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EKPHRASIS AS A DESIGN METHOD

Gero, John (1,2)
1: UNC Charlotte, United States of America; 2: George Mason University, United States of America

Abstract

Ekphrasis is the expression of a concept that is represented in the medium of one domain in the medium of another domain. This paper presents the results from exploring the concept of ekphrasis as the foundation for a computational design method. It presents a formalization of design by ekphrasis before describing its application in in a simple engineering design task involving the design of the cross-section of a beam to optimize multiple criteria. The new domain is as genes in an evolutionary domain that includes the introduction of new operators within that domain beyond the standard evolutionary operators of crossover and mutation. This generates a space of genomes beyond those that were there at the commencement of the process. Designs, i.e., cross-sections, produced in this new domain not only look different but have performances that are better than the Pareto-optimal designs produced by the original genetic operators. Design by ekphrasis can be considered as a framework for designing that involves transforming any design space in one domain into another design space in a new domain with contingent processes in the new domain.

Keywords: Design methods, Design theory, Creativity

Contact:
Prof. John Gero
UNC Charlotte / George Mason University
Department of Computer Science / Computational Social Science and Architecture
United States of America
john@johngero.com

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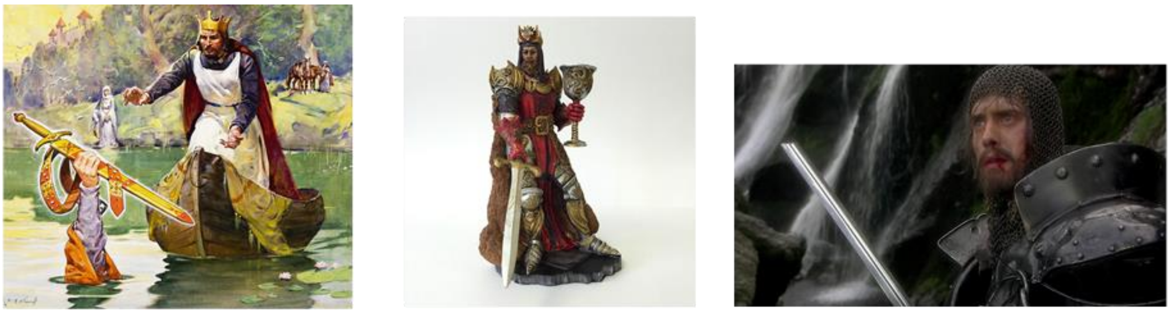
1 INTRODUCTION

Representation is a fundamental notion in externalizing knowledge. Science and engineering science has a long history of representing ideas in the form of mathematical or logic expressions. Mathematics has become the natural language for representing engineering behaviour. In using mathematics re-representation concepts have been found to be useful in obtaining solutions to difficult to solve equations. For example, the Schwarz-Christoffel conformal mapping provides the foundation for the ready solution of many difficult partial differential engineering behaviour equations (Driscoll and Trefethen, 2002). As engineering research has increased its ambit to include new areas such as engineering design, the representations of concepts are often symbolic rather than mathematical and appear as expressions rather than equations (Coyne et al., 1990). All externalization of mental concepts is representation and is a form of *ekphrasis*.[1]

Ekphrasis, originally described by Plato in the *Republic – Book X*, is the expression of a concept that is represented in one medium in another medium. He used the example of a bed, which has three expressions: the physical object, the representation of the bed as an image, and the bed represented in another art form. It has been used extensively in the arts and literature such as when a scene from a poem is the basis of a painting or when a sculpture describes a dramatic event previously described in prose. This paper takes the idea of ekphrasis and applies it to design as a framework for what otherwise appear to be disparate approaches to designing.

