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Shape-finding in Biophilic Architecture: Application of AI-based Tool

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Artificial intelligence (AI), biophilic architecture, form-finding.

Abstract

The emerging application of AI-based tools in creative practices encourages analysing how these tools could be integrated into ecological architectural design. This research was aimed at identifying the possibilities of applying AI-based tools and approaches for shape-finding in the field of biophilic architectural design. The research encompasses review and analysis of literature, the experiment of shape-finding using AI-based tool VQGAN+CLIP, and the evaluation of generated images according to the system of biophilic design criteria adapted for the purpose of image evaluation. The experiment of shape finding demonstrated that the use of keywords describing the characteristics of natural systems and the VQGAN+CLIP code allow generating unexpected, interesting forms which correspond to some biophilic characteristics. Such forms can be the start of a further creative search for the architect.

Introduction

Relevance of the research. According to predominant narrative, humanity and planet Earth go through the geological epoch of Anthropocene in which human impact upon the planet is 'both stratigraphically significant and irreversible' [1]. According to J. Zylinska [1], this narrative directs attention to ecological crisis, increases environmental awareness and calls for effective ecological theories and praxis that could help to repair the planetary damage. This call is referred to as Anthropocene imperative [1]. J. Zylinska has noted that the abbreviation of Anthropocene imperative and artificial intelligence (AI) coincide and views the potential of artificial intelligence in the accomplishment of environmental goals [1]. The symbolic interconnection between artificial intelligence and Anthropocene imperative drawn by J. Zylinska [1] inspired this study focused on the interconnections of artificial intelligence (AI) and biophilic design and its aesthetic, ethical, and environmental implications.

The accomplishment of Anthropocene imperative is not only driven by technological progress; deep understanding of human-nature connections and ethical, aesthetic implications of environmental actions are equally important. One of the theories dealing with human-nature interconnections is biophilia hypothesis developed by E. O. Wilson during the last decades of the 20th century. E. O. Wilson defined biophilia as 'inborn affinity human beings have for other forms of life, an affiliation evoked, according to circumstances, by pleasure, or a sense of security, or awe, or even fascination blended with revulsion' [2]. E. O. Wilson grounded the hypothesis with evolutionary logic, intercultural comparison and psychological methods [3]. The essence of biophilia hypothesis can be summarized in contemporary terms as follows: humans may have evolved a need to connect with nature, and nature provides substantial well-being, cultural and social values to humans [4]. Since the publication of biophilia hypothesis, the increasing number of studies have analysed and proved the psychological

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and physiological health benefits of experiencing nature [5]. However, contemporary urban inhabitants tend to stay indoor longer (approximately 90 % of the time daily) and spend less time in the outdoor recreational areas. Especially during the COVID-19 pandemic, most of the urban dwellers had limited access to urban green areas or countryside, and this not only caused social isolation but also aggravated health problems [5], [6]. The discipline of biophilic design that has stemmed out of biophilia hypothesis promotes the integration of natural elements and the characteristics of natural environment into the built environment leading to a significant positive impact on human health, well-being, and productivity [7]. The trend of biophilic design seems of particular importance bearing in mind current abovementioned disconnectedness of human life from nature. According to W. Zhong et al. [6], restoring the connection with nature has been recognized as one of the most urgent challenges in contemporary urban architecture. As W. Zhong et al. [6] note, there are several challenges connected to biophilic architectural design: the need to understand and explore how 'nature' can be integrated and expressed in architecture; to identify and avoid 'green-washing' strategies, when biophilic features and ecological commitments are superficial and play the mere role of product marketing. Moreover, existing research suggests that there are wider positive implications related to human-nature connectedness that can be achieved by biophilic architectural design. According to P. Ch. Wang and Ch. Y. Yu [8], the aesthetic experience of the environment can trigger positive environmental consciousness in humans. Other researchers [9], [10] argue that emotional responses to the natural environment, such as empathy, can lead to nature conservation and more sustainable behaviours. Thus, it is possible to presume that restoring broken human connection to nature in the everyday living and working environments by the means of biophilic spaces of high architectural and aesthetic quality can lead to growing environmental awareness and more sustainable behaviours. The relevance of biophilic design to human psychological and physical health as well as the above mentioned wider positive implications and the threat of superficiality and 'green-washing', when biophilic features are merely attached to conventional business as usual structures encourage analysing the possibilities of aesthetic expression of biophilic architectural forms and the possibilities of shape-finding in biophilic architecture.

