

# Real Time

Extending the Reach of Computation

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# Gradient-Analysis

## *Method and Software to Compare Different Degrees of Complexity in the Design of Architecture and Designobjects*

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*The aim of the research presented in this paper is to provide an additional method and tool for architects and designers as well as students and scholars to analyze the degree of complexity of a design. Fractal analysis (box counting) e.g. is one of these methods already used in architecture to measure the degree of complexity of an architectural design, for example of the elevation of a building. The method of semi-automated gradient-analysis described here focuses on the repetition of gradients and thus of proportion-repetition in a given design as one of several aspects of complexity reduction by redundancy.*

**Keywords:** *Gradient-Analysis, Design-Complexity, Redundancy, Spatial Analysis, Form and Geometry, Proportion*

### INTRODUCTION

In order to analyze aesthetic quality of architectural design, the complexity of a given architectural object or object arrangement can be measured taking different designaspects into account. The degree of complexity detected applying the same methods and rules to the analysis of two or more objects can be compared to make verifiable statements about this complexity in chosen areas of analysis as a part of the overall aesthetic quality (and/or hypothetical design-strategy that led to the materialization of the object).

Based on the assumption that the complexity of an objects appearance is reduced by redundancy (Cube, 1965), which can be measured focussing on different levels of comparison, the gradient-analysis as described here, attempts to find repetition of pro-

portions in general, regardless of what kind of proportion is repeated. In other words; the number of similar relations between measurements on different scales are in focus, not specific relations (e.g. Wagner, 1981). The reduction of complexity is hereby in itself not a goal, but a means to an end, which may be a balance between complexity and readability of form (on this see also Birkhoff, 1933 and Bense, 1971). To achieve such a balance is the domain of the artist or design-professional and, through feedback processes, of the participating user or customer. Therefore the presented tool may be used as one from a greater palette to aid designaspect-analysis. The integration of such a tool into a responsive CAD system combining different methods of design-analysis, aimed at practicing designers and those learning the trade alike, is a future possibility.

From another angle, looking at the layers of complexity of a design might also be interesting out of a cognitive perspective, where redundancy plays an important role e.g. in the cognitive segmentation of figure and ground, enabling the viewer of an object to distinguish it from its surroundings (Guski, 1996).

The area of comparison chosen in this research is the frequency of repetition of gradients, comparing every significant point with all the other points in a 2D representation of the object one by one, successively listing pairs of points and their gradients (regarding the problem of defining significant lines and therefore also significant points see: Ostwald and Vaughan, 2013). The authors do not distinguish between the relation of points that are connected by material edges and those which are not. Points are solely chosen as clearly identifiable references (such as corners or intersections of lines). The authors assume that Gestalt perception does not necessarily require edges, merely possible visual connection suffices. Consequently in a first step the relation between every single point without differentiation is

analyzed. A next step in this research will include the issue of further perceptual relations. A repetition of a gradient is interpreted as an indication of complexity-reduction by redundancy of the objects design as a whole.

## DEVELOPING THE SOFTWARE

The gradient-analysis tool is a makro programmed in AutoCAD resp. BricsCAD using Visual Basic for Applications (VBA) and allows for applying the method. It has been developed in two separate versions (resp. algorithms), one by each author. This approach allowed questions concerning data format, collection of significant points, data refinement, mathematical limitations and other factors of significance for the software and underlying method to arise quickly and thus fueled a fruitful discussion.

The gradient-analysis tool attempts to enable verifiable statements about complexity; by comparing the relation of vertical to horizontal distances measured inbetween all the significant points of a given objects representation in 2D one could also say

