Fuzzy Modelling for Early Architectural Design
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Fuzzy modelling is simultaneously an extension of existing modelling approaches and a negation of one of their main aspects, the crispness of their definition. As a digital equivalent of analogue sketching it allows designers to register and manipulate imprecise and uncertain information. In the framework of design representations fuzzy modelling supports the development of conceptual design models characterized by flexible definition and interaction. The main advantages of such models are fluency, abstraction and continuity, at a level similar to that of analogue techniques. In addition to that they offer the possibility of local autonomy, i.e. segmentation of a representation into self-regulating and cooperating components. Three alternative forms of fuzzy modelling are proposed: (1) Canonical objects with tolerances, (2) objects described by minimal and maximal values, and (3) point sets comprising discrete, autonomous particles that describe the object by their spatial or structural relationships.
1. CRISPNESS, INFORMATION AND INTERACTION

As more design activities are being transferred to the computer, we increasingly realize that the crispness of computer-based models can be an obstacle to certain modes of design thinking and interaction, especially in the early design stages. The same crispness that provides precision, accuracy and control once a form has been determined may impede flexibility, adaptation and feedback while the form is being considered. The situation is analogous to the differences between sketching and drawing in analogue design media and processes: early stages, brainstorms and many tough discussions tend to favor vague, diagrammatic representations that require little time to prepare but nevertheless encapsulate the main concepts one wants to register, study and communicate. Crisp computer-based models are a far cry from such representations. Their chief advantage is the completeness of the description, which may make conflicts and incongruities explicit. However, this can be less relevant to design stages and processes where a design may still be incomplete or where its completeness is not the issue. The fuzziness of sketches and similar diagrammatic representations makes it easier to work with incompleteness and uncertainty, and to defer secondary decisions, concentrating instead on primary issues and higher abstraction levels that match the priorities of early-stage design and decision taking.

Interaction with crisp forms is similarly limited by the precision involved in the manipulation and transformation of especially complex forms. Many handlings required or encouraged by computer modelling systems fail to match the abstraction and ellipsis of the design stage or of the particular focus of a design action. Designers may be unnecessarily burdened with trivial adjustments and secondary or peripheral issues that are normally deferred to a later stage or delegated to other specializations. This is accentuated further by the perceived fixed state and high detail of crisp forms, which may give the appearance of a finished design rather than work in progress. The computer is admittedly the first technology to allow architects full control of form [1] but the usability of computer modelling systems remains severely limited by unspoken assumptions and technical constraints that have yet to be matched to the processes and products of architectural design.

2. FUZZINESS AND DIGITAL SKETCHING

Probably the most promising reactions to the crispness of conventional computer modelling have been in investigations of digital architectural sketching. These cover two complementary areas, the study of digital sketches and the implementation of digital sketching tools [2]. In terms of implementation digital sketching covers a wide spectrum, from the basic simulation of analogue media and techniques with 2D painting programs which produce mostly raster images to the rendering of surfaces in 3D
environments [3]. In CAAD research it has two assumed main lines of investigation. The first focuses on the registration of abstract design ideas (including as a pictorial means to indexing and retrieval [4]) which can be recognized and interpreted as diagrammatic representations that can lead to detailed, crisp models [5–7]. The main target of this line is the paradigmatic dimension of a sketch, i.e. the pictorial symbols it comprises [8], while the syntagmatic (the sequence by which symbols are entered in the sketch) and the mechanical dimensions (the interaction between sketcher and media) have recently attracted some interest too [9, 10]. The second line of investigation concerns immersive 3D painting, usually voxel-based [11–14]. Here again the focus is on paradigmatic matters, with the mechanical dimension an obvious priority in implementation and interaction.

The results of both lines suggest, firstly, that the distance between sketching and drawing is shorter than frequently assumed. From the viewpoints of recognition and information processing both types of representation share many common elements, certainly in the paradigmatic dimension. The main differences are due to the vagueness and ellipsis of representation in sketching and the resulting lack of precision and accuracy in sketches. Many formal and functional relations can be made explicit in sketches so as to constrain the development of design ideas or to facilitate presentation and communication. Such relations and constraints are usually expressed differently in drawings, e.g. implicitly through visual similarity and repetition or explicitly by means of textual annotation. Secondly, design interaction with sketches tends to be more flexible and reflective than with drawings and computer models. Regardless whether this is a matter of mechanical or cognitive ergonomics, it is evident that the digital equivalent of analogue sketching relies not only on the implementation means (from interaction media to graphic primitives) but also on the conceptual structure of the representation.