The aim and methods of research. The aim of the research is to identify the ways of AI-based tools and approaches to be applied in the field of biophilic architectural design with the main emphasis on shape-finding. The methodology of the research encompasses review and analysis of literature and the experiment of shape-finding using AI-based tool and the evaluation of generated images according to biophilic design criteria.

I. Literature Review: AI and Biophilic Design

The volume of research on the AI applications in design is constantly growing. However, literature review has revealed that AI applications in biophilic design is still a new topic with few publications that are directly aimed at AI applications in biophilic design context. It is possible to distinguish two trends in AI applications in biophilic design based on analysis of literature: AI-based tools in biophilic design analysis and AI-based tools in biophilic creativity.

AI-based tools in biophilic design analysis. Research in the field of biophilic design includes recent interesting applications of advanced tools including virtual reality [7] and AI [4], [5]. Virtual reality applications are interesting both as the possibility to pre-test the human response to design solutions as well as from the point of future perspective of generated virtual biophilic environments aimed at distant communication and entertainment. The research by M. Mollazadeh and Y. Zhu [7] has revealed that virtual realities can be applied for 'representing combinations of biophilic patterns, providing multi-modal sensory inputs, <...> supporting required exposure time to observe biophilic patterns, and measuring human's biological responses to natural environment'. Architecture is being one of the slowest forms of art considering the time since the early designs are adapted, technically elaborated and built [11], thus virtual reality can become a valuable medium for experimenting with biophilic forms. Meanwhile Sh. H. Hung and Ch. Y. Chang [5] carried out the study of identifying biophilic elements and qualities in the photographs of urban green spaces using Google Vision AI. This study explored the possibility to utilize the AI-based image recognition system for classification of landscape-related label content in the images of urban green areas and predicting the impact of the features of environment on people's psychological state. The research of Ch. Chang et al. [4] involved social media and AI in providing the evidence of biophilic hypothesis linking the content of nature in 31 534 analysed photographs with positive memories and life satisfaction. Both studies [4], [5] demonstrate that AI-based tools can be applied for identifying the biophilic features and elements in the images including the images of biophilic architectural design.

AI-based tools in biophilic creativity. The science of architectural design is fundamentally one of form development and research [12]. Before discussing the application of AI-based tools in biophilic designs generation, it is important to distinguish between shape-finding and form-finding in architectural creativity. According to N. S. Goldsmith [13], shape-finding approach is based on designer's personal visualizations; meanwhile the form-finding approach involves looking at processes in nature in order to uncover ways in which to organize the design. In the second case the aesthetics of the form is an emergent property from the developed natural forms more than a purposeful creation. H. Elshanwany et al. [14] distinguish similar dichotomy in design process: personal inspiration, intuition, sense of beauty of the architect and design approaches based on rules and fulfilment of design requirements. Both approaches are valuable in the field of biophilic design. In this research we focus on the shape-finding process, which involves more creative freedom, chance-based creativity [15] and sometimes unexpected results and can be applied in the initial stages of project idea development and design. Literature review has not revealed the cases of biophilic design shape-finding using AI-based tools. There is a body of literature on advanced computer technologies in architectural design [14], although the main focus is on parametricism [11]. However, the experience of AI-based creativity in the field of arts can be very useful in this regard. Computer generated art is in the art scene since the 1970s; meanwhile the works of art created using AI-based tools had proliferated, gained visibility and socio-cultural relevance since the second half of the 2010s [16]. There is a growing volume of research on combining AI and cultural production [17]. The comprehensive reviews by E. Cetinic and J. She [15] and D. Grba [16] can be distinguished in this field. According to M. Mateas [17], AI-based art is not a sub-field of AI studies, but a new interdiscipline; the same statement can be applied to AI-based architectural shape-finding. The term 'generative art' [1], [15] is often used for AI-based art that involves randomness, complexity, and machine learning architectures – the art that is produced by the systems with some level of autonomy [15], [16]. Such features of generative art as randomness [16], chance, surprise element and certain level of uncontrollability [18] make this field of creativity interesting from the point of view of shape-finding.