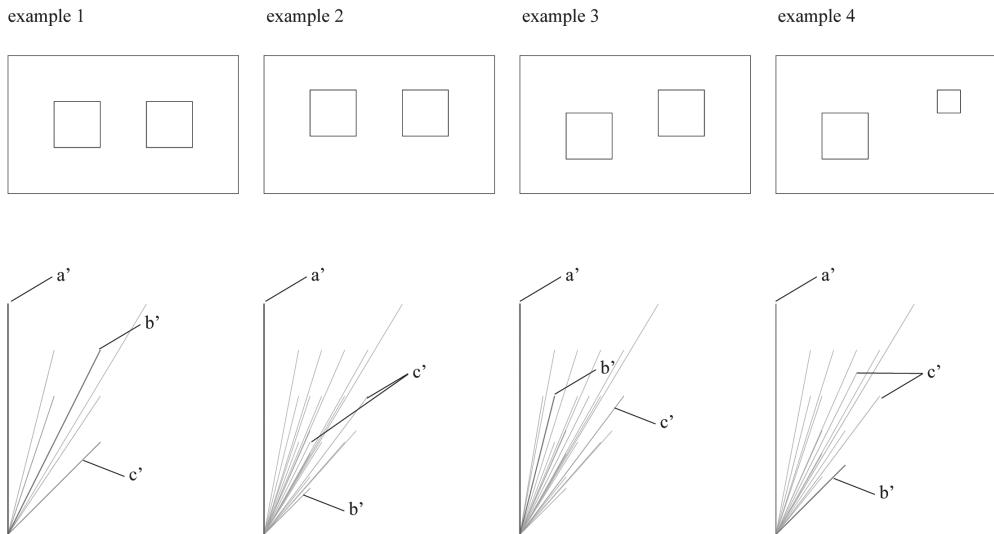


Figure 1  
First analysis of simple elevations with successively increasing proportion-complexity (a=red ... most repetitions, b ... second most repetitions, c ... third most repetitions)

the degree of proportion-complexity is measured, i.e. the number of proportions that are repeated and how often these proportions are repeated, in this case, proportions of rectangles that are enclosed by edges as well as those that are solely defined by two opposing corner points.

### Testcase Selection

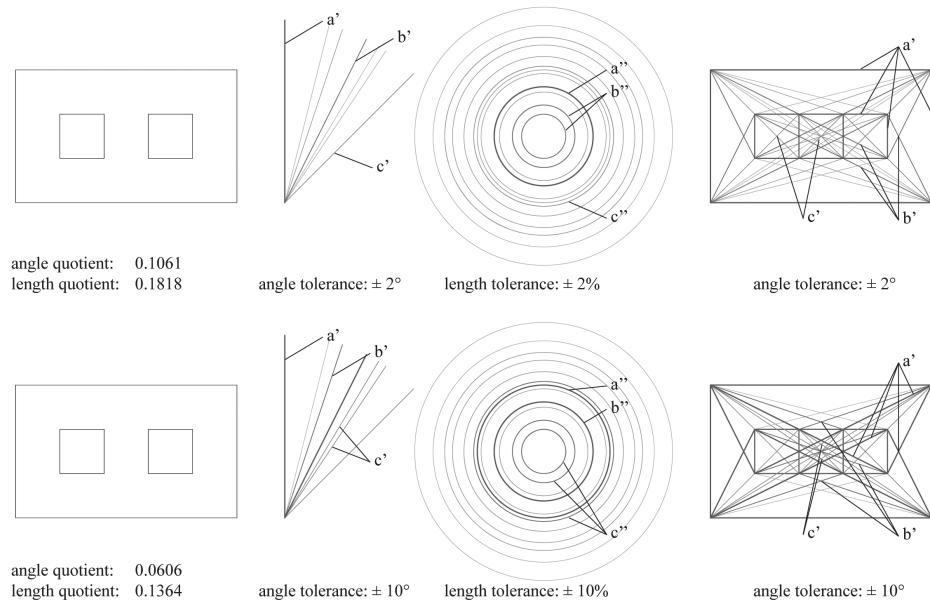
For the first experiments a simple and artificially to the purpose designed façade-like 2D object with arranged proportions overall and then successively up-graded entropie has been used (figure 1).

Angles are measured as diagonals of the virtual reference rectangle from lower left to upper right corner. They are then represented as a bundle of lines, in figure 1 underneath the scrutinized objects. Lower angles than 45° are mirrored over the 45° angle to compare all angles as diagonals of standing up rectangles. The different colors of the angle-

representations signify the number of repetitions. Starting with red for the angles repeated most, then yellow, green, blue for successively lesser numbers and finally grey, to signify the lowest number of repetitions.

These first gradient-analyses made repetitions of proportions visible and showed that the chosen abstraction might be a useful representation of decreasing proportion-redundancy in correlation with increasing complexity of form distances and measurements. In a next step the output was refined (figure 2); the representation of angles and distances was separated, an angle-redundancy and distance-redundancy quotient (also referred to as length quotient), allowing different margins of error (see also Wiemer and Wetzel, 1994), automatically calculated and an additional graphic output of detected connections between points within the element under scrutiny generated.