In the arts ekphrasis or ekphrastic expression involves the transformation of concepts represented in one medium into isomorphic concepts represented in another medium (Fowler, 1991; Goldhill, 2007; Knapp, 2011; Leader, 2014; Newby, 2002; Scott, 1992). Take as an example the mythical story of King Arthur and Excalibur, the foundation of the rightful sovereignty of the British. The precise nature of the story and what it exemplifies is not of interest here. What is of interest is that the story is depicted in multiple other forms. It is expressed as a painting in Figure 1(a), as a sculpture in Figure 1(b), and as a movie in Figure 1(c). All three are examples of ekphrasis where the nature of the medium of expression allows for different expressions. In the rest of this paper will use the term domain in lieu of medium to bring it into line with the terminology used in design research.



(a) (b) (c)

Figure 1. King Arthur and Excalibur represented as (a) a painting, (b) as a sculpture, and (c) as a movie

Ranjan, Gabora, and O'Connor (2013a; 2013b) showed that the cross-domain interpretation of artistic ideas, i.e., ekphrastic expression, can be tested empirically and that such a cross-domain interpretation of artistic ideas can be the basis of a form of creativity.

The remainder of this paper introduces the concepts of ekphrasis and its use in designing, presenting it more formally before presenting an example of an implemented system that produces designs that are novel and surprising through ekphrasis. The paper concludes with a discussion of the use of ekphrasis as a framework for designing.

[1] This paper is based, in part, on talks given at CAADRIA2017, April 2017, Suzhou.

2 EKPHRASIS IN DESIGN AND ITS RELATIONSHIP TO RE-REPRESENTATION

2.1 Re-Interpretation in Design

In design, we are familiar with the notion of representing ideas in different ways and particularly so when we use computation since all computation is symbolic, i.e., we have transformed the design idea into symbols and those symbols are acted on not the design idea. Representation and re-representation have a well-established role in design and in computational models of design. Schon's reflective model of design is based on this representation and re-representation approach (Schon, 1983). Many design models and methods have been constructed from this foundation (Damski and Gero, 1994; Davies et al., 2003; Jupp and Gero, 2004; Karmiloff-Smith, 1995; Kulinski and Gero, 2001; Kurtz, 2005; Oxman, 1997; Sperber, 2000; Veale, 2006).

In re-representation the original representation is transformation into another representation that can be in the same domain and can use the same processes as used on the original representation. For example the domain of the representation might be geometry and topology used to desceribe an object and the processes might be those produced by carrying out homogeneous transformations on the object in that representation. As an example take three square that are located such that their outline is an L shape, Figure 2 top left. The L shape can be represented by its perimeter, Figure 2, top right. If we apply a rotation around the object center to both the original representation that used squares and the re-representation that is based on the perimeter we obtain different results, Figure 2, bottom left and bottom right.

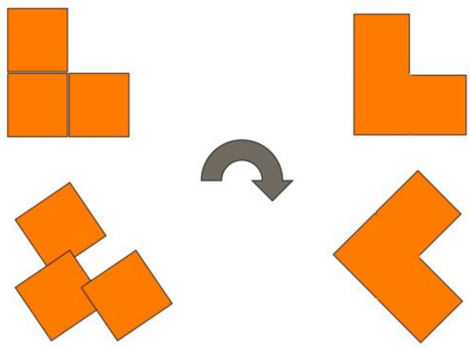


Figure 2. Changing the representation of the L shape from being composed of three squares to a single shape and then executing the same process on both representations results in two different outcomes

We will draw a distinction between re-representation and ekphrasis such that re-representation is encapsulated by ekphrasis and becomes a degenerate condition of it.

2.2 Ekphrasis in Design

There are two significant differences between the use of ekphrasis as practiced in the arts and in design. First, we have a double ekphrasis in design. After we transform from the initial domain, d_1, into a second domain, d_2, we need to transform the results of the activity in domain d_2 back into the representation of domain d_1, which is the original domain of the design. Second, we carry out processes in domain d_2 that do not necessarily have a counterpart in domain d_1. The processes in d_2 are contingent on d_2 and are a consequence of the paradigm of that domain. The representations in domain d_2 offer affordances that are not available in the representations in the initial domain. The activity in domain d_2 may be capable of producing new and surprising results in domain d_1 and as a consequence can be considered the basis of a creativity method. Further, we can produce new processes in d_2 that generate completely new results compared to previous results in d_2 that are then transformed back into d_1. Thus, ekphrasis materially differs from re-representation as used in design.