According to T. Hassine and Z. Neeman [19], the art generated using computers has a long and diverse history and involves a wide range of tools and approaches towards AI-human interaction. The activities in the field of generative art have particularly intensified in recent years after DeepDreams, neural style transfer (NST) and various applications of generative adversarial networks (GANs) algorithms have been invented and gradually became available to the artists' community through user-friendly platforms.

DeepDreams. DeepDreams algorithm was developed and presented by A. Mordvintsev in 2015 as a method designed for the advancement of interpretability of deep convolutional neural networks (CNNs) by visualizing patterns that maximize the activation of neurons [15]. According to J. Zylinska [1], "DeepDreams works by identifying and enhancing patterns in images, leading to the algorithm 'finding' human eyes or puppies in any regular photographs". The distinctive stylistic effect of visualizations with psychedelic and hallucinatory aesthetics attracted attention of digital artists [15] and consequently DeepDreams became re-purposed as creative tool [1].

Neural style transfer (NST). L. A. Gatys et al. introduced the NST method in 2016; this approach has demonstrated the successful use of CNNs in creating generated visual content by separating and combining the so-called content and style of the images: separate the content of an image from its style, to combine the style of one image with the content of another. This invention was followed by many new research contributions and applications [15], [19].

Generative adversarial networks (GANs) art and text to image art. GANs were introduced by I. Goodfellow et al. in 2014 [15]. According to E. Cetinic and J. She [15], this technological innovation was the turning point in the attempts to use machines for generating novel visual content and has most significantly contributed to the contemporary rise of the AI art movement. GANs demonstrated the impressive results in generating convincing fake variations of realistic images for various types of input image content and are now a frequent tool in the creative process of many digital artists, especially those having science and engineering background [1], [15]. GANs use two neural networks: a generator and a discriminator. The two neural networks are placed in an adversarial relationship, with one – generator – tasked with generating convincing and correct input, the other – discriminator – to classify generated images as fake and the real images from the original sample as real. Their ongoing interaction makes both networks to improve learning from each other while trying to outdo one another in obtaining 'good' results. The optimization process ends at the point that is considered a minimum in relation to the generator and a maximum to the discriminator [1], [15]. Various modifications of this technology and its training settings were soon developed in the work of creative artists. In 2021, the advanced neural network was introduced allowing to generate images from text captions. E. Cetinic and J. She [15] conclude that advanced text-to-image synthesis models, such as DALL-E presented by OpenAI, will represent an important trend in the future of AI art. Recently another text-to-image tool – VQGAN+CLIP (*Vector Quantized Generative Adversarial Network* and *Contrastive Language–Image Pre-training*) was introduced in the publication by K. Crowson et al. [20]; the authors underline that it is a new methodology, 'which is capable of producing images of high visual quality from text prompts of significant semantic complexity without any training by using a multimodal encoder to guide image generations' producing 'higher visual quality outputs than prior, less flexible approaches like DALL-E' and others. The VQGAN+CLIP code is available in a public repository for art experiments.

II. Research Methodology and Results

Methodology. Experimenting is important in both artistic and practical discipline of architecture. According to A. Riekstins [11], 'the discipline of architecture is stagnating and basically recompiling and reinventing the previous experiences based on their success and failure' if no experimenting is performed. Virtual environments and generative AI-based art practices provide endless possibilities for experimenting with architectural shapes and aesthetics. T. Hassine and Z. Neeman [19] note that 'AI-generated art has a potential to change the environment of the art world'. In this research we raise the hypothesis that this change can be brought to the field of architectural creativity as well. Biophilic shape-finding experiment using AI-based tools presented in this research consisted of the following steps:

1. Selection of the algorithm for generation of images. The necessity to generated new biophilic shapes and images as a way of chance-based creativity [15] determined the selection of VQGAN+CLIP code. This code, available in public repository [20], allows generating images of sufficient visual quality from text quotes and keywords. The code without any interface platform was used in order to avoid the aesthetic uniformity of 'platform art' identified by several digital art critics [1], [16].