The addition of flexibility and abstraction to this conceptual structure can be achieved through the fuzzification of digital architectural representations. This involves the transformation of the crisp values of architectural entities and the geometric shapes used for their implementation into fuzzy numbers. In their simplest form these fuzzy numbers are represented by triangles (Figure 1), where the apex is set above the crisp value \( C \) and the base indicates the tolerances (range of
The base has a left-hand limit $L$ and a right-hand limit $R$. The number is therefore described as:

$$(L, C, R)$$

The values in the range have various degrees of membership, ranging (for a triangular fuzzy set) from 1 at the apex to near 0 at the left and right-hand limits.

Fuzzification of a form transforms the crisp shape into a canonical form (which can also be characterized as typical, prototypical or average, even though the term canonical captures best the cultural and conventional aspects) with geometric and spatial tolerances which make explicit the uncertainty and flexibility concerning its position or shape. In lines tolerances are described by a left-hand offset distance $L$, the canonical shape $C$ and a right-hand offset distance $R$ (Figure 2):

$$(L, C, R)$$

In 2D or 3D a fuzzy shape $F$ is described by an inner limit $I$, the canonical shape $C$ and an outer limit $O$ (Figure 3, Figure 4):

$$F = (I, C, O)$$

The fuzziness of a form can be determined by several constraints that indicate the range of possible alternatives. For example, the left and right hand-offset of a wall axis can express the width spectrum of relevant construction types (on the basis of availability as well as performance characteristics such as thermal and sound insulation), while the inner and outer limits of the contour of a space can be defined by the spatial requirements of activities to be accommodated in it. It is obviously possible...
to have multiple constraints that determine different aspects of fuzziness. In the wall example, in addition to construction and performance parameters, we can also consider aesthetic preferences, which influence the overall shape of the wall, and spatial constraints, which determine its position. All these constraints form complementary concerns that can be integrated in a single fuzzy form or represented by separate fuzzy shapes that come into action when the relevant aspects are being considered. The latter option does not imply alternative versions of an entity but incremental elaboration of a form on the basis of a gradually increasing number of constraints and preoccupations.

In addition to the fuzzification of a whole form, we can fuzzify its parts (totally or selectively) by expressing coordinates as fuzzy numbers.
A canonical shape \( C \) with the coordinates \((x_0 \, y_0, x_1 \, y_1, \ldots, x_n \, y_n)\) becomes the fuzzy shape \( F \):

\[
F = (I, C, O) = ((I, x_0, O), (I, y_0, O), (I, x_1, O), (I, y_1, O), \ldots, (I, x_n, O), (I, y_n, O)) \tag{4}
\]

This attaches tolerances to salient features so as to make abstraction variable. Such variability agrees with the resolution changes common at any moment of a design process: a designer can be simultaneously busy with matters of different magnitudes and specificity levels, e.g. with the overall form or function of a staircase and the detailing of a balustrade. The content of representations used (including sketches) reflects this, e.g. through the use of mixed conventions and resolutions. From a cognitive and computational viewpoint this also agrees with the structure of visual recognition and representation, in particular the use of multilevel modular representations [15].

Variable abstraction and specificity are also instrumental for the empowerment of a representation with local intelligence and autonomy: the representation can be segmented into self-regulating and cooperating local entities that facilitate the analysis and development of a design with abstraction and specificity appropriate to the requirements of each particular problem [16]. An element such as a wall is subject to different constraints that determine its form with respect to its purpose and context. These constraints may be hard to implement in a single parametric model that regulates the whole entity. By allocating the constraints to the relevant parts of the wall (junctions with other building elements and critical connections to the bounded spaces including openings) we can define the wall as a collection of cooperating entities that can resolve local problems individually (Figure 5).

Fuzzification of architectural representations can be implemented on top of any crisp representation, in practically any implementation environment (i.e. computer-based modelling systems). Adding tolerances to a shape involves a simple augmentation of its definition with just two parameters. These regulate the acceptability of a number of transforms and provide relevant feedback to design actions, e.g. when the shape is dilated or translated beyond its limits. This feedback is appropriately fuzzy, based on degrees of membership; it does not merely signal a violation of the basic constraints.
but indicates the degree of acceptability with reference to the canonical shape and its variations.

