Information Design Journal 27(2), **p. 144–190**

doi.org/10.1075/idj.20026.ata
Publication date: October 3, 2022

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Applications of the Document Towers method of representing document structures

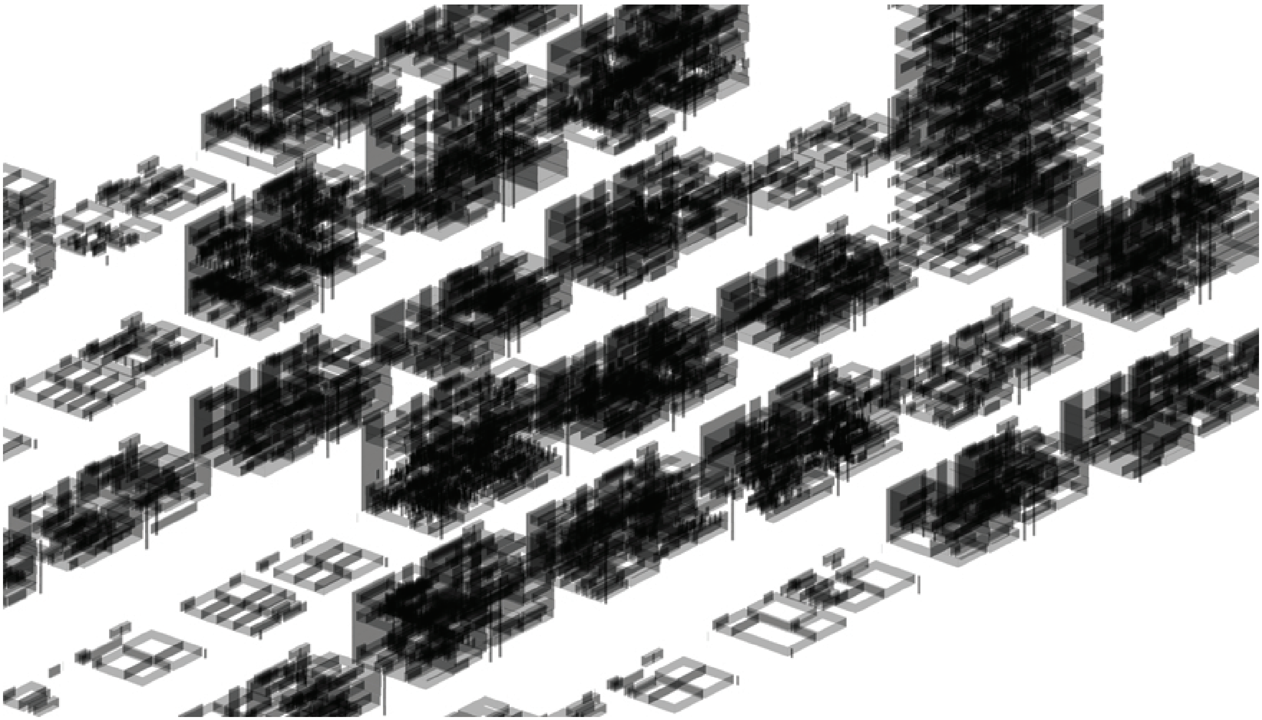

Figure 1. One possible interpretation of the above picture is that of an architectural plan of a cityscape. We see a Cartesian street grid, buildings of various sizes and complexities, and what might be the lower part of a twin-bodied skyscraper. There appear to be rooms and pillars. We might think of dollhouses, of blinking lights and zipping cars, of the electrifying bustle of rush-hour crowds of a metropolis. And, in a sense, we are right, because this visualization paradigm, called Document Towers, represents the bounding boxes of text paragraphs, stacked by successive double pages of selected articles of the Information Design Journal. Rather than the life of city dwellers, the visualization reveals the patterns of written communication and the spatialization of ideas in a scientific journal. Some articles have a more homogeneous, settled organization, while others are more dynamic and fragmented. This type of document structure representation not only fosters insights and prompts questions, but also favors a rich diversity of applications, a central topic of this article.

Keywords: document structure, document representation, document analysis, information systems, visual metaphors

This article argues in favor of representing the spatial distribution of information within and between documents, by surveying a broad variety of potential applications, including the entire document lifecycle, multiple sensory modalities, and a large spectrum of tasks and users. The theoretical explanations of this richness are a further facet of the article, and can be summarized as follows: (1) insights emerge from focusing on information structure, rather than information meaning; (2) spatializing information creates new information; (3) simplification increases the polyvalence of representation models; (4) introducing mystery in communication channels motivates discovery and diversifies insights; (5) approaching information design as a *Gesamtkunstwerk* multiplies the applications; (6) information is a manifestation of a link between structures and the actions these enable, while information design is the art and science of creating such links. The argument is developed around the concrete example of a document structure visualization, the Document Towers, which uses the metaphor of architectural models to represent documents.

"*Our language can be regarded as an ancient city: a maze of little streets and squares, of old and new houses, of houses with extensions from various periods, and all this surround- ed by a multitude of new suburbs with straight and regular streets and uniform houses.*"
– Ludwig Wittgenstein, *Philosophical Investigations*, §19

1. Introduction

The reader who begins to think about document structures will soon discover that these lead to a surprisingly large number of applications. This article discusses the utility of representing document structures from three distinct viewpoints relevant to information design:
(i) to enable practical acquaintance with a specific document visualization technique, the Document Towers, which also provides a case study around which to organize the material contained herein;
(ii) to present an illustrated survey of potential applications of the broad information class represented by document structures, (iii) to rationalize the applications' richness, and champion the inclusion of key factors in what could be termed "the information designer's practical toolbox". Visualization, applications, and theory form a system of interlocking themes that complement and explain each other.

The article's core thesis is that information structure is in itself informative and complements information semantics. From here derives the relevance of document structure representation for information design: after all, what is the essence of information design if not the structure of information, given that the discipline does not concern itself with the production of content. Moreover, information *is* structure. To convince oneself, it will suffice to shuffle the letters in this paragraph, which will change its meaning.

This work is motivated by the apparent lack of a survey assessing the utility of document structure representation. The utility of the Document Towers is also a recurrent discussion topic between their creator and potential users; thus, the matter has been deemed sufficiently consequential to warrant a dedicated study to answer a manifest need.

The findings of our study show that document structures are relevant throughout the lifecycle of documents and related tasks and users. For example, the extraction of physical and logical structures is essential in the fields of document engineering and analysis for digitization and conversion purposes, and accordingly underpins the societal changes driven by digital technologies. The quality of human interactions with digital document information systems also depends on the user's ability to request, extract, represent, and navigate document structures, from everyday e-reader usage to the analysis of multimedia resources in virtual reality, that electronic avatar of Victorian-era panoramas.

This article focuses on text-based analog and digital documents and libraries, such as books, magazines, forms, posters, and product labels, characterized by a mix of alphanumeric text, lists, tables, pictures, and graphics. Document structure is defined as the spatial distribution of information within a document. The information can be of any kind – commonly semantic (e.g., topics, named entities, connotations) or logical (e.g., titles, paragraphs, notes, tables, images), while the structure is defined by physical attributes (mainly the coordinates of entities within the page and the document, but also colors, typeface names, or descriptors such as perceptual crowding). All sensory modalities of information representation are considered, from visual to audio to tactile. Reviews of document representations can be found in Fekete & Lecolinet (2006) and Keim et al. (2010).

This section has set forth the article's objectives, motivations, relevance, and subject matter definitions. The next section introduces the reader to the Document Towers, as a case study in document structure representation. The following section presents theories generalizing key aspects of the Document Towers, whose operational role is to facilitate better understanding of the proposed applications and the generation of new ones. The subsequent section is the article's *res materia*, in which potential applications of document structure representation are surveyed. An assessment of the work's place in the relevant literature concludes the article.

Figure 2. These pictures represent examples of the architecture-as-documents metaphor implemented in reverse in the Document Towers paradigm. The National Library of France in Paris (top picture) stores documents in four glass towers shaped as open books, intended to convey the idea of open culture. The windowless, monolithic AT&T telephone exchange building at 33 Thomas Street in Manhattan, New York (bottom picture), is an architectural exponent of opaque information. Fittingly, it is presumed to house an information surveillance facility of the National Security Agency (Moltke & Poitras 2016). (Credits: V. Atanasiu, Google Street View)

2. Case study

The Document Towers will serve as a case study to anchor the discussion with a concrete example of document structure representation. The Document Towers paradigm, visualization, and open-source software were first introduced in Atanasiu & Ingold (2021), and their usefulness for the quality control of digitization workflows has been evaluated on a real-world historical newspaper dataset at the Swiss National Library (Atanasiu 2022b). This publication in the Document Towers series intends to demonstrate (i) that the number of potential applications is much greater, (ii) that some of its key characteristics are common to other types of document structure representations, and (iii) that it facilitates the investigation of the role of such factors as spatialization, mystery, and *Gesamtkunstwerk* in information design.

We first provide an overview of the techno-cultural background of the Document Towers. We then explain how to create and read the visualization. We use a case study to demonstrate insights obtained from Document Towers. We conclude by situating the paradigm's salient features within the broader perspective of document representation.

The Document Towers visualization implements the architectural metaphor of DOCUMENTS-AS-BUILDINGS, an analogy with a lengthy history. The romantic art critic John Ruskin famously compared Gothic cathedrals to books set in stone, alluding to their shared narrative dimension (Schoenherr 2004). The definition of architecture as "a machine to inform with" provided by the architect Le Corbusier, who was also an accomplished book designer (De Smet 2007), has been extended to documents in a variety of instances, such as the letter-shaped Book Pavilion of the futurist Fortunato Depero at Monza in 1927 (Tavares 2016: 150–153), and Dominique Perrault's French National Library in Paris in 1996, whose high-rise towers resemble open books (Vidler 1993).
In the domain of graphic arts, typotecture is a style in which written characters are drawn to mimic individual buildings or whole cities (Heller & Ilić 2013; Jenser 2002); a style popularized by movies such as *Tron* (1982) and *The Matrix* (1999), in which space is made of streams of information. The zeitgeist of the second half of the 20th century abounded in information-spatializing metaphors, both in common and technical language: cyberspace, information superhighway, electronic frontier, goto and return commands, front- and back-end development, file up- and download, network ports and tunnels, Internet websites, firewalls and clouds, the professional field of Information Architecture, the virtual world Second Life, and many more (Wertheim 2000, Munro 1999). Information spatialization appears to be a deeply entrenched technique of human cognition, both cross-culturally and diachronically. One noteworthy example is the mnemotechnique known as the Art of Memory, spanning the period from Greco-Roman antiquity to the Enlightenment, and consisting in placing information in imaginary buildings, which provided an effective system for "squirreling" memories back (Yates 1966). Similarly, the "songlines" of Australian Aborigines on mythical animals and their deeds encode sequences of landmarks to support cross-continental navigation (Chatwin 1988); for the Apache people, places are where wisdom is found in the form of geolocated stories (Basso 1996), a concept not dissimilar to the French historian Pierre Nora's description of how "places of memory" (*lieux de mémoire*), such as statues, monuments, or battlefields, are integral to building modern national identities (Nora & Jordan 2001–2010). The convergence of the spatial, the semantic, and the social in architecture and urbanism is also a continuing source of inspiration for technologists of information systems (Chalmers 1995, 1999). It has led to mainstream human–computer interaction paradigms, via the cognitive mapping of data, software, and

operations to graphical user interfaces, such as windows, desktops, icons, and various interaction patterns, as well as many experiments in three-dimensional representation (Dodge & Kitchin 2001). Representations of text-based documents as three-dimensional architectural models have also been developed in a series of projects at the MIT MediaLab from the 1970s to the 2000s (Cooper & VLW 1994; Sparacino, Davenport, & Pentland 2000; Dragulescu 2009), and more recently, for visualizing the nested structure of HTML entities in the Firefox web-browser (Mozilla 2021) and Java software packages (Alam et al. 2009) as pseudo-urban landscapes.

The Document Towers paradigm is part of the cultural and technological tradition outlined above. Its main contribution is the way in which it provides access to information in documents, by representing the physical structure given by the graphical layout, rather than the logical structure of the linguistic dimension. This difference in access results in a difference in the kind of information made accessible, while the architectural metaphor provides a familiar framework with which to interact with the visualization, i.e., to increase its "affordance" (Gibson 2015: 119–135; Norman 1990).

To visualize documents as Document Towers, the starting point is to obtain the coordinates of the bounding boxes of document objects, such as pages, paragraphs, and images. These are recorded explicitly in electronic document formats such as Adobe's Portable Document Format (PDF) and InDesign Markup Language (IDML) (Adobe 2008, 2006), and are recoverable from document images following conversion to formats such as the Analyzed Layout and Text Object (ALTO) (Library of Congress 2021). For the technical details of the extraction procedure, the reader is referred to Ingold, Bloechle & Rigamonti (2014) and Tang (2012).