2. Selection of keywords for image generation. Digital art scene critics notice technocentric character of generative art, for example, D. Grba [16] notes that 'technocratic or techno-fetishist mentalities have been haunting computational arts since their outset'. In order to test the possibility to generate biophilic shapes using the text-to-image AI-based tool, it was decided to use two pools of keywords: 1) keywords related with biophilia, biophilic design, ecology, nature and sustainability; 2) random keywords (Fig. 1). Keywords related with biophilia and biophilic design were selected based on existing biophilic design guidelines [21], [22].

3. Development of criteria for generated images evaluation. According to T. Hassine and Z. Neeman [19], the criteria for artistic evaluation of generative artworks has not yet adequately emerged. According to them, the emergence of new AI-based tools in the field of creativity calls for new modes of both artistic creation and artistic analysis [19]. For developing the system of criteria for evaluation of generated images, the analysis of several systems of evaluation criteria and design approaches was carried out. The analysed approaches and systems – sustainability aesthetics [23], [24], biophilic healing index [25], 14 patterns of biophilic design [22], elements and attributes of biophilic design [21], and biophilic interior design [26] – allowed developing the system of criteria [27] for evaluation of biophilic qualities of architectural and environmental shapes based on the analysis of the features of generated images. The distinguished criteria subdivided into five categories – features of environment, shapes and forms, patterns, light and space, human-environment relations – are presented in Fig. 2.