Figure 2  
Succeeding analysis  
of simple elevation  
using different  
margins of error  
(a=red ... most  
repetitions, b ...  
second most  
repetitions, c ...  
third most  
repetitions)



In figure 2 the image on the left shows the object itself, followed by the representation of angles as bundles of lines. In contrast to figure 1 the lengths of the lines are now normalized, since only their orientation is looked at. The third image shows the different distances between points, regardless of the orientation of a connecting line, with the same coloring of repetition as used for angles: Starting with red (in figures marked as *a*) for the most repetitions and ending with grey for the smallest number. The last image finally represents the repetition of angles in the original object preserving the length and using the coloring of the second image of normalized angles.

The angle-redundancy quotient ( $R_\alpha$ ) is calculated by the number of different angles ( $C_r$ ,  $r$ : all repetitions) divided by the total number of angles ( $C$ ; see formula 1 and 2), i.e. the number of every possible connection of points.

$$R_\alpha = \frac{C_r}{C} \quad (1)$$

$$C = \left( n \cdot \frac{n-1}{2} \right) \Leftrightarrow \quad (2)$$

$$C = n! \cdot \frac{1}{k! \cdot (n-k)!} \quad (3)$$

(with  $k=2$  and  $n$  = all single connections)

This is also true for the distance-redundancy quotient. A tolerance coefficient takes into account that angles that differ only very little may be perceived as similar and/or that the drawing of the object may not be accurate (see also 'Setting the Margin of Error' presented later in the paper). E.g. for a tolerance coefficient of  $+/- 0.1^\circ$  all angles inside this range are counted as a repetition of this same angle. In future work statistic interpretation of the tolerance coefficient will be given further thought. In this stage of the research, the current number of test-cases is too low to provide significance in this regard.

### **Aims of Result Representation**

Since the representations of the analysis have potentially different recipients and user-contexts, allowing the output to adopt different forms seemed useful. Which output might be applied in specific cases has to be decided accordingly.

To enable the design-professional to make an informed decision on possible design-alteration of a work in progress, a combination of separate angle- and/or distance-representation with summarizing numerical output may be sufficient, while a proportion analysis of historic buildings could call for the additional output of connections (and even distance-representing circles) within the element, as well as the listing of all angles and distances in an Excel sheet. The latter should only be undertaken using the tool with the precondition that such an analysis is accompanied by further historical and other contextual information. The problem of individual interpretation and focus on certain parts of data can of course not be solved by software.

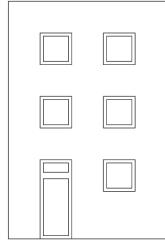
As part of an evaluation process in an evolutionary algorithm for proportional optimization, the provision of data to be used to define a fitness-value may be wished for, calling for the numerical output in summary, utilizing the angle- and distance-redundancy quotients.

### **LIMITATIONS OF UNDERLYING DATA AND DATA ANALYSIS**

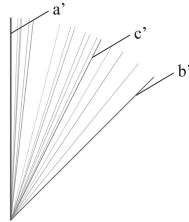
In general the system shouldn't be asked to give conclusive answers considering design-quality or -value as a whole. It will not enable its user to verify speculations on specific thoughts of a designer or be of help proving assumptions about which particular proportion is especially aesthetically pleasing to people in general. Its purpose is rather to give clues in addition to other methods of analysis and to generate hypotheses; e.g. concerning the cognitive effort it may take to read a design in correlation to its complexity and by which geometric alteration this effort could possibly be reduced - if this seems necessary or desirable.