Ekphrasis can be treated as both a design method and a framework for a class of design methods within which a number of disparate existing methods can fit. As a framework, it provides structure to determine commonalities amongst apparently different methods. As a method, it provides an approach to the production of designs that may be creative (Miller and Mair, 2006; Milligan et al., 2007). Any representation offers affordances and any change in representation offers new affordances that can be acted on to produce new behaviours and hence may potentially produce creative results (Gero and Kannengiesser, 2012).

3 FORMALIZING EKPHRASIS

3.1 Representation and Re-Representation

We can describe all computation, C, as being composed of representation, R, and processes that operate on that representation, P. This can be written as:

$$C = \{R,P\} \tag{1}$$

Designing computationally involves design processes, P^d, operating on a design representation, R^d, producing designs, D. This can be written as:

$$D = (R^d \times P^d) \tag{2}$$

Where all design representations are composed of elements, E, and relationships, R:

$$R^d = [E, R] \tag{3}$$

Re-representation involves a transformation process, T^R, applied to the original representation, R^{d0} resulting in R^{dn}:

$$R^{dn} = T^R(R^{d0}) \tag{4}$$

Hence, designs are produced by applying the processes associated with the original representation, P^{do}, to the new representation, resulting in new designs, D^n:

$$D^n = (R^{dn} \times P^{do}) \tag{5}$$

3.2 Ekphrasis in Design

However, in ekphrasis in design we have two phases, the first is the expression in a new domain and the second is the transformation back into the original domain. We can describe ekphrasis using the same symbols as we used to describe representation and re-representation.

Computation, designing computationally, representation and re-representation remain the same, except that the re-representation is in a new domain, N, resulting in R^{dN} and associated with this new domain are processes that substitute for the processes in the original domain:

$$R^{dN} = T^R(R^{d0}) \tag{6}$$

In the first phase we have the added activity of substituting the processes that apply in the new domain, P^{dN}, where S^P is a process substitution process:

$$P^{dN} = S^P(P^d) \tag{7}$$

Designing in the new domain becomes:

$$D^{dN} = (R^{dN} \times P^{dN}) \tag{8}$$

In the second phase we need to transform designs back into the initial domain using an inverse transformation operator, T^{-R}, to produce designs from ekphrasis, D^E:

$$D^E = T^{-R}(D^{dN}) \tag{9}$$

with the expectation that the designs produced through ekphrasis will not necessarily be the same as those produced without it:

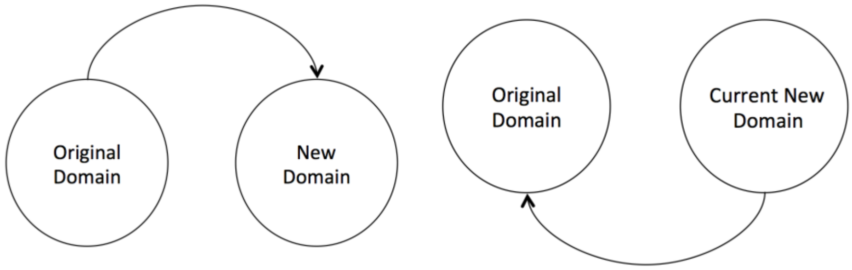
$$D^E \neq D^n \tag{10}$$

Figure 3 illustrates these transformations and substitution graphically.

Re-representation is encapsulated within ekphrasis when no process substitution occurs such that:

$P^{dN} = P^{do}$ in Equation (7).

This is a degenerate condition in ekphrasis.