The resulting representations have a sketch-like quality in that a form does not have to follow precisely the strokes entered by the designer. Instead, the type and shape of the stroke provide indications of the allowed variation and adaptation around a canonical position. Imperfections in a stroke are accepted not merely as mechanical errors but also as indications of flexibility or uncertainty in the shape or position of the denoted entity. Any interpretation of the solid black lines in Figure 6 cannot fail to return a square and a cross outline, presumably symmetrical, rectangular and rectilinear. The informality of the strokes suggests that the dimensions and position of the shapes have not been precisely finalized yet. The addition of the multiple gray lines can be interpreted in two ways: firstly, as graphic annotation that accentuates the integrity or structure of the shapes, and secondly as an attempt to widen the tolerances concerning shape and size. Similarly, the canonical shape in a fuzzy form represents the initial assumption concerning its overall geometry, while the tolerances express the uncertainty or transformability of this geometry.

3. FUZZY VARIATIONS

The representation of a fuzzy form as a triumvirate of a canonical form and two limits forms the fundament of the proposed approach to fuzzy modelling. However, comparisons with free-hand sketching and investigations of the operation of the principles of local intelligence and autonomy suggest a couple of variations. These derive jointly from computational possibilities and design attitudes towards the definition and manipulation of generic or abstract forms.

3.1. Objects Described by Minimal and Maximal Values

If we dispense with the canonical form, the tolerances define an entity by its minimal and maximal values, i.e. its potential extent as a range of acceptable positions and sizes. The definition of a fuzzy shape $F$ becomes:

$$F = (l, o) \quad (5)$$

Figure 6. Fuzziness in sketching.
The inner and outer limits are no longer constraints on a canonical shape but the minimal and maximal version of the shape (Figure 7). Such a definition implies a greater degree of flexibility or uncertainty, as it diminishes the number of salient features in the shape. Entities defined by a canonical form with tolerances can coexist with entities defined by their minimal and maximal values. Such coexistence may suggest a differentiation of entities in terms of specificity or rigidity.

Fuzzy representations using only minimal and maximal values are analogous to a popular sketch primitive, multiple lines (Figure 8). By describing a form with multiple lines a designer can express clear preferences for the overall geometry of a form without committing to a precise shape or size. This allows room for future elaboration and local perturbations without losing sight of the initial decision and ultimate intentions concerning the form.
3.2. Point Sets

One step further from minimal and maximal values is the complete
discretization of a form and its representation as a point set of particles
which define the boundary of each entity (Figure 9). Each particle of a
boundary is defined as a fuzzy shape with or without a canonical shape,
depending upon the rigidity and related properties of the overall shape. The
behaviour of each particle is semi-autonomous, on the basis of its affinity
with other particles of the same boundary and its spatial relationships to
particles of adjacent boundaries (proximity and composition of
neighbourhood). Such relationships form the basis for the transformation of
the particle model into a continuous geometric model [17].

Point sets represent a departure from the view of fuzzy modelling as a
digital equivalent of sketching or even as a unification of sketching and digital
modelling towards autonomous processes that complement the activities
and decisions of the human designer. The low-level discretization of point
sets reduces the influence of general constraints imposed by the designer
and allows for extensive automated resolution of local problems by
autonomous micro-entities with a limited intelligence. Depending on user
control and particle definition, the possible effects vary from uncontrollable
local perturbations or efficient normalization of local perturbations
(smoothing) to the dissolution of user-defined entities or the formation of
new entities on the basis of relations between user-defined entities.

4. AUTONOMOUS OPERATIONS
IN FUZZY MODELS

Fuzzy modelling reinforces and facilitates the autonomy of entities and the
consequent automated resolution of local problems without requiring
interventions by the designer who nevertheless retains control. The first
stage of local intelligence and autonomy concerns the self-regulatory adaptation of a form. In its simplest form this adaptation is a uniform transform of the canonical shape within the defined tolerances: the form can translate, rotate, reflect, dilate or shrink at will (in response to intrinsic requirements or contextual conditions) so long as all parts of the shape or at least its salient features remain within the defined tolerance zones (Figure 10). For example, a use space in an office building can adapt itself to quantitative requirements of activities it should accommodate by increasing or decreasing its size. Similarly, changes in the overall form of the office building or in the arrangement of circulation could trigger rotations or reflections of the form of the space so as to ensure the appropriate relations between the spatial arrangement inside the space and e.g. daylighting or pedestrian circulation.