Once object coordinates have been extracted, they are employed to create a three-dimensional graphical object; for example, by using the Document Towers open-source MATLAB software (Atanasiu & Ingold 2021). Figure 4 illustrates the process of simplification, extrusion, and projection leading from a page to a wireframe resembling an architectural model, where paragraphs and images correspond to rooms, double pages to floors, documents to buildings, and libraries to cities. This is how the architectural metaphor of documents-as-buildings comes about and how it is read.

To demonstrate how insights can be derived from the visualizations, articles from the Information Design Journal (IDJ) have been visualized as Document Towers (Figure 3). The choice is part autopoetic playful gift from the author to his hosts, part curiosity about the layout evolution of a design journal, and part need to understand its graphic design in order to write this article. To keep the volume of data manageable for the reader, three representative volumes spanning the journal's lifetime were selected.

The low-rise "buildings" are the articles published in 2017, except for the front corner building, which is the inaugural article of the first issue of 1979, while the high-rise "tower" represents the articles of 2002, stacked one on top of the other. The choice between horizontal and vertical presentation depends on the visualization compactness one wishes to achieve, and on how important it is to distinguish the different articles from the same issue from one another. Red slabs represent the boundaries of physical pages, as specified in the PDF files from which the wireframe models were generated; the double pages appear as twin towers, in their logical reading order, top-down and left-to-right. The location of the low-rise Document Towers within the Document City matrix reflects the article sequence within the respective issue. The high-rise Document Tower was placed to avoid obscuring other buildings, a phenomenon typical of three-dimensional representations. To avoid obscuring other buildings, the user can rotate, pan around, and zoom into the visualization.

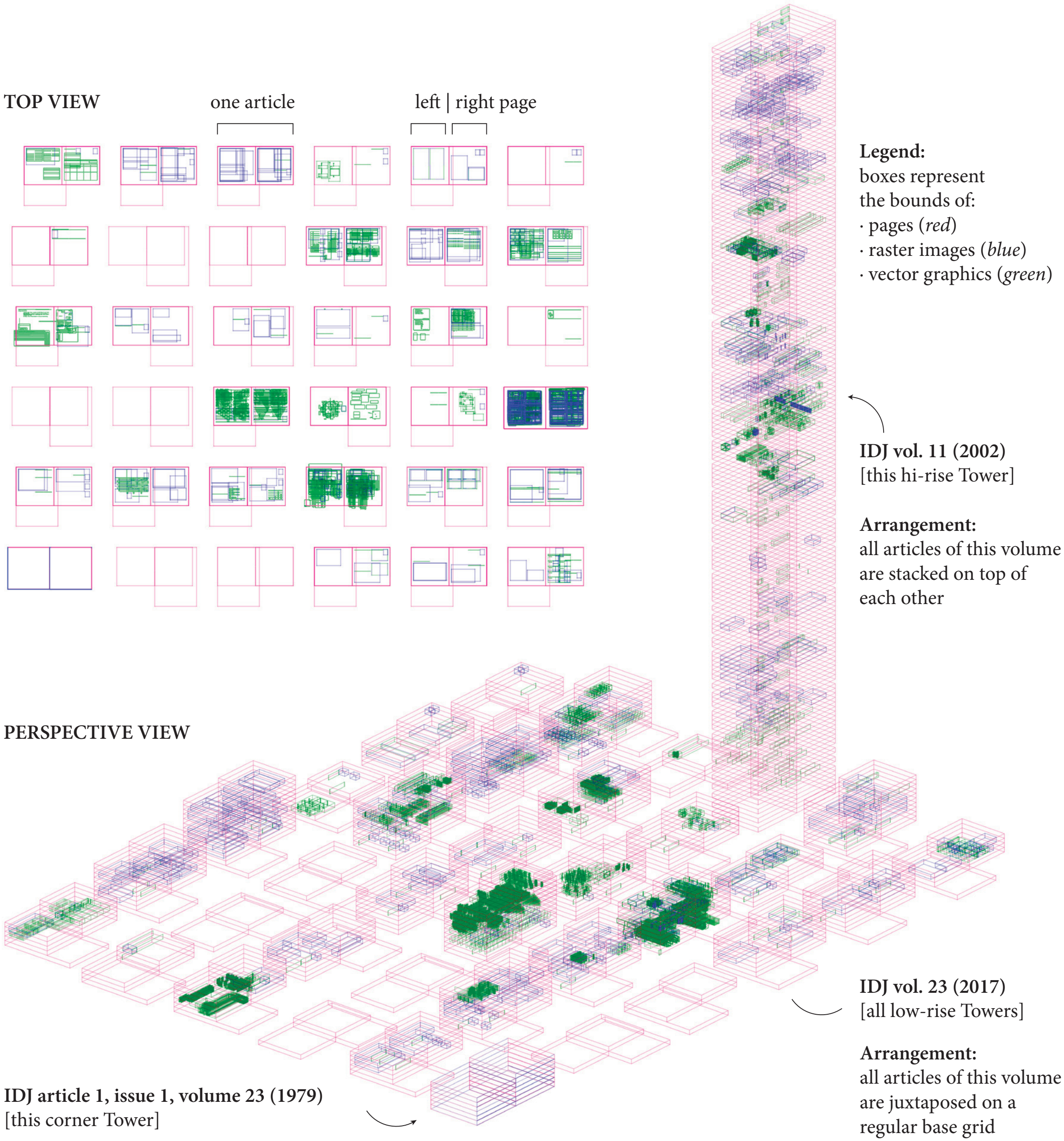

Figure 3. Document structure of selected IDJ articles

The oversize slabs at the bottom of some buildings represent a page containing terms of use appended to the documents at download time by the digital library system. Blue slabs stand for the boundaries of objects identified in the PDF as raster images, such as pictures taken with a camera, while the green slabs are vector graphics, such as those found in diagrams or used as rulers in tables. Figure 1 depicts text paragraph boundaries as gray slabs; these are obtained from the documents in the central area of Figure 3.

Turning now to the insights made possible by the visualization, let us first appraise the visual pattern in Figure 3. This may be best characterized as "uniform heterogeneity", in that it strikes a balance between types of articles. Text-only articles (of predominantly red color) are largely theory articles, reviews, and editorials; image-based articles (mainly blue) are typically practice-oriented; articles using diagrams and tables (with green components) are indicative of qualitative evaluations. In other words, the Document Towers allow for a diagrammatic reading and "visual proof" of the journal's editorial philosophy as a place that offers a diversity of perspectives to readers with diverse backgrounds and interests (Westendorp & van der Waarde 2001). When comparing the visual pattern of articles from 2002 with those from 2017 it seems that the balance of content has remained stable over time, with a slight increase in the number of vector objects; this is possibly due to a proliferation of quantitative evaluations, presented in tabular form. Here the reading made by the author shifts from elementary to speculative, and the visualization from comprehensible signifier to hermetic symbol. This increase in uncertainty—or information entropy—shows that some representations are endowed with the ability to prompt unexpected questions, and this should be welcomed.

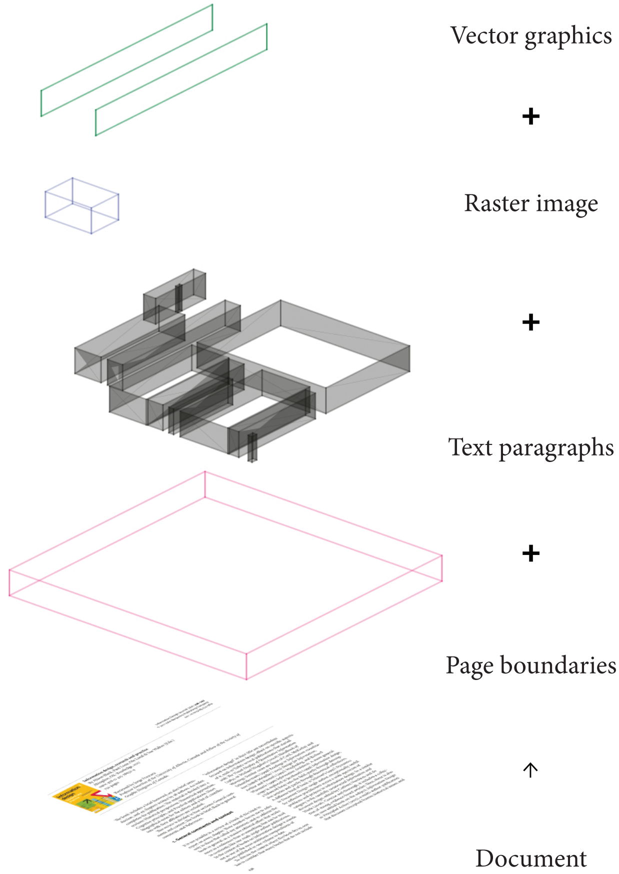

Figure 4. Representation procedure—This figure illustrates how a PDF document page is transformed into elements of a Document Towers visualization. The representation is generic, and any information that can be attributed to a location in space is representable. Some document formats allow to relate object coordinates to additional information (here, for example, the type of object).

Several other features of the visualization catch the eye. For example, the 1979 article is remarkable in that it appears to be composed entirely of raster images covering the whole page surface. In fact, this article is scanned, so that every page is indeed a picture. One application of this observation pertains to the management of digital libraries in terms of costs, resources, and quality. Understanding the percentage of scanned documents in a dataset facilitates the planning of the acquisition and allocation of the resources necessary to perform optical character recognition (necessary for scans, but unnecessary for digitally born documents). It also makes it easier to estimate the quality of answers to textual searches made by humans or machines (different between the two document types). The reason for selecting the 2002 issue for visualization should now be clear. Since articles until that date were scanned, they all exhibit a uniform pattern, therefore displaying this pattern is redundant. However, it is via visualization that the author obtained this valuable information.

The simplicity of producing the Document Towers, the straightforwardness of the metaphor, and its visual attractiveness are also important factors (Turner 2017: ix, 3–8). Figure 3 also reveals a striking fact about document structures, namely, that logical and physical structures are consubstantial, not distinct, that is, they are enforced by conceptual models of document markup languages that separate content from presentation. Because documents designed to communicate with humans have physical materiality, the information they convey must be spatialized to some degree. It is from information spatialization that many applications derive, such as the exploration and discovery via visual search. This contrasts with spoken and written language search interfaces, which demand that users know what to look for in order to formulate queries.

3. Theory

Why does a representation such as the Document Towers "work"? Why is it insightful, and why does it yield so many applications? The reasons advanced here generalize beyond a specific visualization, and thus should contribute more broadly to the theory of information design (Pettersson 2016).

3.1 Agnosticism

The Document Towers paradigm is marginally contingent on document medium (codices, scrolls, hypermedia, and other spatial embeddings of information can be equally represented), on the document encoding (object coordinates can be extracted from many formats), on the type of extracted information (provided that coordinates can be attributed to it), and on the representation modality (Document Towers can be rendered graphically, printed in three dimensions or in relief, and/or sonified). Consequently, the strong agnosticism of the representation makes it highly suitable for a broad range of applications.

3.2 Essentialism

The Document Towers visualization reduces documents to the essential. The wireframe architectural model emphasizes structure by removing the opaque material of paper, leaving behind an object as transparent as a "crystal goblet", to use a famous metaphor defining good typography (Warde 1956). The deliberate choice of simplicity (as opposed to a realistic rendering in the manner of SimCity) intends to diminish visual clutter, avoid complex software requirements, and reduce the cognitive load of interacting with virtual three-dimensional objects. The abstraction process, nevertheless, stops short of transforming documents into numerical artifacts, however compact and easily manipulable they may be. Rather, the Document Towers provide unmediated and intuitive access to the object's geometry, one benefit of structure-preserving models of information.

3.3 Spatialization

Information spatialization cannot only preserve and reveal information, but also create information (sometimes useful, sometimes spurious). Consider the case of three text paragraphs and the impact of their configuration on their meaning. Arranged vertically and equally spaced, they will be perceived as a single visual and semantic unit. Sliding the middle paragraph laterally will mark it (again in both visual and semantic terms) as an outlier, and perhaps as a marginal gloss. Moving the third paragraph diagonally away from the rest, the hierarchy between them is reinforced; another possible connotation emerges, related to the modernity and sophistication of such a design, in that it is asymmetrical, in contrast to the symmetry observed by classical typography (Tschichold 1995). The principle at work here is that inhomogeneities developing from spatio-temporal relationships have both energetic—i.e., material tension—and informational potential (Atanasiu 2022). The reduction of matter and information to energy is what allowed the computer science pioneer Carl Zuse to formulate the idea of the universe as a computing machine (Zuse 1970; Stonier 1990). The phenomenon is fundamental to cognition, as found by Gestalt psychology in the empirical work on grouping and other perceptual "laws" (Metzger 2006), and to social relations, as epitomized in the work of the sociologist Niklaus Luhmann on "distinction" (Luhmann 2006). Furthermore, the informational properties of spatialization explain the fascination for visualization of diverse thinkers such as the philosopher Charles Pierce, for whom "all mathematical reasoning is diagrammatic" (Peirce 1902); the statistician Edward Tukey, father of the Exploratory Data Analysis (Tukey 1977); the mathematician Benoît Mandelbrot, who declared that "blind analytic manipulation is never enough" and whose fractals have become psychedelic household items (Mandelbrot 2002: 48); and the physicist Richard Feyman, inventor of the eponymous notation for particle physics. Approaching "problem-solving by means of imagistic representations" (Gauker 2011) has often been instrumental in spawning new research fields.