(a) (b)

Figure 3. (a) Ekphrasis moves from an original domain to a new domain through transforming the representation in the original domain to those in the new domain and substituting processes from the new domain for those in the original domain; (b) a second ekphrasis occurs after designing in the new domain that moves the design back to the original domain through transforming the representation

4 A DESIGN SYSTEM THAT USES EKPHRASIS

4.1 How Ekphrasis Is Formulated

Let us demonstrate ekphrasis with a simple standard design synthesis task initially formulated as an optimization task (Papalambros and Wilde, 2017). Consider the problem of designing the cross-section of a beam. The structure space consists of cross-sections of the pre-defined shape with a fixed area, Figure 4. This shape is determined by 4 parameters (the width and height of the top and bottom rectangular flanges and the width and height of the middle rectangular web) with the same range [1,100]. The area of the cross-section is fixed and is set equal to 16. The fulfilment of this area constraint is guaranteed by scaling the shape. The problem has a two-component behaviour (fitness) function, **F**, which consists of the moment of inertia, **I,** and the section modulus, **Z**.

Figure 4. The cross-section template that defines the original structure space

The representation consists of rectangles and their relationships. These elements and their relationships are the sets of variables that make up the representation of a design, R^{do}.

$$R^{do} = [\{rectangle1, rectangle2\}, \{topological\ relations\}] \quad (11)$$

Any design in this domain is the result of values of the length and width of rectangles for a fixed topological relation, P^{do}, operating on R^{do}. If we transform the representation into a genetic representation, we get:

$$R^{dN} = [\{genes\}] \quad (12)$$

$$P^{dN} = [\{crossover, mutation\}, \{expression\}] \quad (13)$$

$$D^{dN} = ([\{genes\}], [\{crossover, mutation\}, \{expression\}]) \quad (14)$$

A standard genetic algorithm found the following Pareto-optimal designs in the original design space, Figure 5. Because they all have the same genetic structure, they all have the same characteristic form.

4.2 Producing a new P^{dN}

We take this genetic crossover as our starting point. However, crossover does not result in potentially different designs since all the designs that can be produced are already encapsulated in the genome. The basic assumption behind the genetic crossover construction is that the genetic representation is fixed and static, implicitly defining all the designs that can be described/generated using it.

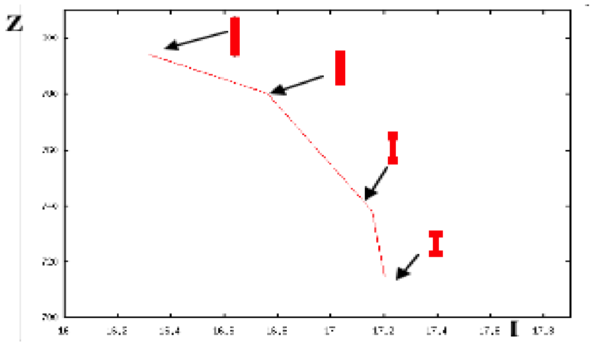


Figure 5. The Pareto set for the initial structure space with the corresponding shapes

Working in the genetics domain we can derive new processes within P^{dN}. In our derivations, we commence with the standard genetic crossover. Then we re-cast it as a type of natural number interpolation operation. The next step is a generalization of interpolation where we replace natural number interpolation with a more general type of operation – real number interpolation and extrapolation that allows for a continuous path rather than a discrete path in the gene space. In models of natural genetics extrapolation has no meaning as there are no genes beyond the representation of the genes in the genotype. However, when we have a path equation for the path of the interpolation we can use it to extrapolate. As a result, we construct a computational combination operator from the genetic crossover operator that is capable of generating designs, which cannot be generated using a crossover-based genetic combination, Figures 7. This can also be seen an operating in the phenotype space, Figure 7. Since each of these generalization steps includes genetic based crossover as a particular case, it is possible that both initial genetic crossover-based and generalized interpolation/extrapolation combination operators give the same results as the genetic crossover for some designs.

