** words, such as 'tower', 'building', 'space', and 'structure'.

There are no ***names*** or ***periods*** that come up in the main topical groups or most influential elements, and the only topic that can be connected to ***technology*** is 'drone' (Fig. 10: 2016).

It is interesting to note that the word 'water' is among the words that are part of both the most influential topics and the most influential elements in the abstracts, and this has a rather uniform distribution throughout the years (see 2008–2010, 2012–2014, 2018–2020 in Fig. 10). 'Water' is used in connection to ***sustainability*** and framed as a problem that needs to be addressed through architectural projects for a sustainable future. Less frequently, 'carbon' and 'air' appear among the most influential words in the abstracts (Fig. 10: 2014, 2020).

Words that can be connected to ***'human'*** (in orange) have a growth in frequency from 2008 onwards. This can be seen both by looking at the relative frequency of 'human' in the abstracts, but also by looking at the most influential topics in the

abstracts (see Fig. 10: 2018–2020). In the years 2006 through 2015, the most influential topics in the abstracts were ‘structure’, ‘building’, ‘skyscraper’, ‘space’ or ‘project’. ‘Structure’ is very often among the most influential words in the abstracts (see 2006 to 2008, 2013, 2015 in Fig. 10). From 2016 onwards, ‘people’ is used more often (see 2016–2018, 2020 in Fig. 10), although a trend towards this was already indicated when ‘resident’ was included in the most influential topics in 2012. This is a similar trend to what we saw in AD article texts, and it shows that the topics surrounding computational architecture change over time and that there is a transition of interests from building (as a noun and as a verb) to the act of habitation, people, and humans.

2006
Main topical groups:
22%: building space area
20%: tower spatial single
17%: body proposal program
15%: skyscraper city structure
Most influential elements:
skyscraper building space structure

2007
Main topical groups:
19%: urban skyscraper form
13%: tower *system* energy
12%: structure vertical element
12%: water skin air
Most influential elements:
building city space structure urban

2008
Main topical groups:
18%: tower water main
18%: building space *system*
15%: city urban area
12%: skyscraper layer exist
Most influential elements:
urban vertical tower structure

2009
Main topical groups:
17%: city high urban
14%: space program create
11%: water level sky
11%: *system* ade series
Most influential elements:
water tower city *system* space high production produce

2010
Main topical groups:
23%: city tower world
19%: space level housing
13%: skyscraper project create
10%: water provide year
Most influential elements:
city skyscraper building project

2011
Main topical groups:
16%: structure main site
14%: city skyscraper world
12%: specific plant layer
12%: area recreational housing
Most influential elements:
city area skyscraper project

2012
Main topical groups:
14%: city locate resident
14%: structure floor part
13%: skyscraper project build
13%: water sea *system*
Most influential elements:
city tower skyscraper water building

2013
Main topical groups:
21%: city water energy
16%: earth top surface
16%: structure building *system*
13%: skyscraper project life
Most influential elements:
city water energy structure

2014
Main topical groups:
17%: structure space create
15%: tower water result
15%: city urban project
14%: capture carbon method
Most influential elements:
city tower capture carbon

2015
Main topical groups:
17%: space land area
14%: city construction *system*
14%: building skyscraper living
11%: structure vertical spatial
Most influential elements:
city structure space building land

2016
Main topical groups:
26%: city people project
17%: building skyscraper human
17%: module large drone
15%: space create vertical
Most influential elements:
space city building

2017
Main topical groups:
26%: city population world
17%: space urban skyscraper
17%: waste natural structure
15%: factory bring life
Most influential elements:
city building factory

2018
Main topical groups:
17%: building people space
16%: water *system* infrastructure
15%: city area world
14%: structure energy power
Most influential elements:
city building water people

2019
Main topical groups:
19%: city time living
17%: building skyscraper year
15%: space area create
14%: structure project *system*
Most influential elements:
city space building

2020
Main topical groups:
24%: skyscraper tower structure
23%: energy air water
20%: building space time
15%: people living world
Most influential elements:
building residential energy people

Fig. 10 – eVolo abstracts of winning projects and honourable mentions 2006-2020. Main topical groups and most influential elements as analysed using the Infranodus NLP. There are 96,016 total words and 9,988 unique words. The topics are presented year by year.