3.4 Mystification

Building the Document Towers paradigm around a metaphor is a well-known design method to facilitate the use of representations (Lakoff & Johnson 1980; Zhang 2008: 215–237). However, combining the metaphor with the sibylline simplicity of the wireframe architectural model engenders mystery. The meaning of a picture such as that in Figure 1 is not instantly comprehensible, but the similarities with a cityscape are sufficient to prompt attempts at explanation. Effective information design does not need to be crystal clear communication (pace Warde); mystery has a role to play, as is well-known in marketing. Mystery first teases and attracts, then motivates the viewer to "crack the nut"; and may finally lead to a great variety of insights, due to the combinatorial variability of subjective and contextual factors (Zhang 2008: 191–213). Information design by deliberate mystification is an appropriate technique to elicit discoveries when the information is unknown or insufficient to the information designer. The Baroque era was a great time for the design of mysteries. Chiaroscuro. Caravaggio. Athanasius Kircher. **Ex tenebris lux!**

3.5 Holism

The art and science of communication have been rightly defined as a *Gesamtkunstwerk* (Flaskamp & Schmidbauer 2003), a term equally applicable to the field of information design, given the role communication plays in it. To take the Document Towers paradigm as an example, we see that it harnesses an extended cross-cultural history and commands an interdisciplinary perspective, that it channels information through visual and haptic modalities, and that it addresses multifarious users and tasks; it is data- and user-centered, situated, and embodied. In brief, the adoption of a holistic, systemic attitude is a significant factor in the emergence of the diversity of applications.

3.6 Enaction

People see little meaning in document structures if they cannot imagine applications; information emerges from structure only if it leads to some form of action, be it physical, symbolic, or delayed. This is known in psychology as "enaction" and it is closely related to embodiment: the idea that motor activity is integral to cognition, perception, and emotion (Coello & Fischer 2016; Stewart, Gapenne, & Di Paolo 2010). It is a notion reverberating through many domains. In linguistics this notion rejoins the stance of pragmatics (from Greek *pragma* "act"), according to which language is about achieving goals, not communicating thoughts (Huang 2017; Gauker 2003). It has been proposed as a theory of visual art as social agency (Gell 1998); and it is also a core tenet of Buddhism, in which non-action (*nirvana*) releases from existential meaninglessness perpetuated by a chain of actions (*karma*) (Collins 1998). Translated to this article's context, enaction creates the conceptual and operational link between document structures and applications, from which information on documents arises. From this perspective, information and information design may be defined as the linking of some structure with some action.

Figure 5. Document sonification—This is a scene from Wim Wenders' movie *Wings of Desire* (1987) where an angel listens to the flow of the readers' thoughts in the State Library of Berlin. Similarly, Mark Twain said: "In a good bookroom you feel in some mysterious way that you are absorbing the wisdom contained in all the books through your skin, without even opening them." Document structures have both a simplicity and a complexity that make them eminently suitable for sonification, to realize Wenders' and Twain's visions. But the picture also suggests another idea for information designers: Not every piece of information has to be made explicit, and allusions are sometimes more appropriate, as in this metonymical use of an image for a soundtrack that the reader is required to imagine. (Credits: WDR)

4. Applications

It is a truism that document content is more than words and pictures (Ehrmann, Bunout, & Düring 2019): it is narrativity (Pflaeging 2017), materiality (McKenzie 1999), form (Hiippala 2016), affect (Turner 2017), context (Agarwal 2018), and more. Similarly, documents and interfaces are dependent on know-how, resources, management and politics for their development and use (Thylstrup 2019). In brief, the components of information systems form a multidimensional ecosystem (Dorte 2012). To reflect on this characteristic and its impact on the usefulness of document structure representation, the following sections are organized along the following basic design dimensions: representation modalities, document media, extractable information types, application tasks, and relevant user categories.

Applications are generally illustrated by a use case scenario. Vignettes provide visual demonstrations of relevant topics, selected from the work on Document Towers. This content should be understood as made of pointers to places beyond the horizon, intended to stimulate the imagination of readers. It may be best used by searching for specific items, or by skimming, as one would when using a catalog.

4.1 Modalities

Document structures can be represented in different modalities (i.e., human sensory channels). The advantages and disadvantages of these modalities are well known and widely discussed in textbooks on information design (e.g., Ware 2008). Some of these modalities are discussed here to illustrate their impact on document representation.

Visual
Of all sensory channels, visualization is the one that offers the greatest communication *bandwidth* and *resolution*. Static visualizations facilitate data *comparisons*, as several visualizations can be presented concomitantly in the visual field, in contrast to auditive information, which is deployed over time. However, three-dimensional visualizations, such as the Document Towers, can easily become inscrutable due to *occlusion* and *crowding*. Visualizations also *monopolize attention*.

Audio
Data sonification allows for *simultaneous* attention to information streams delivered through more than one sensory channel. For example, reading two books concomitantly is challenging, whereas reading and listening to music is not. Much like odors, auditive representations can elicit *emotional responses* more easily than visual representations. Audio has, however, *narrower bandwidth* and *spatial resolution*, and is also more *difficult to design* due to psychological, cultural, and subjective variability.

Somatosensory
Haptic feedback (the sensation of weight or proprioception) and *tactile* feedback (texture sensation) are part of document interaction, and as such are natural representation modality choices (e.g., indentations in address books facilitate faster access to alphabetic name groups). Ongoing research looking at tactile sensation stimulated by ultrasound interfaces suggests that future electronic documents could be explored via touch. This would be especially useful for *visually impaired people* and would also relieve the tedium of conducting the basic tasks of browsing and navigating.

4.2 Media

This section discusses the advantages of both media-independent and media-specific representations.

Analog vs digital
In digital publishing, there is no need to physically print a new book if you wish to change the typeface, nor there is any need to wait for a physical copy to arrive in the mail to start reading the book. Although convenient, this can make one forget the advantages of hardcopy visualizations of document structures. Paper-based representations do not need electricity

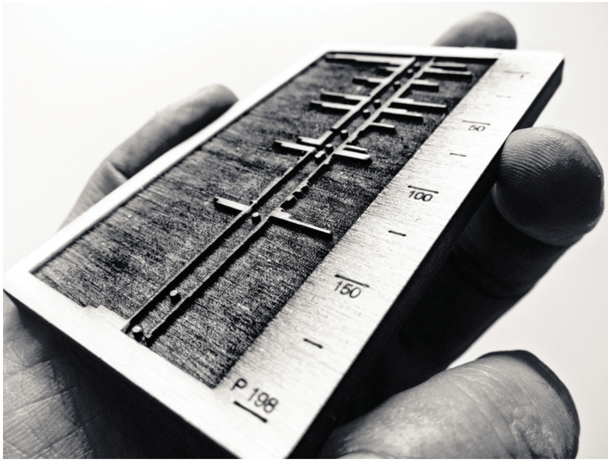

Figure 6. Tactile document structures—This laser-engraved wooden tablet encodes in a histogram-like manner the degree of layout regularity of a books' double-pages. The tactile document interface is a compact alternative structural representation of the Document Towers, especially suitable for document navigation by those who are visually impaired. For such an application, the "historgram" could be embossed on book covers. (Credits: V. Atanasiu)

to be consulted, can be pinned on a wall as constant reminders, and do not disappear when the computer is shut down. Moreover, paper-based representations do not require regular software updates to remain operational and can be spread across as many tables as there are available to extend the display surface. Paper-based representations do not necessitate huddling around a screen or darkening the room to make a projected page legible, and they allow anybody—not just the person monopolizing the mouse—to point out a passage of interest.

Complexity

Structural complexity and its representations differ depending on whether documents are printed, handwritten, or hyperlinked; and increases based on whether the scale is a character, a page, a document, or an entire collection. Page thumbnails might be sufficient for overview and are certainly a common representation. However, heavily annotated documents are better represented with the transcribed text presented separately on selectable layers, as it is the case with documents found in physical archives. Documents found in online archives are in practice rarely represented in more sophisticated ways than categorized title lists, despite much creative research on the visualization of cyberspace.

Format

The digital format of documents has an impact on both the content being represented and the quality of the representation. For example, the extraction of text from document images is not as simple as the extraction from XML files, reading order in PDFs is often not preserved, and the exact location of paragraphs in InDesign documents cannot be inferred from source files alone (since it depends on the proprietary layout software).

4.3 Information

The information extracted from documents takes the form of *coordinates* and *labels* of *entities*. Entities are any physical, logical or semantic information; or other types of information such as page boundaries, headings, and concepts. Labels are the names by which entities are designated, such as "Heading Level 1". The coordinates define the physical extent of the entities within the pages and the document stack for codices. The physical, logical, and semantic structures are affected by a number of factors, such as psychological, social and cultural factors.

Figure 7. Figure 7. Embodiments—The materiality of document structure representation determines its utility, the information extracted, and the user experience. Hard copies are more persistent visualizations than displays on computer screens, and provide more display space, but computer interfaces allow for real-time interaction with the data. Simply by manufacturing a representation in a specific way may endow it with new usages. The bottom picture presents the structure of one of the author's books, represented as a Document Tower; printed on an oblong, rigid piece of paper, it is simultaneously a handy bookmark and a table of contents. When the Document Towers visualization is reduced to a ribbon pasted on the book spine, its internal structure is made visible even if the book is closed. In this case, we can determine the number and length of chapters based on the number of wider ribbons, which indicate chapter beginnings. (Credits: V. Atanasiu)

Physical structures

Geometry
Three-dimensional *coordinates* of the extent of pages, paragraphs, words, characters, symbols, pictures, and other entities; the shape can be reduced to rectangles, a natural form for many document entities such as pages and paragraphs.

Psychophysical structures

Descriptors
Layout, shape, color, texture, and other document descriptors can be classified, and their spatial distribution represented. Representing font sizes, for example, can reveal the location of titles and footnotes, while italics are indicative of important concepts, citations, or foreign words. These could be correlated with section topics and reveal the style of the author.

Perceptual phenomena
In order to improve readability, the following should be detected in documents: *Saliency* (the degree to which an area in the perceptual field attracts attention), *optical vs geometrical centers, kerning* (character spacing influencing the segmentation of strings in words), *rivers* (spurious curves formed by the random vertical alignment of spaces in contiguous text lines), *crowding* (which impairs

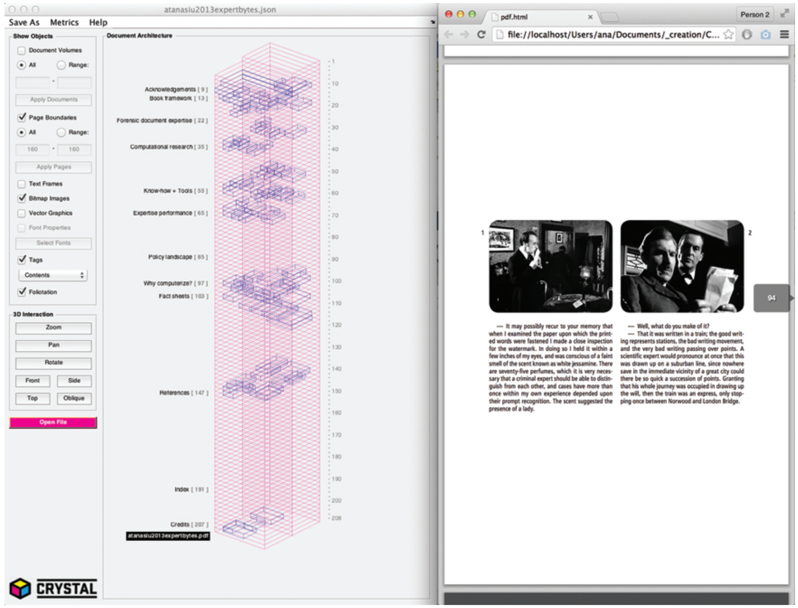

Figure 8. Structural navigation—Through the interactive interface of the Document Towers software various document objects can be selected and the visualizations manipulated. Pages are hyperlinked to the original PDF document, which is shown on the right opened by the user at a specific page in a web browser. This navigation concept would be particularly useful to implement in e-readers. While such devices often have the functionality to present the logical structure of documents (i.e., tables of contents), there is also an interest in displaying the physical structure (the layout), as it provides a different kind of information. The three-dimensional view offers the added benefit of providing an overview of the whole document.

readability), *occlusion, optical illusions*, and *perceptual effects*. Representing their spatial location helps in selecting the occurrences requiring inspection, which will depend on how important an issue they appear to be and where they occur (the Adobe InDesign layout software has an option to highlight hyphenation and justification violations on each page, but does not allow an overview of their distribution over the entire document to be generated).