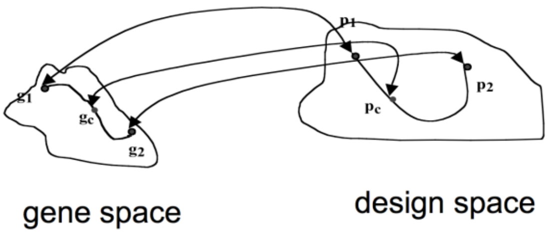


Figure 6. The process of interpolation between two parents results in a continuous path rather than a discrete path between the two parents in both gene space and design space (Gero and Kazakov, 1999)

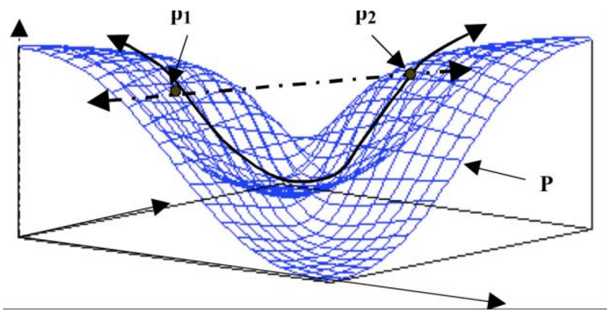


Figure 7. The illustration of the crossover-induced interpolation in P (the original structure space) and direct interpolation in enlarged space P+. The enlarged space P+ represents the complete three-dimensional space and the set P represents the surface in it. The solid line represents an interpolation in P (the mapping of the line segment in Figure 5 in genotypic space), whilst the dotted line represents an interpolation in P+ (Gero and Kazakov, 1999)

These designs are represented using an F-representation (Pasko, et al., 1995) as real valued functions F(**x**) such that F(**x**)>0 is inside the object, F(**x**)=0 is on its boundary and F(**x**) <0 is outside of the object. Here **x** is a 2-d vector with a defined feasible bounded region D: $\mathbf{x} \subset D$. We can use the approach proposed by Fujimura and Makarov (1997) to find interpolating functions in these F-representations. These interpolation functions apply in both genotypic and phenotypic spaces, are continuous and are not restricted to interpolation within the original values of the genes.

4.3 New Designs Using Ekphrasis

The designs from the Pareto front in Figure 4 are re-represented in F-representations, as real functions F(x), and their combinations produced using two types of interpolations – linear interpolation and non-linear interpolation.
We now have:

$$R^{dN} = [\{genes\}] \tag{15}$$

$$P^{dN} = [\{interpolation\}, \{expression\}] \tag{16}$$

As a consequence designs become:

$$D^{dN} = ([\{genes\}], [\{interpolation\}, \{expression\}]) \tag{17}$$

We then transform the results in the new domain back into the original domain

$$D^{E} = T^{-R}([\{genes\}], [\{interpolation\}, \{expression\}]) \tag{18}$$

The results are shown in Figures 8 and 9. From visual inspection of the resulting designs it is clear that even the use of the linear interpolation leads to the design space being extended, and that non-linear interpolation leads to a more far-reaching extension.

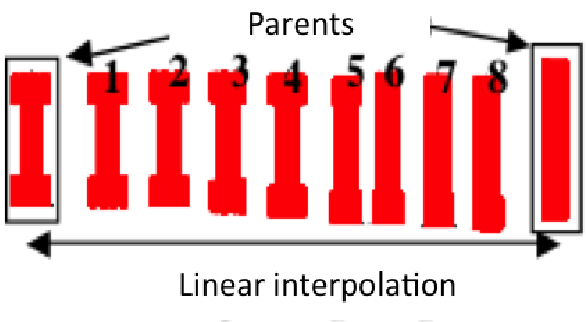


Figure 8. Ekphrastic designs from linear interpolation in the genetic representation domain

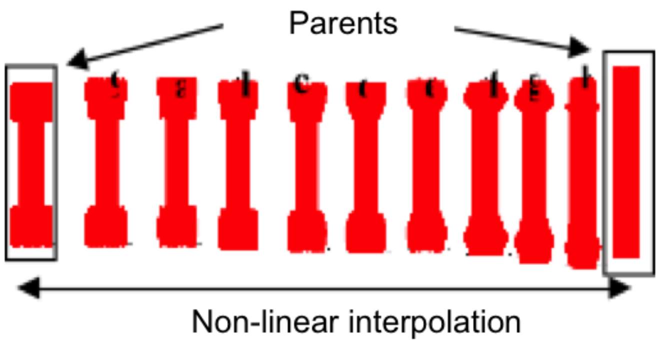


Figure 9. Ekphrastic designs from non-linear interpolation in the genetic representation domain