5. Discussion

Computational architecture makes use of a specific vocabulary that allows for the refinement of ideas and the cultivation of culture around the field. This section discusses the topics that consistently appear in ways of talking about computational architecture and the topics that come in a periodic fashion.

5.1. Recurring topics in ways of speaking about computational architecture

Computational architecture is more interested in the future rather than the past, in the new rather than the historical, and in the urban rather than the rural—all this broadly follows the field of technology. In architectural theory, the 'rejection of history' has been well debated, at least since modernism. The discourse is dominated by the West, although projects from China have won mentions in eVolo in recent years (see Section 4.2.). The avant-garde of the 70s is mentioned across the corpus, and there are references to the Moon, Mars, and space exploration.

In general, the discourse is developed and hybridised with topics coming from the natural sciences, specifically biology and physics. Topics from mathematics are also prevalent in, but the contribution of explicit mathematical topics was concentrated in the period between 2010 and 2012. Importantly, the topic of sustainability comes up often and consistently.

Strangely, eVolo contains words related to biblical characters such as Noah and Moses, and biblical places such as Babel—which comes up in titles with a surprising frequency. Almost every year, a number of eVolo Skyscraper Competition winners or honourable mentions have the word 'Babel' in their titles. It might be interesting to investigate the origin of projects which make these biblical references.

The words 'form', 'space', and 'system' often appear as main topics in ComPara. While 'space' and 'form' are traditional concerns in architectural theory, the word 'system' might be newer in architectural discourse, and understanding how and where it is used could uncover interesting patterns.

5.1.1. Sustainability

In general, sustainability is described as a problem to which architecture (many times enhanced by technology) is seen as a solution. Investigating how sustainability is understood in the field of computational architecture over time is a possible direction

for future research. The following are potential research questions that can be investigated: What does it mean to be sustainable? Can sustainability be achieved? How will we know when we have achieved it? Can sustainability be described without reaching tensions about diverging interests?

Sustainability comes up as a topic more often in the eVolo corpus, where most projects state problems related to the environment and climate change that the project can solve. Generally, the projects start with stating a problem that is dramatic and large, and continue with suggesting highly technological, built (conceptual) solutions that can solve the problem. The problems mostly deal with high population density and its associated issues of over-population and pollution of the sea, earth, and sky. Stressed infrastructures, desertification, the depletion of natural resources, potential nuclear disasters, or the melting of polar caps are frequently mentioned. This results in a series of words hinting at rather pessimistic realities and futures such as 'cemetery', 'landfill', 'Chernobyl', 'garbage', 'plastic waste', and 'pollution' (see Fig. 10). However, these futures are saved by the solutions suggested through the projects. But starting in 2015, the word 'problem' becomes more frequent than the word 'solution' in the abstracts. This might show a transition towards a different understanding of sustainability as a more complex or wicked problem (65). To exemplify the problem-solution dynamic, *Noah's Ark: Sustainable City* (an honourable mention from 2012) is a floating city that could support all living species once they have been evicted from land 'by natural disasters, warfare, whatever disasters the end days may bring' (66). *Oceanscraper* (67), is a large underwater architectural structure that 'does not have to abide by the laws of gravity' and would use decommissioned Russian submarines lying on the sea bed as nuclear power sources. *Moses: A Decentralized Floating Network of Skyscraper Cities* (68) and *The Promised Land Waterscraper* (69), are solutions to rising sea levels. The metaphor of the ark appears a couple of times in the projects as a solution to apocalyptic futures. All of these conceptual projects clearly articulate a real-world problem, usually related to sustainability, and then continue to offer solutions to that problem. The solution does not have to be feasible, or even realistic, in any way, but the problem needs to be real and of monumental proportion. This corresponds to design's inbuilt optimism in general (70), and also follows hopeful views that technology will solve most problems. While investigating sustainability understandings in the winning projects and honourable mentions of the eVolo skyscraper competition would be a research paper on its own, it can be said that sustainability is understood as a limitation

in these conceptual projects, and as a problem, or something to resolve. It is important to note here that the calls of the competition frame the projects responses and that the calls change slightly year by year, although the core focus remains on high rise architecture, technology and sustainability.