Logical structures

Format

An electronic document may contain variously formatted elements: *electronic text, raster images, vector graphics, fonts*, and visible and total *substrate area*. The spatial statistics of these elements are highly informative for many users, as illustrated by the Document Towers case study in Figure 1. To be able to ascertain from a visualization the presence, quantity, and location of images in a document is helpful even to the casual user.

Encoding

Determining the distribution of font code-maps (e.g., ASCII or Unicode) in a document illustrates the usefulness of document structure representation and is of interest to the developers of document-format conversion software.

Functions

An efficient manipulation of documents (e.g., browsing, navigation, bookmarking) relies on the quick and reliable identification and memorization of functional entities, such as tables of contents, headings, paragraphs, footnotes, page numbers, references, indices, and bar codes. The representation of entity distribution is key for the successful completion of the tasks.

Styles
Functional entities are rarely marked as such for the reader (e.g., there is no label next to a title saying "This is a title"). Instead, they are made visually distinctive (a text line is usually a title if it is set in a larger size than the rest of the text and appears at the top of a page, possibly separated from the subsequent lines by whitespace). Therefore, revealing stylistic structures brings to light the functional structure of a document.

Identities
The distribution of font names, languages, scripts, and other classified objects has a broad spectrum of potential users—e.g., historians studying the diffusion of languages, forensic experts comparing typefaces used in documents under investigation, big data analysts interested in linguistic patterns, researchers engaged in the ground-truthing of documents for the purpose of evaluating novel document analysis algorithms.

Flow
Reading order is a document structure of particular importance in the automated conversion of documents from analog to digital, or between different digital formats. Reading order allows for the successful execution of simple and recurrent tasks such as copying of text from multiple-column PDF documents and reading them in the right order. This is particularly useful for the visually impaired. Visualizing text flow also helps ensure that the document is indeed readable and that it is read in the intended order, even by machines. The visual *scanning path* is distinct from reading order, and is task-, user-, and context-dependent; it represents the sequence of readers' fixation locations as they skim a document to quickly assess its content or find specific information. The physical structure of this process is of interest to psychologists studying reading, as well as designers considering ways to improve readability.

Semantic structures

Semantics
A keyword search within documents is one of the most expected interface features. The results of *a keyword* search can be visually represented, for example, by the use of colored notches next to the scroll bar. A more sophisticated document structure would make it easier to represent the distribution not only of keywords, but also of *topics*.

Named entities
People, organizations, places, and periods all have names, and their distribution within documents is just as useful to learn as that of other keywords.

Sensation structures

One important aspect of literary analysis and screenplays is the ability to represent, mentally or physically, the type and intensity distribution, within a document or movie, of *emotions, atmospheres, colors, sounds*, and plot *pace*.

4.4 Tasks

This section presents a selection of tasks significant to various application domains that could potentially benefit from the representation of document structures at different stages of the *document life cycle*.

General qualities

Polyvalence
Document structures are characterized by a broad set of possible representation modalities and extractable information, as shown above. They are also characterized by having many potential applications and users, as will be seen in this and the next sections.

Ergonomics
The polyvalence of the Document Towers is largely due to their *adequacy* to represent the underlying data. One spatial object (a document) is represented by another spatial object (an architectural model), thus propagating a fundamental property of the source (spatial relationships) in the target domain. The problem resembles that of a map vs a verbal description of a territory in terms of description length.

The ergonomic *advantages* of document representation are those of sensory representation in general, as will be made apparent below. In brief, such representations are appealing, intuitive, holistic, complementary to quantitative analysis, and technically lightweight. The *limitations* are also generic, notably the difficulty of computing with words and images, and the limitations of human perception and cognition.

One important ergonomic aspect of document representation that became apparent while evaluating the Document Towers is their *human and social qualities*. In addition to involving the use of the senses, being aesthetically appealing, and providing a playful experience, the inclusion of interactivity makes the workers feel appreciated for their skills, and, as a result, they become more involved in the project. This would not have been the case under a completely automated system.

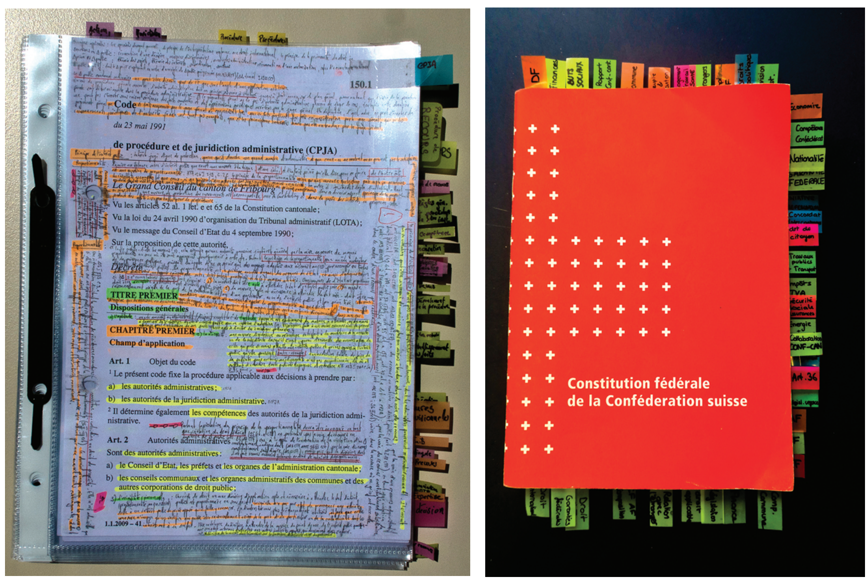

Figure 9. Information from structure—Law texts color-coded and bookmarked by students at the University of Fribourg, Switzerland. The typographical object has been strikingly morphed into a physically very different entity, in which structure is a means of accessing and personalizing information. (Photo: V. Atanasiu)

Efficiency
Another advantage of document representations such as the Document Towers is that their polyvalent and ergonomical aspects come at a low cost. If we take the example of quality control of digitization workflows, it becomes evident that only the development of multiple specialized software could fully encompass the range of issues detectable through the simple Document Towers visualization. Certain representations are therefore less costly and require less parametrization, maintenance, and training; they are characterized by *minimal investment and high yield*.

Create

Design
Representations such as the Document Towers make it possible to view a document in its entirety at a single glance, and this opens up the possibility of *top-down, parametric document design*. Rather than laying out pages individually and retaining only a mental image of its structure, or a verbal description, as is typically the case in graphic design, one could instead imagine a process in which designers work on the overall shape of the document, its visual rhythm and functional structure, leaving their implementation to algorithms.

Modeling
Document structure representation can support document *style transfer* from a source document to a target document at the pre- and postprocessing stages. This would enable understanding of the style characteristics and control of output quality.

Digitization and conversion
The extraction of the logical structure is essential to document digitization and format conversion, principally for *labeling functional entities and styles* and establishing *reading order*. The digitization and conversion of tasks such as project management and quality control, as well as of lower-level tasks, would benefit from document structure visualization. Representations can help to *categorize* data prior to digitization and conversion. Representations can also help to *select* appropriate categories according to various criteria, such as expected quality, processing speed, and costs. These are important commercial factors that are not always explicitly integrated into digitization and conversion workflows. The same visually guided categorization can lead to *more realistic document models* for training neural networks. Measurements of information distribution are additional insight sources for *improving output quality* and stating *confidence levels*; structure visualization is a method for understanding, defining, and testing such measurements.

Management
Being able to visualize document collections can help with *policy making* and *decision support*. Document processing and archiving institutions, in particular, would benefit from this. Of particular interest are the organizational aspects of digitization and conversion projects, specifically for *evaluating* the types, recurrence, and relevance of issues, and for *allocating* financial, human, temporal, and technical resources. The organizational aspects of digitization and conversion projects are also helpful for *planning, monitoring*, and *communicating* between team members, between different levels of management, and between data holders and service providers.

Quality control
Missing pages or images, misclassified documents, and metadata errors are among the anomalies that can be detected through representations without great investment in custom software.

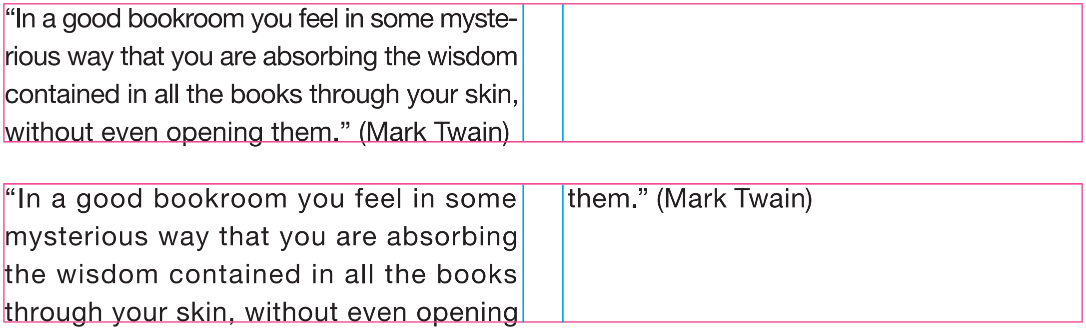

Figure 10. Information uncertainty—This figure exemplifies the impact of document format on the representation of document structures, as well as the limits of visual, non-numerical analysis. The above texts are laid out in InDesign, each placed within a single text frame (red) in two columns (blue), set in Neue Helvetica LT typeface, and kerned according to the font metrics (top) and the proprietary algorithm (bottom). The exact spatial extension of the text cannot be known from the document text file alone, where only the frame location is recorded; thus, the InDesign software is needed to resolve the uncertainty.

Interact

Attract, fascinate, entice
Representing the structure of books on their spines can be seen as a marketing strategy. It helps customers decide whether to buy or not to buy the product on the shelf.

Intrigue, explore, question
Document structure representations are not always understandable at first sight. *Mysteriousness*, however, can be a desirable cognitive quality, in that it is often a strong incentive to explore the object in question, with the result being visual document analysis and a formulation of questions about the represented documents.

Collaborate, discuss, convince
A document representation is a tangible object, and as such, it is a fertile ground for human *interaction* and *debate*, in a more concrete way compared to an abstract idea about information enclosed in documents.

Images vs numbers
Perceptual representation and quantification are complementary document analysis methods that allow the integration of human and machine information processing capabilities. For example, visualization allows for more *serendipitous* discoveries and *holistic* analysis in comparison to statistical document descriptions. Moreover, the inherent *fuzziness* of visualizations may also contribute to a more *flexible* understanding of data than that permitted by "crisp" numerical analysis. However, statistics *scale up* more easily than visualizations: a number representing the mean of a distribution or a line indicating the distribution in a diagram has practically unbounded summarization power.

Explore vs search
Exploration is, by definition, undefined and open-ended, unlike *search*; the former is *holistic* while the latter is *focused*. Document structure representation supports both these information retrieval modalities, as exemplified by the Document Towers.

Sensory vs language interaction
Interacting *linguistically*, in speech and writing, with a document library typically involves performing *searches*, while *sensory* scanning (e.g., visually) promotes *exploration* (we are unlikely to spend hours chit-chatting with Alexa but can get lost surfing on Pinterest). The fundamental difference between these two tasks is worth supporting in the design of information retrieval systems. Consider, for example, a keyword search in a document collection represented as a document City: the results would light up like apartments illuminated in a *city by night*, an interaction paradigm integrating linguistic search and visual exploration.

Hands-off access
Representations of document structures make documents *transparent*; there is no need to open them if we can peer inside. Visualization can transform opaque gray archive boxes into “crystal goblets” of information.