As described in Section 4.1 we commenced with the two extreme designs in the Pareto set shown in Figure 5 as parents and transformed their representation into the evolutionary domain. We then added the new evolutionary process that turns the trajectory between the parents into a continuous path. This produces a new domain that potentially contains designs that are not in the original domain. The original

domain produces designs that are all composed of rectangles. Designs generated using ekphrasis are composed of shapes not found in the original domain of rectangles. This is a consequence of generating designs that sit inside the boundaries of genes rather than only at their boundaries. It is the parallel of comparing the real numbers with natural numbers and finding that the real numbers are much more numerous that the natural numbers and that between each adjacent pair of natural numbers lies an infinite set of real numbers.
We can plot these designs produced using ekphrasis on the Pareto-optimal front and we note that some of them dominate previous Pareto-optimal designs, Figure 10. From this example, we can see that this generalized combination operator in the form of continuous interpolation generates designs that perform better than those produced by genetic combination alone.

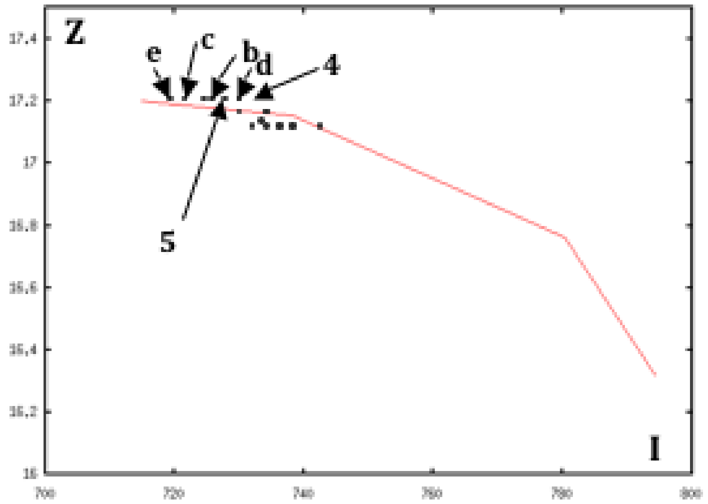


Figure 10. Some of the designs produced using ekphrasis plotted on the Pareto-optimal front that was generated using standard genetic operators

The range of beam cross-section designs that can be produced by ekphrasis can be extended through the use of different interpolation and extrapolation functions. An example of such a novel and unexpected design is given in Figure 11.

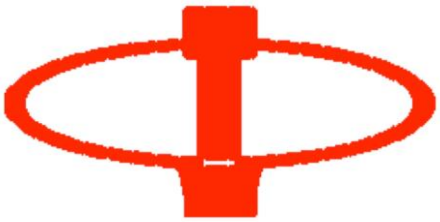


Figure 11. A novel and unexpected design for the beam cross-section resulting from a different non-linear interpolation function than that used to produce the designs in Figure 9

5 DISCUSSION

In this example, we can observe (and measure) differences in the designs produced using ekphrasis compared with those produced using the original representation in the original domain. The most noticeable differences are:

- The flange shapes are not rectilinear.
- A lack of symmetry around the horizontal axis.
- A lack of symmetry around the vertical axis.

These three additional characteristics of the designs produced using ekphrasis indicate that the design space they belong to, D^E, is different to the original design space, D^n. The design space D^E contains some designs that are superior to the Pareto optimal designs in D^n.