AD and eVolo reference sustainability and technology differently: while AD is filled with topics that have to do with technology and with fewer references to sustainability, the opposite is true for eVolo, where sustainability is a recurring topic throughout the years, and technology is less often referenced directly.

5.1.2. Biology

Throughout the years, biology and topics which can be associated to it frequently appear in both AD and eVolo. This simply puts quantitative data behind Phillip Steadman's (71) statement that 'as a matter of historical fact, biology, of all sciences, has been that to which architectural and design theory have most frequently turned to.' Recently, other studies have looked at the relationship between biology and architecture, and similar points were made by (72), (71), (73), (74), (75). Biology comes up as a topic strongly connected to computational architecture. Tracing the depth and scope of biology's influence as a model, as a metaphor, as an analogy, as a source for novel building materials, and as a field to entangle to computational architecture into a new paradigm, as suggested by (76) can be subject for fruitful future research. Looking specifically at the relationship between sustainability, biology, and computation in contemporary architecture can also make for interesting investigations. Technological advancements help to integrate biology and architecture and revisit the idea of growing living buildings.

Based on the topics that come up constantly surrounding computational architecture, namely technology, sustainability, and biology (and to a lesser extent mathematics and physics), it can be argued that the field is currently shaped according to the following model:

(Mathematics + Physics + ***Biology****) * Technology / Sustainability*

Technology helps to explore and enhance old (but yet unexplored) or new ideas from mathematics (as argued for example in (77)), biology, physics (as discussed for example in (78)) in architecture, while sustainability comes as a constraint or limitation, sometimes to avoid creating purely technological explorations.

5.2. Waves of influence

While the topics described above appear with a rather even distribution, there are topics that are more popular in certain periods. In (79) Heinrich Wölfflin read the history of art in waves, explaining that art takes turns between being fascinated with the static aspect of life (the classical) to focusing on the dynamic aspect of life (the baroque) and returns in an upward spiral. Looking at the topics that come up in ways of speaking about computational architecture, similar waves of influence might be visible. Fig. 11 shows a map of topics that come up when speaking about computational architecture. On the upper part are the topics that come up in waves, and at the bottom are topics that come up constantly in the corpus.

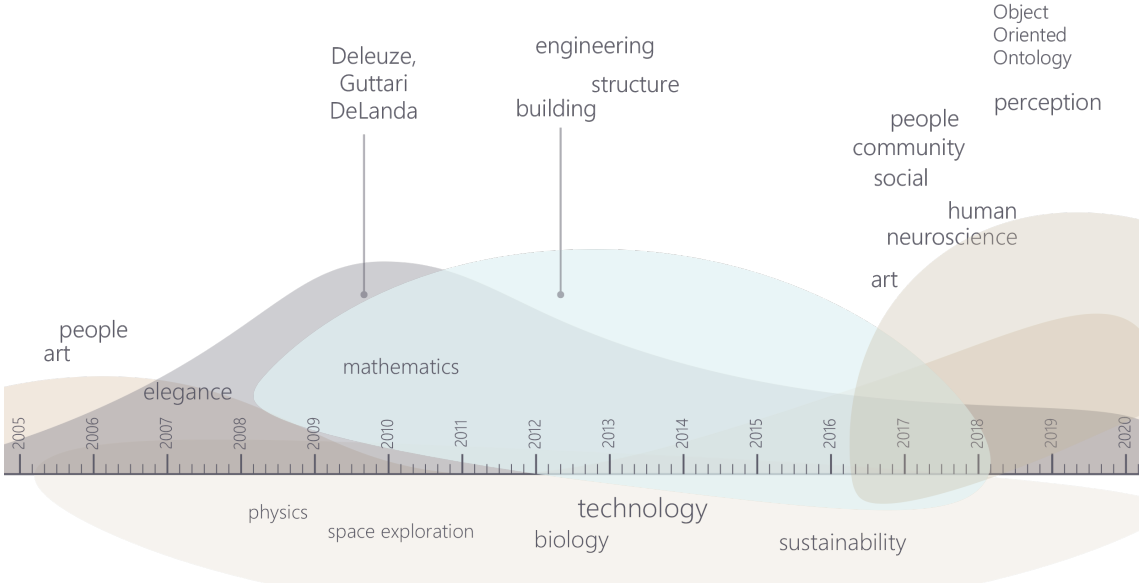

Fig. 11 – Topics that come up consistently and in waves in ways of speaking about computational architecture