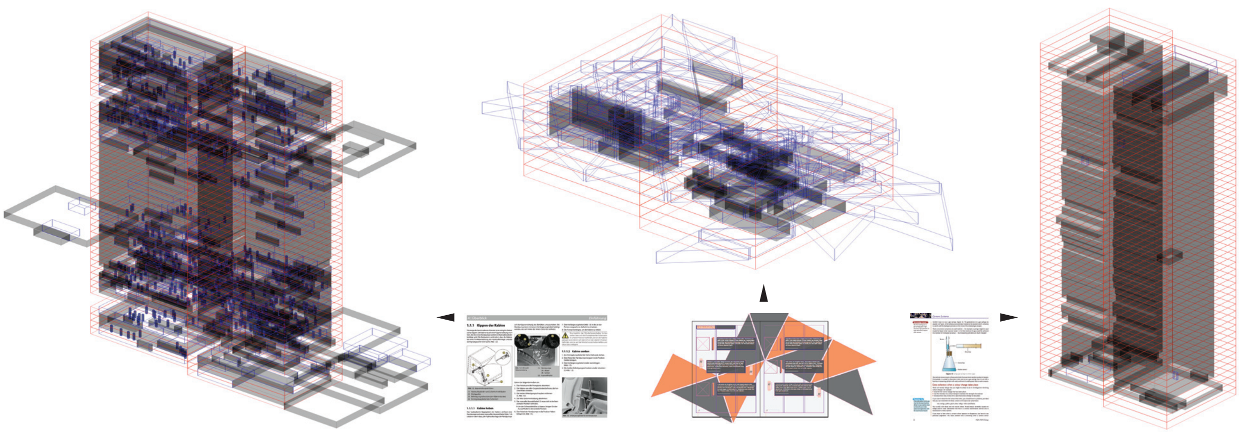

Figure 11. Classification—The 3D representations, based on InDesign files, create differences in documents when visible at a glance.—Left: A truck-driving manual is replete with pictures and diagrams, hence its heterogeneous aspect. Note the frames outside page boundaries, leavings of the book designer; while imperceptible to the reader, they could attract the attention of book historians or forensic investigators.—Center: A complex and dynamic document, representing the portfolio of a graphic artist.—Right: The simplicity of the layout suggests this to be a novel, as there is little visual variation. In reality, it is a biology school manual containing many figures, tables, and sidenotes. The designer has succeeded in hiding them within the flow of a single frame per page. If changes are needed, it is much easier to perform them with this design method than to reposition numerous small frames. The visualization is indicative of the designer’s expertise, and it is a tool for managers to evaluate costs based on document complexity.

Process

Index
A search engine that preserves the spatial distribution of information is especially useful for documents, given that these are spatial objects (or, in their digital form, use a spatial mental model imported from the physical structure of analog documents and the physical world). Rather than being a list of document titles, the answer would take the form of a *document City*, with the relevant documents highlighted, while document proximity would provide additional *contextual information*.

Overview
A detail-rich overview of single documents or collections is one of the main qualities of document representations. It avoids viewing and manipulating documents through the "*keyhole*" of the spatially and mechanically limited computer display and hardware interface.

Perspectives
Because representations have a vast design space in both physical and psychological terms, they excel in creating multifarious perspectives on data. The way users would benefit from a Document Towers City that is a static picture is likely to be different from the way they would benefit from an interactive model, or a sonification.

Compare
Structures are the "fingerprints" of documents. Their representation enables visual analytics useful in *stylistic analysis* for literary studies, forensics, and pattern recognition.

Classify
Representations support *human-guided* document classification and clustering. This can be seen by how the Document Towers enabled distinguishing between articles and monographs, and between scanned and native digital documents.

Triage
As shown by the model of medical emergency triage, document triage is a classification type characterized by the *rapid speed* with which it is conducted and the *uncertainty* surrounding the nature of documents (Atanasiu 2022). Document triage for intelligence purposes is another application example; a further example is that of a journalist operating under tight deadlines facing large amounts of documents to sift through. In such cases, visualizing layout complexity helps to quickly identify potentially information-rich items.

Navigate
A document structure representation is similar to a table of contents. A document structure representation, however, is more useful since it allows for arbitrary types of information to be presented concomitantly and at a higher spatial resolution. For example, the Document Towers can use different color codes for text paragraphs, raster images, and vector graphics. Such a *document signage device* complements the classical table of contents and facilitates *navigation* for e-book users and *browsing* for the visually impaired.

Remember
Effective representations often implement familiar *mental models* for data manipulation. For example, the Document Towers use an architectural metaphor to convey the spatial distribution of information in documents. Recovering information becomes a question of recalling where it is and how to get there, a task that is often more straightforward than describing complex

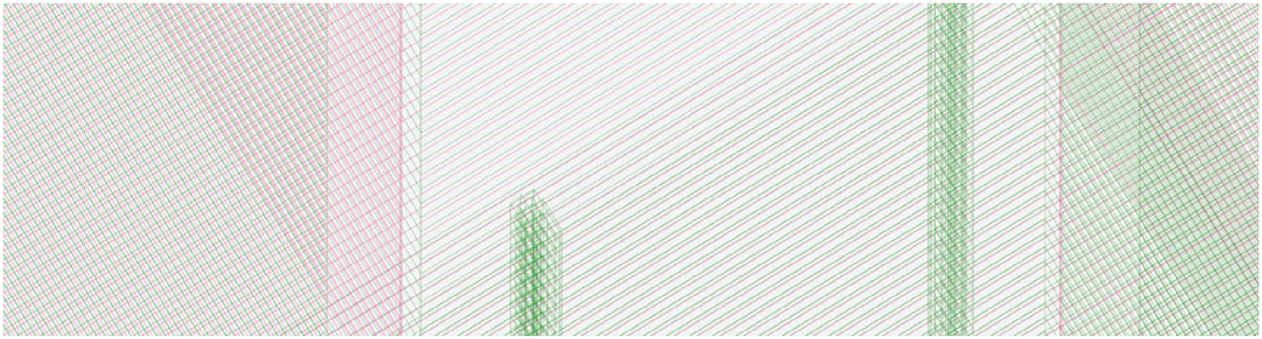

Figure 12. Ars electronica—This tartan-like texture was obtained by zooming into a Document Towers visualization. It could potentially be turned into a tapestry, which would provide an excellent backdrop for a reading room in a library; it is auto-referential scientific art. Another quality which might captivate a psychologist or an art historian: This specific view was identified by the author after some probing into Document Towers. The question therefore arises as to what specific properties made it so aesthetically appealing as to be selected from among many others. The answer should also be of interest to the information designer.

information and scrolling through a long list of results. Information spatialization can help prevent users from getting "*lost in cyberspace*".

Evolution

Document *genesis* is a complex process of confluence in a physical, logical, and semantic structure, often concluded with its publication; this is followed by a phase of *alterations*, some intentional (e.g., annotations) and some accidental (e.g., stains), and ends in *destruction* or *recycling* (e.g., palimpsests). It is not only the humanities that are interested in recovering and monitoring document life cycles, but also publication designers, digitization managers, and forensic experts. Static (images), dynamic (movies), and interactive representations of changes in digital or physical documents are human-accessible means of *keeping records* and visualizing *trends*.

Forensics

Human analysts are also indispensable to forensic practice, and representations can provide intuitive support to the work of these experts. For example, document structures can be easily compared in view of quantitative identification or verification.

E-reading

Until e-readers consisting of a hundred or so individual electronic papers are produced, the browsing of electronic documents will remain a more *tedious* task compared to the browsing of analog paper documents. This is especially the case for professionals consulting large numbers of documents and for the visually impaired. These issues can be mitigated through document panoramas, which facilitate browsing, purposeful navigation, information localization, and memorization.

Access

Access
Document structure representations can act as *substitutes* for the original documents when these are inaccessible—e.g., remotely stored physical documents, fragile documents, documents in exhibition showcases, or confidential documents.

Preservation
Ancient manuscripts and historical publications (such as those printed on brittle 19th century industrial paper) are fragile, valuable, and irreplaceable artifacts. Therefore, librarians want to minimize their physical manipulation. Document structure reproductions help *preserve* cultural heritage while still providing *access* to contents.

Reconstruction
For damaged documents (e.g., by shredding, water, fire, bugs, or fungi) which exist only as fragments, structural representations can function as *virtual models*, similar to reconstructed archaeological vessels or buildings, which are built from pieces of the original and patched with plaster.

Privacy
Representing the document structure of sensitive archives and confidential or private documents requires a compromise between *restricted access* and *anonymization*, and some degree of *disclosure* and manipulability.

Security
Digital texts which use the same color as the background are virtually impossible to read and can pose security problems for unsuspecting readers. This trivial obfuscation technique illustrates how document structure can be an additional investigative tool for *law enforcement* and *intelligence*.

Share

Training
The quality control of digitization workflows comprises manual and automatic steps. Document structure representations can not only be part of the process, but also serve to train workers by *demonstrating* what structures are, what types of issues exist, and how to detect them. This training could help developers of digitization quality control software better *understand* data and tasks to identify, select, and develop appropriate computational tools.

Education
Document representations such as the Document Towers can be used as *teaching material* in areas such as computer science (e.g., visually demonstrating differences in digital document formats and their impact on computational document analysis and usability), the humanities (e.g., book history and paleography), and the arts (e.g., book design and typography). They can also be used in primary education to foster children's enthusiasm for books, for the information contained within them, and for the science behind their production (e.g., presenting documents as doll houses).

Outreach
Visualization and other information representation modalities have promising outreach potential and can reach the broader public by virtue of being founded in *sensory experience*. It is easy to envisage how libraries, archives, museums, organizations, and firms in possession of document collections could use representations to communicate online, in print, or through exhibitions showcasing the value of their holdings, in addition to traditional means such as displaying the documents themselves or by statistics.

Marketing and merchandising
The sensory appeal of document representations can be leveraged for marketing purposes by publishers, bookshops, repositories, and document processing software producers. *3D-printed* Document Towers, or Document Towers *texture* wrapped on various objects (e.g., pens), facilitate the merchandising of information representation.

Art
Making art with information (Wilson 2002; Ars Electronica 2021). The Document Towers patterns can be used for *textile* production or as *murals* in library halls and reading rooms; document Cities can become the electronic versions of 19th-century *panoramas*, and the Document Towers can become the electronic versions of *doll houses; video games* could be played within real book structures, such as Umberto Eco's medieval library-centered novel *The Name of the Rose* or JG Ballard's quasi-Shakespearian social decay drama *High-Rise*, which plays out in a London tower building. Such *narrative* artwork would not be arbitrary, but rather emerge from the data structure. Wim Wenders, whose movie *Wings of Desire* depicts angels listening to the hum of readers' thoughts in the State Library of Berlin, explains that "storytelling is ultimately nothing else than producing meaning" (Stahl 2019).

4.5 Users

Fields
Almost everyone can benefit from document representation: from content creators and document producers, to access providers and developers of computational infrastructure and software, to professional document analysts and casual readers. An overview of the benefits of document representations and who would benefit from them is provided in this section, with references to selected entries in the Tasks section (→ *in italics*).

Benefits
Businesses and organizations can expect the following major benefits from document representations: increased competitiveness, cost reduction, quality improvement, optimization of planning, monitoring, quality control, and communication.

In the field of computer science, three main benefits of using document structure representations have been identified. (1) The routinely large amounts of data, high processing speeds, and unfamiliar heterogeneous data that computer scientists have to deal with objectively hamper their close investigation of said data. *Representations offer tools for data investigation*. Heavily involving the human senses, these tools open up *more perspectives on the data than mathematical models*. (2) Representations *allow humans to intervene in automated processes* at all stages: understanding data, building and parametrizing models, monitoring processes, making decisions, discussing and disseminating results, etc. (3) Representations *complement quantitative and automated approaches*.

Production
Content creators—private writers, organizations → *overview, navigate, evolution*
Publishing—books, journals, magazines, and newspaper publishers; document designers, editors, marketing → *overview, navigate, evolution*
Software—desktop publishing → *overview, navigate, evolution*

Access
Bookshops—physical and online → *attract, intrigue, explore*
Repositories—libraries, archives, museums, organizations, firms, private persons → *digitization, management, overview*

Software—digitization, migration, information retrieval, indexing, search engines → *modeling, digitization, indexing*

Use

Readers—leisure and professional reading; special needs readers: visually impaired → *overview, navigate, e-reading*

Children → *education, art*

Education—book history, visual psychology, document design, information sciences → *education, evolution, reconstruction*

Journalism → *triage*

Forensics, intelligence → *forensics, security, training*

Administrative document flows → *triage, overview, access*

Exhibition visitors → *overview, marketing, art*

Artists → *art*

Software—research in document engineering, document analysis, and information systems → *explore, triage, e-reading*

5. Conclusions

Let us now briefly assess the contribution of this work to the state of the art and consider some possible future directions.

This article has shown that there is a lack of survey data on the potential applications of document structure representations. It has also been shown here that the usefulness of document structure representations is a major concern of computer science researchers, information technology companies, and research funding agencies alike, which indicates that the marketability of ideas is an important dimension of information design. From this viewpoint, the innovation process can be seen as a chain of stages that goes beyond having ideas and prototyping them; it also includes persuading stakeholders and achieving market breakthrough. The survey of applications is a direct product of market constrains intended to assist readers in similar situations. This conceptual meta-level is a supplemental story line that this article begins unwinding: a field of research analyzing intrinsic and extrinsic factors to find out why some information design ideas prosper, while other wane.