If the constraints relating to the geometry of the canonical shape are relaxed and tolerances attached to salient features like vertices, flexibility increases and allows for controlled deformation. Further relaxation concerns the integrity of the canonical shape, i.e. the number of vertices. The ability to adapt by changing the number of vertices and hence sides and surfaces means that an entity can react to e.g. overlapping conditions and create its own perturbations (Figure 11).

Adaptation with full relaxation of general geometric constraints is the default for fuzzy entities defined by minimal and maximal values if the inner and outer limits are dissimilar. Similarity between the limits provides stronger geometric constraints concerning e.g. the orientation of sides or surfaces. In point sets particles behave in a manner identical to complete shapes with the exception that their transformability is restricted to non-uniform scaling.
as the resulting fuzzy forms are formed by structural and spatial relationships between particles. Autonomous, self-regulatory transformation is triggered by spatial relationships between fuzzy shapes, primarily overlapping. As in analogue sketching, the vagueness of a boundary is instrumental for the resolution of conflicts. In canonical shapes with tolerances we distinguish between three main cases of overlap (always from the perspective of a single shape and in order of magnitude):

- intrusion of the outer zone,
- interruption of the canonical shape and
- intrusion of the inner zone (Figure 12).

Each case triggers a different action. Intrusion of the outer zone can be treated lightly, even if there are several such intrusions. Interruption of the shape is a serious violation, as it challenges the integrity and performance of a design entity. Still, such interruption might be ultimately acceptable, especially if it does not result into a major alteration of the canonical shape. Intrusion of the inner zone is a problem of even higher priority because it concerns not only the canonical form but also its acceptable tolerances, which generally correspond to primary constraints.

The conflict resolution system that determines a form’s autonomous response to such problems relies on criteria derived from the structure of the fuzzy shape, such as the range of fuzziness (a small range indicates low tolerance: a rigid object) and external constraints, such as the character of an element (e.g., use spaces are harder than horizontal circulation spaces and load-bearing elements are harder than infill walls). Put together they determine the plasticity of a fuzzy shape. When shapes with different plasticity degrees overlap, the softer shapes are more easily deformed but...
normally never beyond the minimum indicated by their tolerances. This
minimum should not be equated with the inner limit. Soft shapes may be
translated and deformed beyond that limit, provided that the basic
constraints (usually area and topology) are not violated. When a soft shape
reaches this minimum, the request for adaptation is passed on to the harder
shape in the relationship. If the harder shape cannot be modified to a degree
that satisfies the constraints of the problem, the decision is deferred to the
user who can redefine the situation.

In shapes described by their minimal and maximal values conflicts are
treated in the same way. Lack of a canonical shape and the consequent
unification of the inner and outer zones normally indicate a softer shape.
Therefore, such shapes are generally subject to more deformation. Point
sets behave in an altogether different manner. Each particle attempts to link
itself to similar neighbouring particles. Isolated particles die out and the
remaining ones form groups indicating boundaries using chain coding [18].
Conflicts between these groups are resolved similarly to canonical shapes
with tolerances, with the following differences:

- Canonical shapes for particle groups are produced by skeletonization
  only if the user explicitly requests it.
- If two particles belonging to two different groups overlap fully or
  partially, their first reaction is to retreat towards the centroid of
  their own group.
- The plasticity of a group varies along the boundary depending upon
  the width of its cross-section (measured in number of particles).

A final aspect of local intelligence and autonomy is the filling-in of leftover
space. The informal character of sketching means that space between

Figure 12: Overlap cases:
- Interruption of the canonical form (left).
- Intrusion of the inner zone (top).
- Intrusion of the outer zone (right).
entities can be left vacant. Also the outline of a floor plan is frequently
vaguely defined. Soft shapes, such as horizontal circulation spaces, attempt to
fill in the leftover space, especially if its dimensions are small. This may
compensate for losses that occur due to conflicts with harder shapes. The
normalization of the outline by filling in deep concavities is a matter of
choice by the user who decides if this may be attempted and to what extent.

5. DESIGNING WITH FUZZY FORMS

Experimental prototypes of fuzzy modelling have been developed as add-ons
to commercial modelling systems with as primary aim not the transition
from fuzzy to crisp, e.g. from sketches to 3D models [19], but to retain a
useful degree of flexibility in the representation of and interaction with
architectural entities. The development of these prototypes involved on the
one hand the interpretation of existing representations and manners of
interaction as fuzzy forms and processes, and on the other the translation
of geometric and spatial constraints into tolerances that define the fuzziness
of an entity.