Ekphrasis can be considered as a framework for designing that involves transforming any design space in one domain into another design space in a new domain with contingent processes in the new domain, producing designs in that new domain and then transforming them back into the original domain. One of the notions related to creative designing processes is that an important means of characterising them is to determine whether they have the capacity to change the state space of possible designs, often called exploration. Of the three state spaces used to describe designs (function space, behaviour space and state or structure space), only the state or structure space has the capacity to directly produce novel designs as it is changed. Although the other spaces can also be changed and hence produce either novel interpretations or indirectly force the expansion of the state or structure space, there is no guarantee that the state or structure space will necessarily be changed (Gero, 1992). There are two classes of expansion or modification processes. The first class contains those processes that rely largely on external knowledge that is applied to the existing space and as a consequence changes it – exogenous modification. The second class contains those processes that make use of emergent features in the design space and use those to change the design space – endogenous modification. The example interpolation process described in this paper belongs to the first class. Design by ekphrasis has the capacity to encompass both classes of processes.

Ekphrasis can also be used to transform a design space into another domain, take the contingent processes from the new domain and bring them back into the original domain – a form of exogenous modification. As a consequence designing becomes:

$$D^E = T^{-R} (D^{dN}); \; D^{dN} = (R^{do} \times P^{dN}) \tag{19}$$

As an example of an exogenous modification consider design by analogy (Goel, 1997) which can be formulated as this form of ekphrastic designing and as a consequence fits into this general framework rather than sitting as a single class of design processes. In design by analogy the designer transforms their domain into the biological domain and looks for processes that produce the behaviour they are looking for and then brings those processes into the original domain.

As an example of an endogenous process consider the emergence of new knowledge from a design space in the new domain that is then used to modify the design space in that domain.

Ekphrasis can be used a framework for categorising design processes a well as a design method. The model of designing using ekphrasis is given by:

$$D^{dN} = (R^{dN} \times P^{dN}) \tag{20}$$

Designing by re-representation is encapsulated within this when dN = n for the design, dN = dn for the representation and dN = do for the processes, given by:

$$D^n = (R^{dn} \times P^{do}) \tag{21}$$

Designing by exogenous modification is given by:

$$D^E = T^{-R} (D^{dN}); \; D^{dN} = (R^{do} \times P^{dN}) \tag{22}$$

And designing by endogenous modification occurs when $R^{dN'}$ is a process derived by some transformation (T) from designs in the new domain, ie when:

$$R^{dN'} = T(D^{dN}) \tag{23}$$

This paper has presented the concept of ekphrasis and exemplified it through a particular example. It has presented the beginnings of the sue of ekphrasis as a framework for designing.

REFERENCES

Coyne, R. D., Rosenman, M. A., Radford, A. D., Balachandran, M. B. and Gero, J. S. (1990), *Knowledge-Based Design Systems*, Addison-Wesley, Reading.

Damski, J. and Gero, J. S. (1994), "Visual reasoning as visual re-interpretation through re-representation", *AID'94 Workshop on Reasoning with Shapes in Design*, Lausanne, pp. 16-20.

Davies, J., Goel, A. K., and Nersessian, N. J. (2003), "Visual re-representation in creative analogies". In *The Third Workshop on Creative Systems. International Joint Conference on Artificial Intelligence*, pp. 1-12.

Driscoll, T. A. and Trefethen, L. N. (2002), *Schwarz-Christoffel Mapping (Vol. 8).* Cambridge University University Press, Cambridge.