The Document Towers paradigm used here, however, is not without its limitations—for example, three-dimensional visualizations are ill-suited to representing very large datasets. The limitations, however, are largely mitigated by the paradigm's ability to create an overview of one or more documents, and by its ability to facilitate unexpected discoveries about these documents, through a relatively simple technological implementation. These strengths compare favorably with document analysis solutions that are specialized, complex, and make use of non-visual, automated approaches, such as optical character recognition and text-based search engines.

As for the theoretical considerations related to document structure representation, some of these are well-known (e.g., the role of simplicity and metaphors in design), while others merit further investigation (e.g., casting information as potential action, using mystery in information design). These considerations exemplify how the purposeful seeking of vantage points outside the mainstream, counterintuitive or even otherworldly, is a design method in itself (Nodder 2013).

We finish by highlighting the features shared by the application survey of document structure representation, the Document Towers paradigm, and information design theories as forms of *design patterns*: standardized, modular, and generic problem-solving methods (Alexander, Ishikawa, & Silverstein 1977; Sedig & Parsons 2013).

Submission: 30 November 2020
Accepted: 30 June 2022

Acknowledgements

The author is grateful to the three anonymous reviewers for having prompted many new ideas. The author is also grateful to K. F. for never tiring of working to improve the readability of the Document Towers manuscripts.

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idj 27(2), p. 144–190

Annex

Dreams, Architecture, and Information Systems: A brief review of the utility of document exploration, visualization, and metaphors

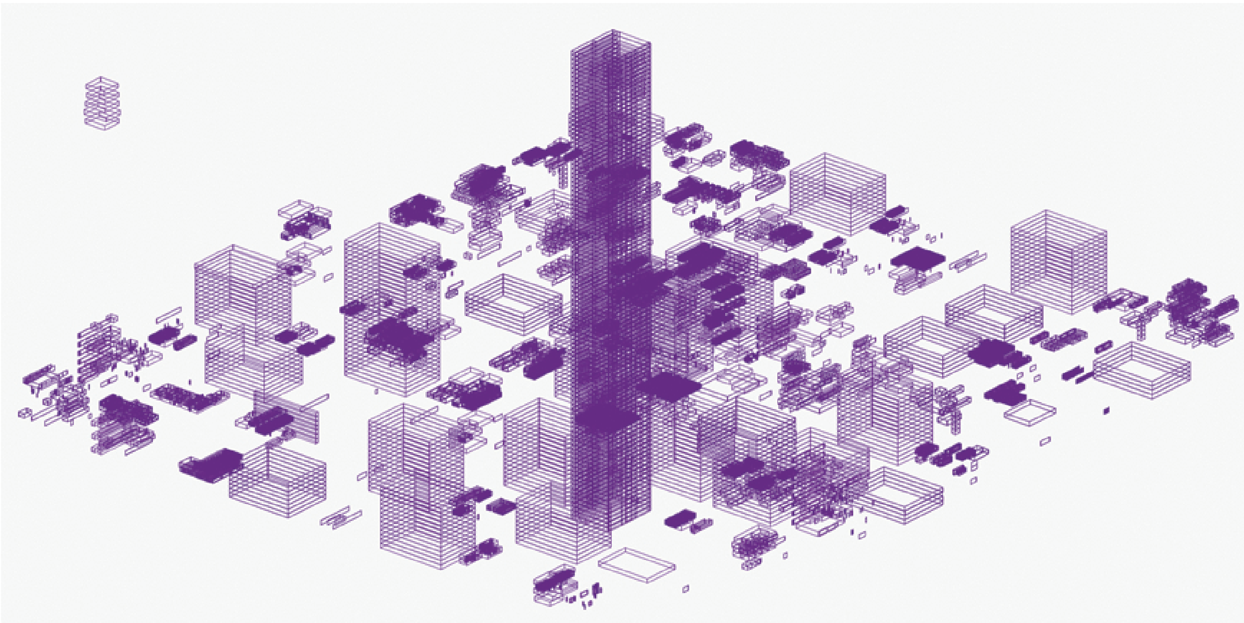

Figure A1. Document City—The Towers shown here stand for eighty-nine PDF documents on the topic of machine learning in a directory ordered by file name on the author's computer; the blue slabs represent the location and extent of raster images in the digital documents. The picture exemplifies three benefits of visualizing document structures.—Misclassification: The collection was supposed to contain only articles, but the presence of a high-rising Tower reveals a monograph among them. This misclassification would most likely have gone unnoticed if not for its serendipitous discovery due to visualization.—Quality: The regular Towers are scanned documents, where each page is a single raster image, while the fragmented Towers represent native electronic documents, in which images cover only a portion of pages if present at all. The implication for a library wishing to offer its readers searchable digital documents is that scanned documents must be identified and the text and logical structure extracted, which means time, costs, and an imperfect search quality. Visualization offers a quick and lightweight solution to anticipate document quality.—Steganography: The small Tower in the upper left corner, attracting attention by its outlying location, is not an individual document, but rather represents images outside the visible frame of the PDF documents. What secrets might they hide?

> *Our ineptitude in getting at the record is largely caused by the artificiality of systems of indexing.*
>
> Vannevar Bush (Bush 1945: 106)

> *It is a misunderstanding that you go to the library to look for a book whose title you know.*
>
> Umberto Eco (Eco 1995: 21)

Prologue

How useful would you expect the oracle to be that exclusively answers your questions and keeps silent about everything else of import—a chasm, maybe, to your right, a slumbering beast to your left, and a wall of fire straight ahead.

The currently dominant digital search engine paradigm behaves in precisely this way. It compels people to view the world through the narrow slit of an input field for keywords selected from the lexicographical stock of specific languages and users, offering little understanding of nuance, ambiguity, humor, mystery, seduction, playfulness, aesthetics, imperfection, inspiration, imagination, creativity, serendipitous perspectives, unplanned exploration, provocation and evocation, allusions and delusions, or the emotional and intellectual hedonism of surfing the Web, of being a *flâneur* on the information boulevards—in short, the oneiric functions of information systems that are diametrically opposed to the conscious goal-directed information-seeking strategies of Cyberman zipping over information highways towards his next waypoint over the horizon of his todo-checklist.

Meanwhile, a panoramic view of the data, such as that enabled by the urban metaphor utilized in the Document Towers, invites the curious eye to make discoveries, the ear to listen as though the data speak for themselves, and the tongue to utter "Eureka!" These are unconscious cognitive processes whose power resides in their complex pattern detection capabilities, the creation of optimal linkages within vast conceptual spaces, and the secretion of the motivational substance oxytocin. They are thus essential to human information processing.

Introduction

This section provides context for the article's general problem of understanding digital documents more generally and the solution provided by Document Towers specifically. It reviews arguments as to why the contemporary emphasis on search tools in computer science research and commercial software should be complemented with support for other tasks, such as exploration, and have other characteristics, such as eliciting serendipity or playfulness. It also reviews arguments in favor of complementing numerical analyses of documents with sensorial interaction modalities, primarily visualization, and demonstrates their suitability for supporting the exploration task, and having such characteristics where imagination and emotion dominate over rational approaches. Moreover, a survey of the use of metaphors, architectural and urban in particular, for understanding and interacting with digital documents and libraries highlights an important ingredient in the creation of effective visualizations and explains why such a metaphor was adopted for the Document Towers technique.

Exploration

Put simply, the difference between searching and exploration is that in the former case, you know what you are looking for, while in the latter you do not (for fine-grained definitions, see references in Bates (2007) and McKay et al. (2019); the linguistic evolution of the terms is retraced in the OED (2019: search, *v*.; explore, *v*.); on theories of information see Buckland (1991) and Marchionini (1991: 5–9); on information-seeking behavior: Fisher et al. (2006) [encyclopedical], Kuhlthau (2004) [monographical], Spink (2010) [evolutionary], Spink & Cole (2006) [new trends], Kalbach (2006) [uncertainty measurement]). Information searching is one of the oldest problems in information science as reflected by the variety of knowledge classification schemes and document indexing methods invented since the first archives of Sumer and even before (Piggott 2012; Lesk 1997: 99–123). Exploration is studied in various fields beyond information science, e.g., psychology, computer interface design, consumer, audience, and organizational research, and environmental planning and architectural design (Rice, McCreadie, & Chang 2001: 173–215; Bates 2007). Browsing, in the case of documents, is less understood, despite being a primary information strategy in physical documentation environments such as bookshops, newspaper kiosks, and library stacks (McKay et al. 2019: 1384). It is also a cognitive strategy more closely associated with work in archives than libraries, given the former's greater potential for surprise, which underlines the importance of translation into the digital realm of such physical clues as "cobwebs in dark corners", the unmistakable signs of forgotten information.

The growing interest in browsing among information science professionals is nurtured by the limited support for browsing in digital information systems (Bates 2007; Race & Makri 2015: 2; McKay et al.: 1384), and the resultant loss of a critical information strategy; a particularly worrisome evolution, considering that physical "library shelves are almost perfectly designed as serendipity engines" (McKay et al. 2019: 1390). The irony of these belated laments is that engaging in exploration by accessing the stacks has been the subject of passionate debate throughout the history of libraries, with consensus shifting between open shelves (until the end of the 18th century, and since in the United States) and closed shelves (until recently in Europe and communist countries), depending on the number of books, cultural progressive attitude, and/or financial resources available (Rovelstad 1976; Atkins 2012: 29–30). Library exploration, and even more so archive exploration, is a privilege in the physical world, and for the time being also remains one in digital environments.

Serendipity is closely related to exploration and has been aptly described as the contrary of "problem-solving information", for which "individuals must experience a 'problem situation'" (Ross 1999: 784). Already possessed of a distinguished socio-historical pedigree (Merton & Barber 2004; Eco 1998), the advent of the World Wide Web (a name itself conveying the image of a spider waiting to see what chance will deliver to its encyclopedic net) has seen considerable attention paid to the concept of serendipity, for search engines in particular, and as a scientific method in general, as reflected in the hundreds of articles on the subject (Erdelez et al. 1997) and its status as a compelling topic for popular science books (Roberts 1989; Hofmann 2013). In the realm of household technologies, it is among the endearing idiosyncrasies of Apple's voice-operated digital agent Siri and her text-based ancestor Eliza, the make-believe psychoanalytical chatbot of the 1960s (Wikipedia: "Siri"; Weizenbaum 1966; Wikipedia: "ELIZA"). Circumscribed to "discoveries, by accident and sagacity" in Horace Walpole's original definition from 1754 (McCay-Peet & Toms 2018: 2–3), serendipity is the animating principle of exploration, but also of search (even the search of extraterrestrial intelligence (Tarter 1984)) and other information-related activities, and has a variety of definitions reflecting the complexity of factors at play (McCay-Peet & Toms 2018: 1; Witten, Gori, & Numerico 2006: 24; Race & Makri 2015: 15–26; Taramigkou et al. 2013: 3). The Document City in Figure A1 demonstrates the salient characteristics of serendipity: detection of abnormality (tall or eccentric Document Towers), sensitivity of the observer to the recognition of valuable objects (awareness of quality and costs of OCR-ed documents), reactivity to and acting upon opportunities (use of the visualization to illustrate this article), an incubation process leading to value recognition (the interpretation of the visualization), utility (correcting misclassification), an unplannable process, unexpected findings, and results that are not guaranteed. Current research is concerned with better understanding serendipity through empirical and theoretical studies (Erdelez 1997), developing methods to induce serendipity (Erdelez 2004; Campos & de Figueiredo 2002), measure serendipity (de Figueiredo & Campos 2001; McCay-Peets & Toms 2012), and design serendipitous learning, research, and information environments (Race & Makri 2015; O'Connor 1988). Document-centered technologies generally use the selection and ranking of text content to create serendipity, rather than letting it emerge spontaneously from the data, as occurs under the Document Towers paradigm (Cooper & Prager 2000). The "Bohemian Bookshelf" is an example of an interface designed for serendipitous book discoveries that explicitly takes advantage of physical aspects (cover color and number of pages), in addition to content information (authors, keywords, and timelines) (Thud, Hinrichs & Carpendale 2012). The Document Towers further reveal other aspects of serendipity that are latent in the literature: opportunistic scanning of the visual field (an information strategy equated with "berrypicking" (Bates 2007: 410)), playfulness that invites the use of the technology; intriguing mystery arising from extreme visual simplification, stimulating the "thoughtful activity" that is visual perception (Noë 2006); bonding with the technology, which is useful to sustaining long-term usage (Ross 1999); and physical embodiment through laser engraving and three-dimensional printing to induce recurrent interaction and persistent memories.

Let us briefly speculate on the broader psycho-societal implications of an imbalance between the ability to perform information search and exploration, as these have a direct impact on appreciating the utility of the Document Towers as document visualization. Search and exploration are generic categories and reflect different goals, as well as specific individual and group behaviors and mind frames. Search is an activity in which you "ask questions from the data", while in exploration, you "listen to the data speak"; one is about points and strict demands, the other is about relationships and unexpected receiving. In information theory terms, the former yields low amounts of information and is rather akin to recovery, while the latter is full of surprises. From a psycho-social perspective, these approaches represent the dichotomy of ego-centric interests and environmental awareness; politically, that of dictatorship and democracy, as the American chemist and Nobel laureate Irving Langmuir remarked in the early years of the Cold War (while defining freedom as "the opportunity to profit from the unexpected", with the underlying message being a plea to government and industry to finance blue-sky academic research, as opposed to mission-oriented projects) (Langmuir 1956: 416).