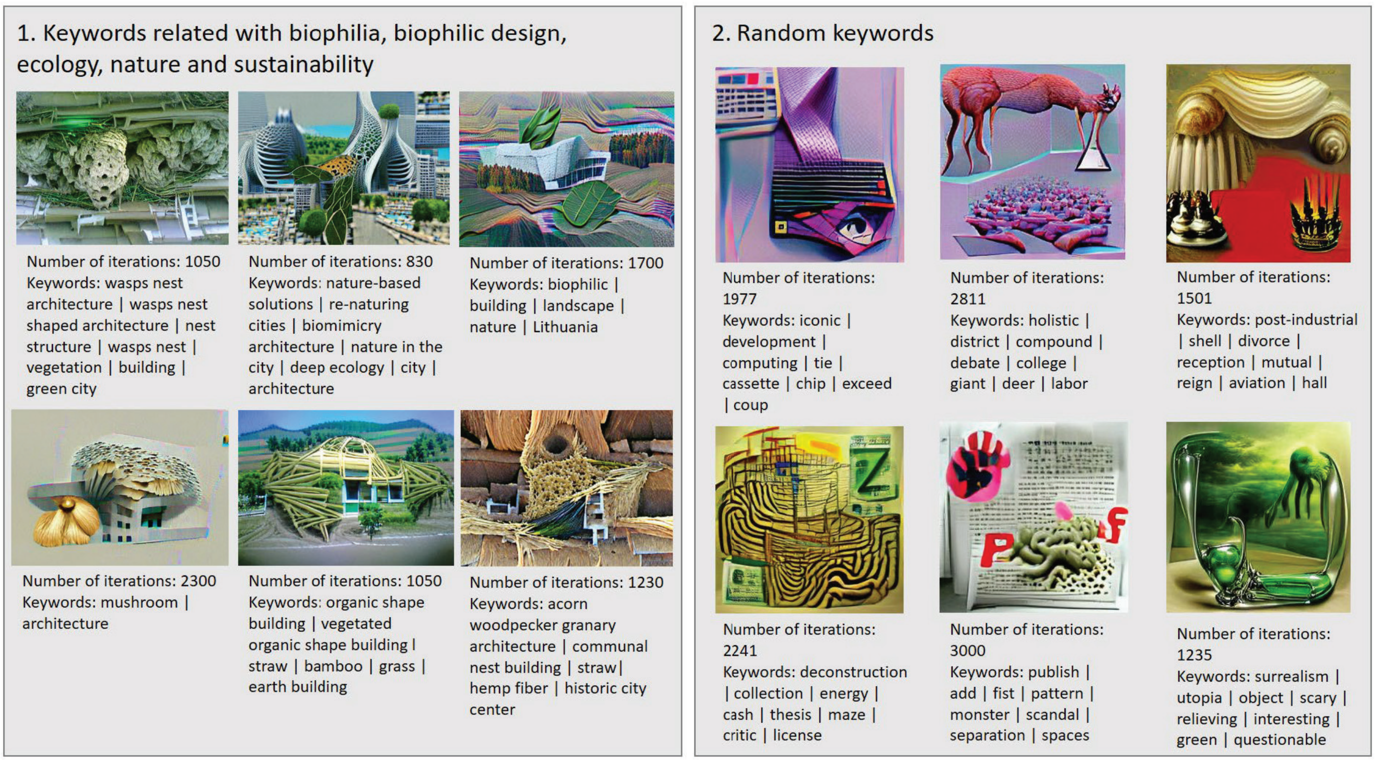

Fig. 1. Examples of images generated using the VQGAN+CLIP code and two sets of keywords [images generated by the authors].

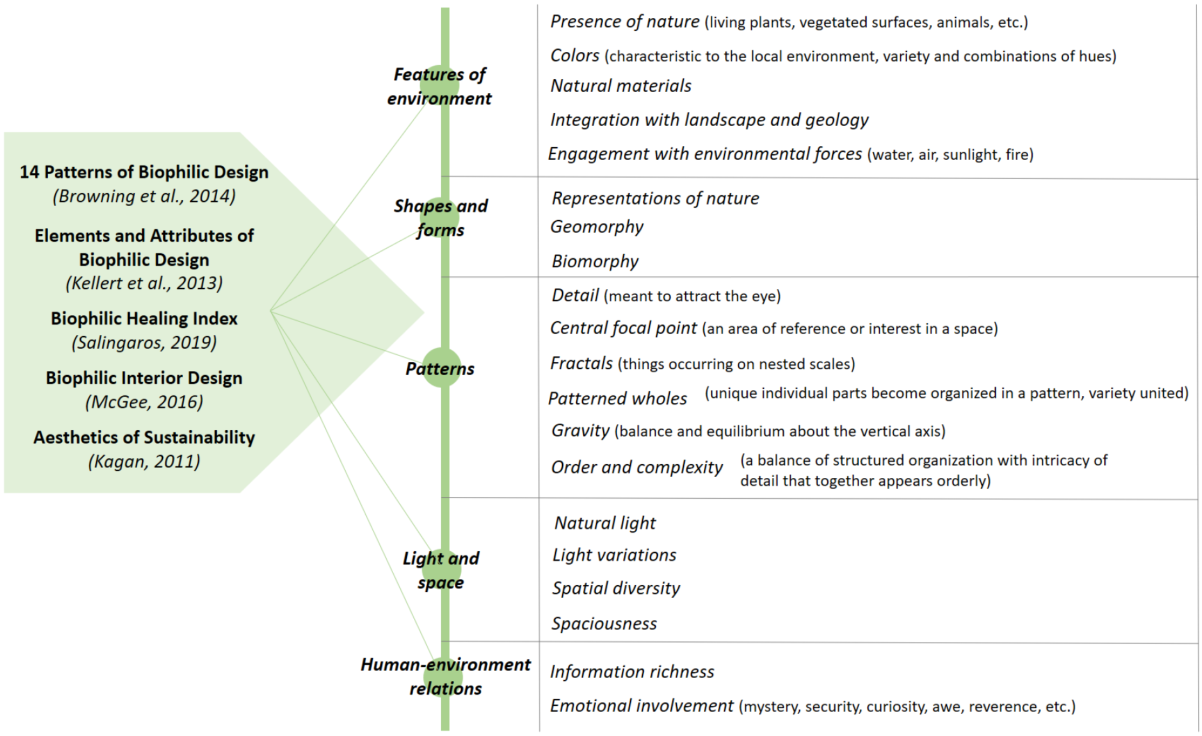

Fig. 2. System of criteria applied for evaluation of generated images [developed by the authors based on references [23]–[27].