Fowler, D. P. (1991), “Narrate and describe: the problem of ekphrasis”, *Journal of Roman Studies*, Vol. 81, pp. 25-35.
Fujimura K. and Makarov M. (1997), “Homotopic shape deformation”, *International Conference on Shape Modeling and Applications*, Aizu-Wakamatsu, pp. 215-225.
Gero, J. S. (1992), “Creativity, emergence and evolution in design”, in J. S. Gero and F. Sudweeks (eds), *Preprints Computational Models of Creative Design*, Department of Architectural and Design Science, University of Sydney, pp. 1-28.
Gero, J. S. and Kannengiesser, U. (2012), “Representational affordances in design, with examples from analogy making and optimization”, *Research in Engineering Design*, Vol. 23, pp. 235-249.
Gero, J. S. and Kazakov, V (2001), “A genetic engineering extension to genetic algorithms”, *Evolutionary Computation*, Vol. 9, No. 1, pp. 71-92.
Goel, A. (1997), “Design, analogy, and creativity”, *IEEE Expert: Intelligent Systems and Their Applications*, Vol. 12, No. 3, pp. 62-70.
Goldhill, S. (2007), “What is ekphrasis for?”, *Classical Philology*, Vol. 102, No. 1, pp. 1-19.
Jupp, J. And Gero, J. S. (2004), “Qualitative representation and reasoning in design: A hierarchy of shape and spatial languages”. in JS Gero, B Tversky and T Knight (eds), *Visual and Spatial Reasoning in Design III*, Key Centre of Design Computing and Cognition, University of Sydney, Sydney, pp. 139-162.
Karmiloff-Smith, A. (1995), *Beyond Modularity: A Developmental Perspective on Cognitive Science*. MIT Press.
Knapp, J. A. (2011), “Harnessing the visual: From illustration to ekphrasis”. In *Image Ethics in Shakespeare and Spenser*, Palgrave Macmillan, pp. 31-46.
Kulinski, J. M., and Gero, J. S. (2001), “Constructive representation in situated analogy in design”. In *Computer Aided Architectural Design Futures 2001*, Springer, Netherlands, pp. 507-520.
Kurtz, K. J. (2005), “Re-representation in comparison: Building an empirical case”, *Journal of Experimental and Theoretical Artificial Intelligence*, Vol. 17, No. 4, pp. 447-459.
Leader, S. (2014), "Ekphrasis and its reverse", *Academic Commons Program.* Paper 11. http://digitalcommons.risd.edu/grad_academiccommonsprogram/11 {RISD paper}.
Millar, K. and Mair, G. (2006), “Multimodality, a stimulant to creativity?”, *Proc. EandPDE 2006*, 8th International Conference on Engineering and Product Design Education, Salzburg, Austria.
Milligan, A., Connor, H., and Ross, C. (2007), “Engineering narratives”. In *DS 43: Proc. EandPDE 2007*, 9th International Conference on Engineering and Product Design Education, University of Northumbria, Newcastle, UK.
Newby, Z. (2002),“Testing the boundaries of ekphrasis: Lucian on the Hall”, *Ramus*, Vol. 31, Nos. 1-2, pp. 126-135.
Oxman, R. (1997), “Design by re-representation: A model of visual reasoning in design”, *Design Studies* Vol. 18, No. 4, pp. 329-347.
Papalambros, P. Y. and Wilde, D. J. (2017), *Principles of Optimal Design: Modeling and Computation, Third Edition*. Cambridge University Press, Cambridge.
Pasko A. A., Adzhiev V. D., Sourin A. I. and Savchenko V. V. (1995), “Function representation in geometric modeling: concepts, implementation and applications”, *The Visual Computer*, Vol. 11, No. 8, pp. 429-446.
Ranjan, A., Gabora, L. And O’Connor, B. (2013a), “The cross-domain re-interpretation of artistic ideas”. *arXiv preprint arXiv:1308.4706*
Ranjan, A., Gabora, L. And O'Connor, B. (2013b), “Evidence that cross-domain re-interpretations of creative ideas are recognizable”. *arXiv preprint arXiv:1310.0519*
Schön, D. A. (1983), *The Reflective Practitioner: How Professionals Think in Action*, Basic Books.
Scott, G. F. (1992), “Ekphrasis”, *European Romantic Review*, Vol. 3, No. 2, pp. 215-224.
Sperber, D. (Ed.). (2000), *Metarepresentations: A Multidisciplinary Perspective* (Vol. 10). Oxford University Press, Oxford.
Veale, T. (2006), “Re-representation and creative analogy: A lexico-semantic perspective”, *New Generation Computing*, Vol. 24, No. 3, pp. 223-240.

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