Figure 3  
 Analysis of an elevation  
 composed of more  
 elements, using  
 different margins of  
 error (a=red ... most  
 repetitions, b ...  
 second most  
 repetitions, c ...  
 third most  
 repetitions)

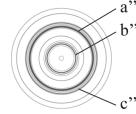
Testcases multistorey building 01 - main with windows (with the 10 most repetitions)



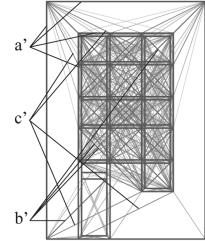
angle quotient: 0.1532  
 length quotient: 0.1857  
 angle quotient: 0.1026  
 length quotient: 0.1675



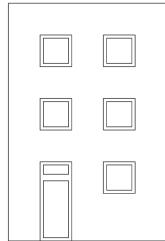
angle tolerance:  $\pm 0^\circ$



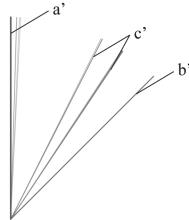
length tolerance:  $\pm 0\%$



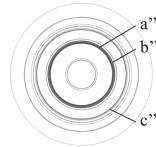
angle tolerance:  $\pm 0^\circ$



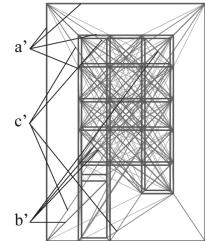
angle quotient: 0.0312  
 length quotient: 0.1026



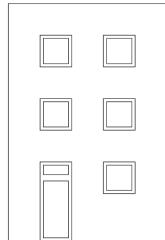
angle tolerance:  $\pm 0.5^\circ$



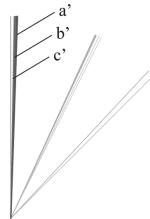
length tolerance:  $\pm 0.5\%$



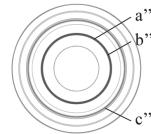
angle tolerance:  $\pm 0.5^\circ$



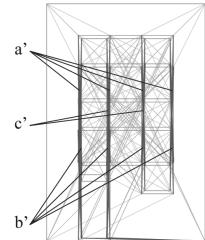
angle quotient: 0.0084  
 length quotient: 0.0416



angle tolerance:  $\pm 2^\circ$

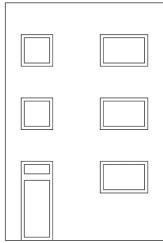


length tolerance:  $\pm 2\%$

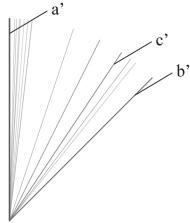


angle tolerance:  $\pm 2^\circ$

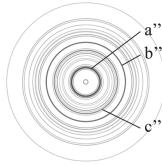
Testcases multistorey building 03 - main with windows (with the 10 most repetitions)



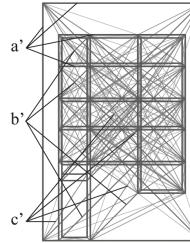
angle quotient: 0.2026  
 length quotient: 0.2422  
 angle quotient: 0.1149  
 length quotient: 0.2006



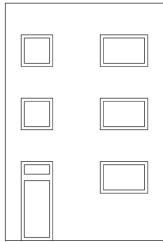
angle tolerance:  $\pm 0^\circ$   
 angle tolerance:  $\pm 0.1^\circ$



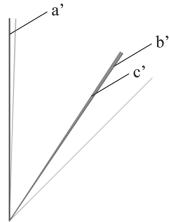
length tolerance:  $\pm 0\%$   
 length tolerance:  $\pm 0.1\%$



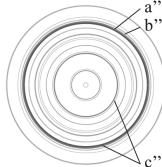
angle tolerance:  $\pm 0^\circ$   
 angle tolerance:  $\pm 0.1^\circ$



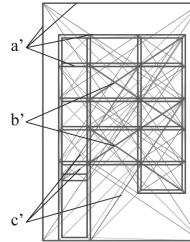
angle quotient: 0.0305  
 length quotient: 0.1052



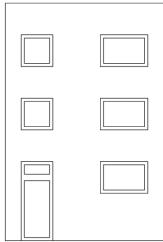
angle tolerance:  $\pm 0.5^\circ$



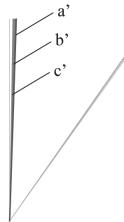
length tolerance:  $\pm 0.5\%$



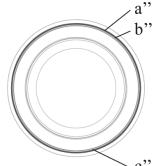
angle tolerance:  $\pm 0.5^\circ$



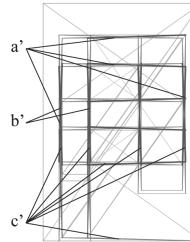
angle quotient: 0.0078  
 length quotient: 0.0422



angle tolerance:  $\pm 2^\circ$



length tolerance:  $\pm 2\%$



angle tolerance:  $\pm 2^\circ$

Figure 4  
 Analysis of an alteration of the elevation in figure 3, using different margins of error (a=red ... most repetitions, b ... second most repetitions, c ... third most repetitions)