One class of applications refers to local conditions and problems that
can be resolved automatically on the basis of well-defined principles but at
the same time allow for a great degree of variation and tolerate many
exceptions, for example the precise positioning of load-bearing elements
with respect to separating walls and doors (Figure 13). In these applications
the canonical form is derived from the crisp model, which can be at any
stage of development, from abstract to extremely detailed, and hence can be
part of early design. Fuzzification amounts to the addition of various
tolerances to different (classes of) elements, usually concerning
dimensioning and positioning.

The main difference with parametric and other constraint-propagation
networks is that constraints are expressed not as bilateral or multilateral
relations but as local tolerances leading to a limited degree of intelligence
and autonomy in the behaviour of elements. However, as several tolerances
derive from contextual conditions their definition poses a number of
problems, some of which can be resolved in a generic manner for a whole
class. The positioning tolerances of a separating wall, for instance, depend
also on interfacing, i.e. connections with other elements. Consequently,
tolerances are smaller at the ends of the wall and at junctions with other
walls (Figure 13). Similarly, the positioning tolerances of exterior walls are
smaller on the external side due to building regulations and formal
considerations.

While such problems can be resolved through fuzzification, fuzzy
modelling is no replacement of global constraints and related schemata such
as the grid of load-bearing elements. Its applicability is limited to the
expression of local tolerances that do not affect major design decisions. The
autonomous behaviour of fuzzy entities is largely restricted to spatial
conflict resolution. Autonomous operations make minor adjustments which
are often imperceptible but nevertheless ensure proper solutions to minor problems, e.g. a slight translation of a column so as to accommodate the positioning of a wider door. However, moving the column beyond these tolerances involves changes to a global schema that are beyond the capacities of a fuzzy form. In this class of applications fuzzification does not replace general constraint propagation networks but reduces the complexity of such networks by integrating object-centred constraints in the representation and behaviour of design elements.

Being object-centred fuzzification may stimulate small opportunistic perturbations. Such perturbations concern not only the shape of soft elements but can also affect the configuration of rigid entities, for example the grid of load-bearing elements. The aforementioned translation of a column by a few centimetres may provide the physical space necessary for appropriate interfacing with other elements without reducing the integrity of the overall structure but may also reduce the consistency of the structure’s geometry, resulting into too much variation in e.g. the connections between posts and beams in a concrete construction.

Another class of applications focuses on the exploration of alternatives and variations. The plasticity and flexibility of fuzzy representations matches key requirements of early design in a way similar to freehand sketching while...
simultaneously allowing for a more precise specification of entities and hence facilitating design analysis and feedback. In the example of Figure 14 and Figure 16 a schematic floor plan comprising several use spaces, a corridor and a staircase is represented by fuzzy forms with different tolerances derived from the designer’s intentions for each element. The staircase has a rather specific form and hence has the lowest plasticity. In the variation of Figure 14 the use spaces take priority over the corridor, as indicated by the presence of canonical forms in the former. In the version depicted in Figure 16 it is the corridor that is assigned a canonical space so as to preserve its form.

The purpose of fuzzy modelling in such applications is not the transformation of a vague representation into a crisp model but to allow the designer to work within the constrained uncertainty allowed by the tolerances of each form. Solutions automatically generated by the conflict resolution system (Figure 15 and Figure 17) are merely illustrations of the consequences of design decisions and serve more as feedback than as departure for a following design stage. The emphasis remains on interaction with design entities and the unobtrusive yet transparent resolution of local conflicts. This may involve morphological considerations but these are normally more evident at a higher level of specificity, i.e. at later design stages.

Figure 14. Fuzzy schematic floor plan.
Figure 15. Automatically generated solution for Figure 14.

Figure 16. Variation of Figure 14.
Probably the most interesting user feedback in early design applications is the request for fuzzy representations of spatial fusions, e.g. overlaps between two spaces. In the example of Figure 15 and Figure 17 the conflict resolution system assumed that either the corridor or a use space should dominate but the designer preferred to preserve both forms (by making visible the posts and beams of the load-bearing structure) and permit a partial overlap that would also facilitate orientation and pedestrian circulation in the building. This suggestion represents a new direction for fuzzy modelling that remains to be tested: fuzzification of spatial relationships, including the possibility of emergence.

A third application area concerns complex 3D forms. As with two-dimensional representations, fuzzy modelling focuses on design interaction with such forms. Fuzzification normally refers to the features of a form, e.g. the vertices of a 3D mesh (Figure 18, Figure 19 and Figure 20), rather
than the form as a whole. The tolerances around each feature are local
derissions of general constraints, for example concerning stability or cost,
and provide transparent indication of the allowable geometric transforms
and of their extent.