That the former system usually keeps this activity shrouded in secrecy (e.g., restricted access to high-quality maps (Monmonier 1991: 113–123)) is not without parallels to how digital search engines give users a false sense of power over their online lives, transforming them into small tyrants who speak in "code" and computer "commands", and destructuring their linguistic abilities to the level of "keywords"; the answers, moreover, are manipulated by incognoscible algorithms obscured behind the wizardly interfaces of Oz. Their addictive allure comes from construing the clicking of hyperlinks as "surfing", the serendipitous experience of "exploration" and "interconnectedness" suggested by the names of major web browsers (e.g., Mosaic, Netscape Navigator, Internet Explorer, Safari) (Wikipedia: "List of web browsers"). Here, lodged at the heart of online information-seeking, we may fathom the oxymoron of

(a) targeted searching brought about by search engines and (b) serendipitous exploration, which is the ostensible function of web browsers.

Visualization

"Blind analytic manipulation *is never enough*." (Mandelbrot 2002: 48). The italics are by Benoît Mandelbrot, whose mathematical objects, the "fractals", became popular as home-grown psychedelic images with the spread of personal computers in the 1980s. For the statistician John W. Tukey, whose book from 1977, *Exploratory Data Analysis*, popularized the eponymous concept in reaction to the hegemony of hypothesis testing or confirmatory analysis in statistics, "the greatest value of a picture is to force us to notice what we never expected to see" (Tukey 1977: vi). In the intervening decades since these statements were made, visualization—alongside representations addressing other sensory modalities, such as sonification and haptic interfaces—has become a common technique of human–data interaction (Fekete et al. 2008; Keim et al. 2010; Ware 2008), including in the domain of documents (Fekete & Lecolinet 2006), as attested by the appearance of the term "visual document analytics" (Heyer & Scheuermann 2009). Visual analytics covers a broad spectrum of activities, from data preprocessing and representation, through quantitative and visual exploration, to interpretation, decision-making, and communication (Keim et al. 2008: 77). Its umbrella research field is diagrammatics, and it deals with the theoretical and practical aspects of the design and reasoning through physical diagrams and abstract schema. Diagrammatics has roots in antiquity and across cultures. It stands at the intersection of the broadest range of disciplines, notably philosophy, logic, mathematics, artificial intelligence, physics, psychology, design, information visualization, and media studies (Schneider, Ernst, & Wöpking 2016; Anderson, Meyer, & Olivier 2002; Varia 2000).

The ongoing work of applying visualization to understanding data processing in one of the most impactful computer science fields, namely neural networks (Rauber 2017; Yosinski et al. 2015), underscores another tenet of this article, namely the actuality of technological transparency with respect to the degree and manner in which the inner workings and the encapsulated and linked data are revealed (Figure 9). Inscrutable but easy-to-use "black boxes" (Latour 1987) oppose insight-rich but complex "crystal goblets"—the ideal of typography that, as Beatrice Warde of the Monotype typesetting corporation remarked in 1930, should convey the crimson shine of its content unhindered to the avid reader (Warde 1956)—and their computer counterparts, the graphical user interface "windows" that create the illusion of data and software covered in transparent skin.

The materiality of documents, the spatial organization of collections, the remoteness of off-site storage, the access rights, the limited screen size, and the intangibility of digital documents are among the factors that make information opaque, even invisible. With light and unauthorized eyes being their enemies, one struggles to produce examples of transparent documents, libraries, and archives (apart from, maybe, the glass slabs constituting the soon-to-be-disconnected memory of the psychotic computer Hal in *2001: A Space Odyssey* (1968), and an artist fashioning the worried astronaut's words "Hal? Hal!" as a glass object (Klante et al. 2004: 126–127), or the giant showcase holding King George III's book collection in the entrance hall of the British Library and the rare books at Yale (The British Library 2019; Campbell & Pryce 2013: 248, 268–269)). It is not even clear whether readers prefer the transparency of sunny, open-plan reading rooms (perhaps, as seen at the National Library of France, surrounded by bucolic vistas of gardens populated by licentious rabbits and squabbling parrots, living modern versions of medieval tapestries (Anonymous n.d.)), or the tiny alcove at the Shakespeare and Co. bookshop vis à vis of Notre-Dame in Paris (Halverson 2016: 289)—cozy cone of electric light surrounded by darkness, "bony O's" (to borrow the Shakespearian image of skull as theater in the Prologue to *Henry V* (Richard 2019: 200–201)) in the seclusion of which they can work on their "imaginary forces" without the distraction of visual stimuli (theater, incidentally, has been shown to bear striking similarities with information processing by computers (Laurel 2014)). Although windows have replaced stone as the building' outer layer in the time between ziggurats and Manhattan, Philip Johnson, who created the icon of American architecture that is the transparent Glass House (1949), still built for himself a library with just one window, explaining that "you're distracted by wind, the sun, the waving of trees. It's very hard to work where you have nature…. And it's very important to get isolation… for contemplation." (Devens et al. 1991). It is indeed a tomb-like isolation that buildings housing intelligence agencies are sometimes intended to provide through their architectural style (Figure 2). If information visualization is born out of the opaqueness and immateriality of documents and their contents, the question of how much clarity is desirable remains a critical parameter of digital information systems.

The success of visualization and other representations relates to how human sensory modalities produce different perspectives on data and have different degrees of processing power, as well as the filtering and transformation necessary to make data acquirable by these sensory systems (Zhang 2008). Transformations also play a role in mathematics and computer science, since finding solutions becomes more affordable by moving problems from one domain to another. One example is the Fourier transform and its fast algorithmic implementation by James Cooley & John Tukey, through which data can be analyzed in either the spatio-temporal or frequency domains, with regularities being easier to identify in the latter (Cooley & Tukey 1956). Natural languages proceed similarly, with metaphors facilitating comprehension by presenting the unfamiliar in familiar guises (Lakoff & Johnson 1980; Indurkhya 1992; Hofstadter & FARG 1995). This principle is also at the root of good design, where it is known as "affordance": the more the form and behavior of objects are familiar to users, more they are likely to use them efficiently (Gibson 2015: 119–135; Norman 1990; Zhang 2008: 215–237; Overhill 2012). It should therefore come as no surprise that the drive to grasp abstract informational entities by projecting them into the tangible space of architecture is deeply ingrained. However, the importance of transformation is far more fundamental than the diverse domains discussed above, in fact, it is the principle of information, energy, and life itself.

Metaphors

Regarding the Document Towers, in addition to the method of visual document exploration that defines the conceptual framework, their substance is three metaphors reviewed hereafter: information-as-place, information-as-document, and information-as-architecture. Their role is to provide efficient mappings between physical or digital documents and cognitive models of documents (Norman 1990: 23–27, 75–79; Dillon 204: 63–64). Metaphors are also compact substitutes for narratives, which play their own roles in information behavior and human—computer interaction (Doty & Broussard 2017; Tufte 1997). For a discussion of the various types of information in the context of information science, see Buckland (1991) and Resnikoff (1989); for metaphors in general, see Gibbs (2008); for their role in visualizations for information retrieval, see Zhang (2008: 215–237); for a human factors perspective on the spatial structure of information, refer to Dillon (2004); on the role of

Figure A2. Mixed-reality library—In a project from the early 2000s of the Conservatoire national des arts et métiers (CNAM), Paris, using the VisonStation hardware by Elumens, a collection of physical books was digitized, rendered as facsimiles, and projected back into the physical space on a half-dome screen (Almeida et al. 2006). Note the axial arrangement of the pages on the left, reminiscent of old-fashioned museal equipment used for the display of individual folios of illuminations or engravings. (Reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer, Technologies for E-Learning and Digital Entertainment by Z. Pan et al., CC-BY-NC 2006)

metaphors in computer science, see Colburn & Shute (2008); Gillan & Bias (1994); Johnson (1994); Wozny (1989), and Weber (1986); on the theory of the design and evaluation of metaphorical interfaces, see Chatwin (1988); Mehrpooya & Nowroozzadeh (2013); Marshall, Nelson, & Gardiner (1987); L'Abbate & Hemmje (1998), and Liebert (1994).

Place

The representation of INFORMATION-AS-PLACE is a deeply ingrained cognitive model in computer science, as evidenced in the technical and popular terminology "goto" and "return" commands, "front" and "back end", "up-" and "download", "physical" and "logical layers", "file paths" and "Universal Resource Locators", computing "platforms" and "pipelines", network "ports", "gateways", "tunnels", "nodes", and "routers", "shells", "firewalls", and "clouds", "chat rooms", "portals", "home pages", "web sites", "under construction", "navigation breadcrumbs", "information superhighway", "Internet café", "the global village", and "cyberspace" (a "Heavenly City" and abode of a "Second Life" that "will feel like Paradise", were only some of the ecstatic visions from before the turn of the millennium (Benedikt 1991: 16, 52), although others were less enthusiastic: "Gomorrah… Hell" (Wertheim 2000: 290–299), "the new domain that [the West] has colonized" (Sardar 1995: 778)) (Bittarello 2009; Stefik 1997: xv–xxiv; Targowski 2016: 171–180; Meyer 2000). Entire scientific fields and professions—consider Information Architecture (Resmini & Rosati 2011) and Document Engineering—bear names that frame information and documents as spatial structures and machines. As graphical operating systems became mainstream in the 1980s, the concept of spatial data management was increasingly applied to problems of digital libraries (Lesk 1997: 163), resulting in a broad spectrum of three-dimensional document representations (Fang et al. 2009; Card 2008). During the 1990s the need to imagine the abstract structure and flow of information on the Internet blossomed into a cornucopia of visualizations employing spatial metaphors (Dodge 2001). Research into hardware solutions designed to master the snowballing deluge of digital data led to immersive physical information exploration environments, room- and building-sized, with names such as "Pocket Cathedral" and "CAVE", cultural references to the Gothic Revival and Plato (Peddie 2013: 419–423) (Figure A2). One aspect for the creators and users of these apparently benign similes to reflect on is their potential impact, which has unexpected legal, policy, and social consequences (Hunter 2003; Osenga 2013; Graham 2013).

It is tempting to see this terminology as a product of the "young, anti-authoritarian" culture of computing and the Internet (Meyer et al. 1998: 525), with a whiff of California coolness, entirely oblivious to the Latin and Greek spoken in the club of elder sciences. Instead, information spatialization should be considered an unsurprising propensity, given the importance of spatial cognition in human life (Landau 2002). Information spatialization has been developed by many *cultures* (Wertheim 2000), especially as an instrument of *memorization*. Such spatialization may provide valuable inspiration for technologists, insofar as our present information systems remove, via hyperlinks or cloud storage, the necessity for the user to remember where information was found (spatial memory) in favor of knowing how to find it (procedural memory). For example, in the Western world, from Greco-Roman antiquity until the Enlightenment, there existed a set of mnemotechniques known as the Art of Memory. These consisted in attaching the information to be remembered, from simple dates to lengthy conference proceedings, to physical or imaginary objects, then placing these in a specific order with reference to real or imagined buildings for later retrieval (Yates 1966). Similary, the "songlines" of Australian Aborigines pertaining to mythical animals and their deeds encode strings of landmarks to support cross-continental navigation (Chatwin 1988). For the Apache people, places are where wisdom is found in the form of geolocated stories (Basso 1996), a concept not dissimilar to the French historian Pierre Nora's description of how "places of memory" (lieux de mémoire), such as statues, monuments, or battlefields, are integral to building national identities (Nora & Jordan 2001–2010) (Figure 2).

Documents

INFORMATION-AS-DOCUMENT representation is also common in computer science, a bibliomorphism that has as many proselytes as detractors (Dillon 2004: 116–117; PopularLibros.com 2010). It ranges from the now-standard, operating system interfaces, where application windows are laid out on screens like papers on a desk (Clarkson 1991), to three-dimensional desktops (Wikipedia: "Project Looking Glass"), to versions with the form and feeling of naturalistic libraries and bookshelves (Card, Robertson, & York 1996; Rauber & Bina 2000; Cubaud, Stokowski, & Topol 2002; Cubaud 2008). Using architecture, urban planning, and landscape as metaphors for organizing digital information continues to be fruitful. Desktops have been represented as floor plans (Henderson & Card 1986), and the structure of software code libraries rendered as stylized cities (Alam et al. 2009) (Figure A3). Moreover, "landscape" is the driving metaphor for the visualization of Self-Organizing Maps (Wise et al. 1995), and multimedia objects can be navigated using maps built with Geographical Information Systems software (Laufer, Halacsy, & Somlai-Fischer 2011).