III. Results and Discussion

In the course of the research 100 images were generated using VQGAN+CLIP code, the images were subdivided into two sets: 50 images generated using keywords related with biophilia, biophilic design, ecology, nature and sustainability and 50 images generated using random keywords (Fig. 3). The evaluation of images was proceeded using the system of criteria presented in Fig. 2. The procedure of evaluation of each image included assigning values from 0 to 2 to each criterion: 2 – the characteristics is fully present; 1 – the characteristics is partially present; 0 – the characteristics has not been observed. The maximum score the image could receive was 40 points. The highest assigned score was 36, the lowest score – 6 (Fig. 4.). The image evaluated with 20 points or more could be considered as biophilic with variety of necessary qualities present. It can be concluded that in the set of 50 images generated using keywords related with biophilia, biophilic design, ecology, nature and sustainability the evaluation of the majority of images (46 from 50) exceeded 20 points; meanwhile, in the second set generated using random keywords the evaluation of 22 images from 50 exceeded 20 points. Overall assessment of both sets was the following: the first set – 1296 points, the second set – 961 points. This allows concluding that the use of keywords related with biophilia, biophilic design, ecology, nature and sustainability allowed generating the images that can be described as biophilic in the most cases; meanwhile, the use of random keywords resulted in more than a half of non-biophilic images.

General visual assessment and comparison of two sets of generated images were completed as well and allow concluding that the images of the first set can be in the most cases characterized by complexity, the illusion of space and depth, natural colours and patterns, and natural references. The second set of images exhibits colours that are rarely observed in nature in such proportions as well as more flat, two-dimensional outlook. This statement can be well illustrated by the selected images which were attributed the highest and the lowest scores (Fig. 4).

Looking from artistic quality point of view, it was observed that in the first set of images where more interrelated (all related with biophilia, biophilic design, ecology, nature and sustainability) keywords were used, the generated images exhibit more compositional integrity; however, in some images, different objects, elements, patterns appear combined artificially, not creating a coherent composition. The objects or scenes observed in the first set of images are more reminiscent to architectural, environmental or design features, thus they can more likely serve as an inspiration to architect or designer. The images in the second set can be identified more as two-dimensional abstract artworks.

Fig. 3. 100 images generated using the VQGAN+CLIP code and evaluation of their biophilic characteristics using predefined set of criteria [images generated by the authors].

Fig. 4. Images which received the lowest and highest evaluations are presented in the upper rows correspondingly and the images distinguished as the most inspiring for architectural creativity are in the lower row [images generated by the authors].

Conclusions

1. The relevance of biophilic design to human psychological and physical health as well as wider positive implications for raising ecological awareness and contributing to sustainability and the threats of superficiality and 'green-washing' reveal the relevance of analysis of possibilities of aesthetic expression of biophilic architectural forms and the possibilities of shape-finding in biophilic architecture.
2. AI applications in biophilic design is still a new topic with few publications that are directly aimed at AI applications in biophilic design context. It is possible to distinguish two promising trends in AI applications in biophilic design: AI-based tools in biophilic design analysis and AI-based tools in biophilic creativity. The use of AI-based tools (DeepDreams, neural style transfer (NST) and various applications of generative adversarial networks) in the field of generative art involving randomness, complexity, and chance-based creativity makes this field of artistic creativity interesting from the point of view of architectural shape-finding.
3. Biophilic shape-finding experiment using AI-based tools presented in this research consisted of the following steps: selection of the algorithm for generation of images, selection of keywords for image generation, and development of criteria for generated images evaluation. Text-to-image VQGAN+CLIP code was selected and applied for image generation using random and biophilic design related keywords. The generated images were evaluated using the system of criteria focused on shapes and forms, patterns, light and space, human-environment relations in the analysed image.
4. The creative experiment conducted in this study showed that the use of keywords describing the characteristics of natural systems and environmentally friendly approaches and the VQGAN+CLIP code allow the generation of unexpected, interesting forms with some biophilic characteristics. Such forms can be the start of a further creative search for the architect.

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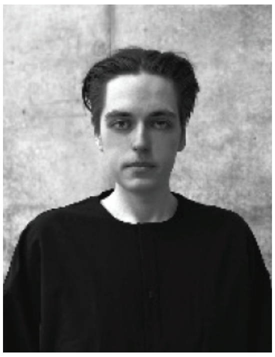

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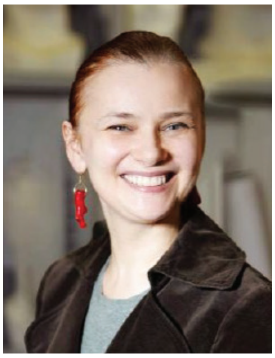

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