While this approach matches the requirements of the constrained
interactive development of amorphous structures, local perturbations
resulting from the object-centred character of fuzzy modelling may weaken
the coherence of complex 3D forms with a strict mathematical definition.
Moreover, tolerances in such forms can be expressed directly and explicitly
in the parameters of the underlying expressions. Consequently, forms that
can be described by succinct mathematical expressions are considered to
be beyond the scope of the fuzzy modelling described here.

Complex 3D forms make problems concerning the integrity of a fuzzy
form more evident: when does a form lose the right to exist? What are the
consequences of its demise for the design? As discussed in the previous
section, intrusion of the inner zone may go beyond the tolerances of the
shape and (depending on the degree of adaptation) deform the shape in a way that contradicts the intentions behind it. From this viewpoint, the integrity of an entity is practically always a matter of semantics. Some of it can be integrated in the definition of fuzzy forms, e.g. how thin or short a wall can become under interference from a column. In other cases it is a matter of human decision and relates to issues underlying geometric representation, sometimes in an implicit way. For example, do holes in a complex surface alter its static performance? Judging from the experimental prototypes developed so far, such questions require either a human decision or extensive constraint propagation networks at multiple levels of abstraction. Such networks are difficult to develop and maintain, and they lack the creativity that is inherent to human decision-taking.

6. CONCLUSION

The crispness and determinism of current modelling techniques makes digital models mostly appropriate for the registration, documentation and presentation of (almost) finished designs. Consequently it is frequently assumed that early, conceptual design stages are best supported by analogue techniques and media, with the computer playing at best a secondary, support role (e.g. explorations of structural principles). This results into (a) a limited utilization of the representational and information-processing capacities of the computer, and (b) a gap between early and late design stages, which inevitably involves misinterpretations, omissions and other transition errors.

The fuzzification of crisp forms is a straightforward operation that makes digital shapes more flexible and adaptable merely by expressing degrees of tolerance and uncertainty. Fuzzy models operate in a manner similar to analogue sketches, allowing a mixture of clarity and vagueness, i.e. presenting certain decisions in a specific even if abstract manner and at the same time deferring other decisions to later design stages. As tolerances and constraints are largely inherent in the definition of a fuzzy shape, the design representation is not burdened with extensive constraint propagation networks that tend to be difficult to establish and especially maintain, as in many approaches to parameterization. Instead, fuzzy forms facilitate the resolution of local problems and conflicts on the basis of the principles of local intelligence and autonomy: each form is capable of addressing a number of spatial and relational problems and regulate or adapt itself accordingly.

Fuzzy modelling should be seen as a companion rather than alternative to parametric approaches. It facilitates distinction between local (and hence largely autonomous) and global constraints and provides an implementation for the former with a maintenance cost that (thanks to instantiation) is quite low in comparison to conventional constraint propagation networks. However, it should be stressed that, as fuzzification becomes more local (e.g. focuses on features rather than the whole shape), fuzzy modelling
becomes more complex and loses part of its conceptual simplicity. In terms of applicability fuzzy modelling appears to be better suited to tasks usually beyond the scope of parameterization, like the transfer of sketching to a digital environment, including the processing of such transfers towards variations and alternatives that explore the ideas underlying a sketch.

Feedback to the human designer may be restricted to significant problems only, i.e. problems beyond the scope or capabilities of specialized local knowledge. For example, the designer needs not concern himself with minor adjustments of the position of a door in a wall so as to allow for efficient and safe entry and exit while accommodating different secondary conditions such as the positioning of a wardrobe behind the door. On the other hand, the coincidence of use and circulation spaces in an office building remains a matter for the designer who has to take decisions concerning the type of the office (e.g. cellular versus open plan) and the resulting character and performance of the building.

Another contribution of fuzzy modelling is fluency and continuity in designing: as both fuzzy and crisp models can share the same digital environment and even refer to the same basic geometric information, designers do not have to switch between modelling programs or between analogue and digital representations in the course of a design project. The fuzzy models that register early design decisions also accommodate the progressive development and refinement of a design towards the crisp versions needed for construction. Moreover, as fuzziness can be added to crisp modelling systems, designers can also work with hybrid representations comprising both fuzzy and crisp forms. For the same reason, feedback to earlier design stages may often involve just turning on the (earlier) fuzziness of one or more forms.

References