5.2.1. Computational architecture between engineering and art

In the entire corpus, art comes up as a topic more often than engineering in general. However, there is a period roughly between 2007 and 2012 when there are more references to engineering and words connected to it (such as ARUP). This also corresponds to the two traditions of architecture-as-technology and architecture-as-art established after the Enlightenment (31). In the words of Nigel Cross, designerly ways of knowing do not fall neither in the humanities nor within the sciences (80).

5.2.2. The Deleuze connection might be fading

ComPara shows numerous references to philosophers Deleuze, Deleuze-Guattari and DeLanda, who was the philosopher whose declared role was to explain Deleuze to architects (81), and who has done so by teaching in many of the avant-garde architectural programmes around the world. All three names appear in the keywords associated with the *Introduction* article in AD. A title of one eVolo project from 2011: 'Rhizome Tower: A Thousand Underground Plateaus' (82), makes a direct reference to Deleuze and Guattari. These correspond to the so-called Deleuze connection to architecture (83), (84), (85), (86), (87). Since 2016, neither 'Deleuze' nor 'DeLanda' have appeared in the AD *Introduction* keywords. 'Deleuze' still appears in the texts of AD articles, but with less frequency. On the other hand, object-oriented ontology (OOO) has been gaining popularity: 'Harman' and 'Morton', together with 'Merleau-Ponty' and 'Heidegger', were part the keywords six times since 2012. The word 'perception' is also much more frequent in 2020 than in previous years in AD article texts.

5.2.3. From object to subject

Perhaps the most interesting trend in the corpus is a transition in interests from object to subject. The frequency of the word 'perception' might be connected to the progression of trends throughout the years. In the period between 2008 and 2012, the main topics revolved around structures, engineering, and building (both as a noun and as a verb). In 2012, both AD and eVolo began including topics that involved humans. In 2012, the word 'human' appeared for the first time in the issue titles of AD, while the word 'resident' is an influential topic in the eVolo abstracts. Since then, topics related to humans and people have been used more frequently (see Fig. 6, 7, 8, 10) and they are discussed in the following ways:

1. Architecture in relationship to the social ('people', 'community', social')

The social is a traditional concern in architectural theory in general. The literature on design for sustainability shows that design is moving from product-level approaches to a social-technical system focus (88). Reappraising the *social* might also be connected to the frequency of the word *system* over the years in the corpus. For computational architecture, this has interesting implications, as computational architecture has long been dominated by: interest in the objects that can be created by means of computation,

the design processes that computation can facilitate, and the development of novel materials and new tools, rather than the social.

2. Architecture in relation to perception ('human')

Perception has also been a topic connected to architecture and its theory (89), although less frequently or directly than the social. Again, this trend echoes what is happening in other design fields. For example, in interaction design, rooted in Dewey's *Art as Experience* (90), the interest has similarly moved from investigating objects to focusing on and studying experiences (91)

3. Human creativity and artificial intelligence ('neuro', 'brain', 'AI', 'machine learning').

Here, the discussions run between the future role of the architect, digital authorship, and toolmaking. Some question whether AI will render the role of the architect obsolete (92), while others state that it will simply become a prosthesis, helping architecture evolve and allowing architects to generate more and better solutions (88). In this way, AI would simply be a continuation of CAAD tools. Recently, much work has been dedicated to using computation to partly automate the generation of architectural solutions (94), (95), (96) while others have tried to articulate the relationship between neuroscience, artificial intelligence, and architecture (97), (98).

In the last few years, the ways of speaking about computational architecture have shown more topics that have to do with subjects rather than objects. It can be said that computational architecture is surrounded by a new subjectivity which has at its core 'people', those for whom architecture is and how they perceive space, but also the future role and relevance of the architect herself.

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