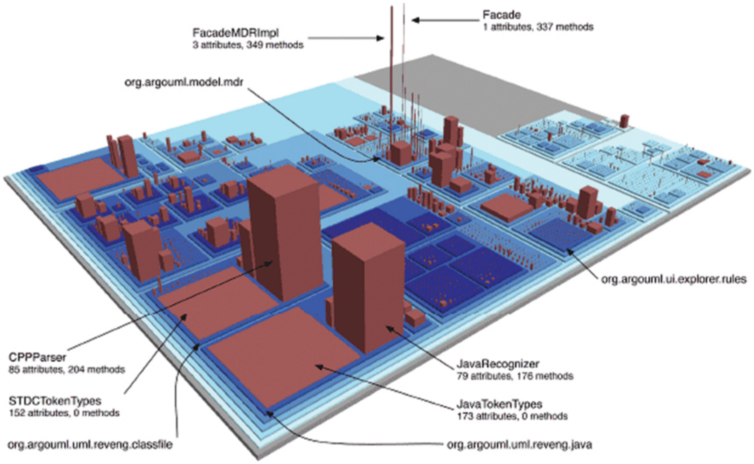

Figure A3. Software architecture—EvoSpaces uses the city metaphor to visualize software properties, here of the ArgoUML Java libraries: Building heights represent the number of methods, base sizes the number of attributes, and their spatial location the nesting level of packages (Alam et al. 2009: 174). The striking similarity between EvoSpaces and Document City reveal that natural language texts and computer code share fundamental structural characteristics. (Reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer, Human Machine Interaction by Denis Lalanne and Jürg Kohlas, CC-BY-NC 2009)

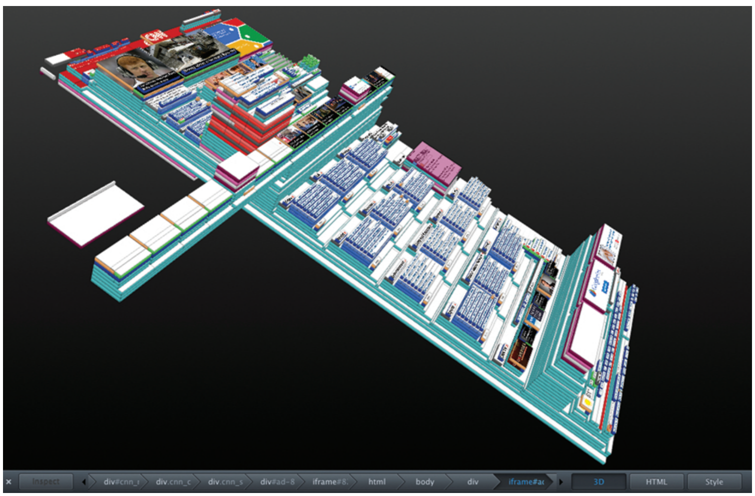

Figure A4. Webpage architecture—The "3D view" extension to the FIrefox webbrowser (until version 46) provided a visualization of the structure of HTML objects within a webpage's document object model, similar to what the Document Towers does for PDFs and other paginated document formats

Spatial metaphors have been used to great effect in visualizing the structure of the World Wide Web, reflecting the awareness of its pioneers of living on an "electronic frontier" (yet another spatial analogy) (Munro, Höök, & Benyon 1999; Markham & Tindberg 2020; Maglio & Matlock 1998; Meyer, Zaluski, & Mackintosh 2008; Markham 2003; cross-cultural perspectives: Galichkina 2016; Meyer et al. 1998). Examples include the representation of webpage elements as a perspective of extruded structures in the Firefox webbrowser (Mozilla n.d.) (Figure A4), the visualization of websites as technical drawings (Dodge & Kitchin 2001: 81–91;

Durand & Kahn 1998), the conceptualization of navigation between Internet domains as a walk through tunnels between various rooms using a game engine Selfridge & Kirk 1999), and the fanciful conception of information as a landscape of swamps, oceans, forests, roads, barns, villages, and liquid architectural structures (Dieberger 1994: 62–65).

Architecture

Body, text, architecture, and urbanism have been interchangeable metaphors in many cultures. A book has a "head", a "spine", and a "tail", while its content has "headings", text "body", and "footnotes" (Milon & Perelman 2012). This bibliographical terminology was reimagined by Archimboldo in "The Librarian" as a human made entirely of books (Wikipedia: "The Librarian (painting)"). Four centuries later, the same cross-mirroring produced the metaphors of computers-as-brains and brains-as-computers (Denett 1984; Searle 1990; Gigerenzer & Goldstein 1996; Massaro 1986; Berman 1989; Casey & Moran 1989; Coleman & Fraser 2011). The architectural metaphor can be traced from the very definition of language as "an ancient city: a maze of little streets and squares, of old and new houses" presented by Wittgenstein (*PI*: § 19; Wittgenstein 2009: 11), and as a tower reaching in vain for divine knowledge in the myth of the Tower of Babel (Atanasiu 2001), to the peculiar eroticism of the Biblical *Song of Songs* ("Your neck is the tower of David") (Anonymous 1925; § 3.4) and 15th century Burgundian poetry ("il n'y a plus nobles logis que sont les cons") (Cowling 1998: 23), down to the topos of the book as a "pocket cathedral" popularized by the Romanticist art critic John Ruskin, painter Edward Burne-Jones, and novelist Victor Hugo (Schoenherr 2004; Le Men 1998: 14, 20, 21), and to "typotecture", the fusion of typography and architecture in bricks-and-mortar and graphic arts buildings and cityscapes of the 20th and 21st centuries (Heller & Ilić 2013; Jenser 2002). Cult movies also use the same metaphors: in *Tron* (1982) humans are envisioned as data packets battling inside computer architectures, while the virtual reality emerging from streams of Japanese characters in *The Matrix* (1999) defines the fabric of space-time itself as information (Dodge & Kichin 2001: 234–237).

At the most general level of INFORMATION-AS-ARCHITECTURE, it suffices to paraphrase the architect Le Corbusier by pointing out that documents and libraries are "machines to inform with" (Hillier 2007: 292). Not unlike other architects who designed their books themselves (Rem Koolhaas (O. M. A., Koolhaas, & Mau 1995)) or had an impact on book history (Renaissance architects (Carpo 2001), the Bauhaus movement (Hollis 2006)), Le Corbusier vouched for the isomorphism between information architecture and living architecture (Le Corbusier 1950: 9; De Smet 2007), taken literally in such famous monuments as the letter-shaped futurist Book Pavilion by Fortunato Depero (Monza, 1927) (CIMAD 2019; Tavares 2016: 150–153) and the book-shaped National Library of France by Dominique Perrault (Paris, 1996) (Figure 2). Computer scientists have examined the commonalities between architectural facades and computer interfaces—their pragmatic aspects, designer vision vs user wishes, aesthetics and politics—to learn from the work of architects (Hooper 1986).

Three specific computational implementations, selected for illustrative purposes, originate with researchers from the MIT MediaLab working at the crossroads of technology and the arts (Figure A5). "Books without Pages" was a project spanning from the 1970s to the early 2000s that attempted to replicate key qualities of the physical document and bodily interactions in its digital avatar and computational infrastructure (Reinfurt & Weisenberger 2014: 19–20). One particularly visionary concept, and technical feat for the times, was to render text columns as surfaces in a navigable three-dimensional space (Small 1999; Cooper & VLW 1994). "City of News"

Figure A5. Information Cities—Three projects on information visualization from MIT MediLab using the architecture and city metaphors: Information Landscapes, City of News, and Cityscape
(Cooper & VLW 1994; Sparacino, Davenport, & Pentland 2000: 179; Dragulescu 2009: 74).
(Credits: Muriel Cooper and the Visible Language Workshop / Flavia Sparacino / Alexandru C. Dragulescu)

uses the metaphor of the urban space, INFORMATION-AS-CITY, as an intuitive spatial model for information display. Remarkably, its design was explicitly grounded in concepts from Classical antiquity and the Renaissance, science fiction, and Cognitive Science (Sparacino, Davenport, & Pentland 2000); we can observe that one of these is the metaphor of INFORMATION-AS-BODY, as addressed by the "Cityscape" project (Dragulescu 2009: 66–76). Here, the representation of feeds on social media as towers resembling futuristic cairns serves to individualize users by "abstract architectural bod[ies]". The city-of-skyscrapers information visualization metaphor results from "the idea that the data we generate online is the result of us living in various habitats, using various tools".

At work in these projects is the construction of a reality in which the physical reflects the virtual and vice-versa, as in a hall of mirrors. The magic exuded by the visualizations is a kind of modern technological exorcism that makes architecture, documents, and interfaces more "user-friendly" through familiar behavior models (Meyer et al. 1998: 524–525).

Parsimony

While document structures have more degrees of freedom when represented as three-dimensional objects, lower-dimensional representation spaces have their own advantages, notably more spatially compact representation, an absence of occlusion, and they allow to visualize the model from all angles without manipulation. The Ribbons technique (Figure 6) belongs to this rich class of tiny diagrams, some of which are ubiquitous—the visualization of location and keyword frequency in document search results, located next to the sliding bar of application windows such as a web pages (Hearst 1995)—while others are experimental: document thumbnails with semantic highlighting, variable text size, and selection of significant graphics (Stoffel et al. 2010; Stoffel et al. 2012; Stoffel et al. 2009), a dashboard of topic distribution in documents (Humphreys et al. 2018) depicted as plots of acoustic signals (Favata et al. n.d.), chat logs timelines (Donath & Viégas 2002), line modification frequency in software code (Eick, Steffen, & Summer 1992), or dominant colors in movie frames (Brodbeck 2011).

Phenomenology

Playfulness is important in the creation of the Document Towers, as shown in its phenomenology. The Document Towers are experienced by the author as a mix of aesthetic pleasure derived from their form, epistemological thrill provided by their function as a source of information, and the satisfaction derived from cognitive action and physical interaction. A similar concept is advocated by the Japanese Kansei approach to industrial design, which emphasizes bonding between users and technology (Schütte 2005) (as illustrated by the care-exigent cyberpet Tamagotchi (Wikipedia: "Tamagotchi")), with the aim of stimulating social knowledge transfers, thus contributing to product adoption and fitness and (hopefully) more harmonious societies. Current research in user experience is operationalizing, for its own ends, the work of Western philosophers, such as Heidegger, Dewey, and Merleau-Ponty, on phenomenology. The aim is to challenge the very definition of what interfaces ought to be: rather than hardware and software, "our thesis is that user experience consists of three core, inter-related elements: involvement, affect and aesthetics" (Turner 2017: ix, 3–8).

The Document Towers' shape is defined by the physical structure of a particular document format, namely the codex, raising the question of what mood and connotations it imparts to users. People confronted with this visualization for the first time often report that the modernist architectural style, the Manhattanesque look and feel of the Document City exhibits a fascinating symbiosis of crystal rationality and lively chaos, and as a result, they draw closer to investigate the visualization at close range (personal observation). Here, we witness how the properties of the cognitive model domain propagate to the source domain of document interpretation. Understanding the response to the styles of built environment and comparing reactions in the physical and virtual worlds is an active research topic in computer games, cultural heritage, architecture, and urban planning (Houtkam 2005; Botton 2014).

Conclusions
This overview of document-related information representations has revealed how the Document Towers paradigm is rooted in an ancient and sprawling cultural and technological ecology. While fascinating, it remains (intriguingly) populated primarily by prototypes.

Perspectives

The opening argument of the article was that information behavior extends far beyond the question-asking offered by today's digital search engines. Based on the case studies of exploration, visualization, and metaphor, the word "dreaming" may be proposed as an overall concept describing what future technologies should support. Could we, in these closing lines, speculate on what that might mean in practice?

"Dreaming" in the context of information systems is defined here as the state between waking and sleep and is characterized by (a) the awareness of both conscious control of thought and unconscious activity and (b) an unusual, "Alice in Wonderland" type of reality. This state is conductive to exploration, since the reality it offers is new, and to solving problems, as it encourages adopting new perspectives—this propensity of dreams being well-known, including in scientific discovery (Samuels & Samuels 1975). Exploration and problem solving imply human—machine integration that goes beyond targeted querying. The information system becomes a system that you think with, rather than simply ask from.

This article has presented some of the methods by which oneiric information systems could be designed, identifying key elements such as mystery (to elicit curiosity), pleasure (to create conditions for playfulness), metaphors (to create new perspectives), and serendipity (to allow for stumbling across useful things one did not think to search for). The role of the physical interface is equally important as regards aspects such as available display space and the haptic exploration and manipulation of data and methods.

Thus, to conclude, future digital information systems would benefit from preserving aspects of organization that have proven useful in physical libraries—which, let us remember, have always been great places for dreaming (Figure 5).

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