### **Setting the Margin of Error**

As Wiemer and Wetzel (Wiemer and Wetzel, 1994) pointed out (and lately Ostwald and Vaughan, 2013), building CAD-data is often flawed e.g. because of less than ideal execution or simply because of necessary compromises regarding abstract representation. This makes it necessary to allow a margin of error in comparing values extracted from a CAD drawing. As well as the decision about the degree of detail and selection of the elements to be analyzed, the extent of the margin of error influences the outcome a great deal. These configurations and the motivations that led to their choosing should always be made transparent; using a successive rise of the margin of error and regarding the resulting output-series as a whole is therefore advisable.

### **APPLICATION OF THE METHOD USING DIFFERENT FACADES**

For further testing a second artificially to the purpose designed multi-storey elevation with more openings has been used (figures 3 and 4). This time also representations for window-frames have been added. In order to represent significant tendencies to repetition more clearly, in figure 3 and 4 only those colors representing the highest 10 levels of angle-repetition are set to visible. As shown in Figure 3 this focuses three main accumulations, using a tolerance of  $+/-2^\circ$ , around  $88^\circ$ ,  $64^\circ$  and  $47^\circ$ ; In contrast to that the example of figure 4, which displays a different elevation layout, only shows two main accumulations for the same tolerance: around  $88^\circ$  and  $54^\circ$ ; consequently the angle-quotient of the example in figure 4 calculated for same tolerance is higher than that of the example in figure 3, which is also true for the other chosen tolerance coefficients in comparison, especially regarding smaller tolerance-values. The complexity of the object in figure 4 is at least slightly higher than in figure 3 regarding the design aspect of proportion. For the moment we must assume that the number of accumulations does not necessarily influence the angle-redundancy quotient, but may constitute an additional information-layer for complexity-analysis.

Regular elements, like sets of staircases, window-frame corners and the like, influence the outcome of the analysis a great deal. These cases, with and without window-frames and/or stairs, should be tested separately and included in any deduction based on a gradient-analysis. In a last series facades from the House Steiner by Adolf Loos have been tested (figures 5 and 6).

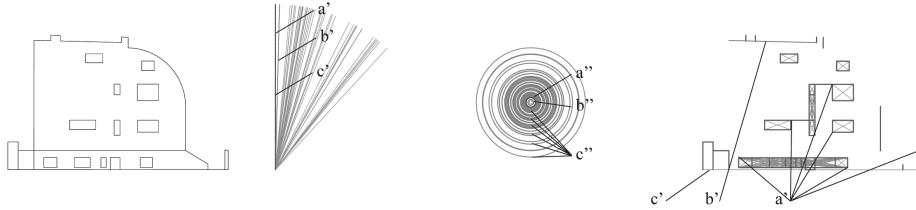
### **CONCLUSION AND OUTLOOK**

The developed software and its underlying method of gradient-analysis may be used to make repetitions of proportions and distances visible in various forms using different outputs for further processing or direct support of an ongoing design. It remains crucial to note: the gradient-analysis is in its core not about a specific proportion (like e.g. the golden section), but about the repetition (and the number of repetitions) of any proportion within a design. Certain proportions thus only become significant for analysis (and possibly cognition by a viewer) because of the number of repetitions within an object under scrutiny by the described method - leaving the aspect of certain special proportions within cultural heritage solely to the users interpretation of the provided data representations.

The described method could be used in education as part of a responsive CAD-system, with the aim of giving feedback on proportional redundancy overall in a given design, being of assistance if a different degree of entropie is wished for regarding its measurement-relations.

Furthermore it will be a subject of future research, to use the method as part of genetic algorithms aiming at generating more balanced designs of building elevations and/or other design objects; the gradient-analysis could be applied in such a process to determine the fitness-value of each successive parent generation.

A. Loos - House Steiner North - main and windows (with the 20 most repetitions)



angle quotient: 0.9269  
length quotient: 0.9623  
angle quotient: 0.0856  
length quotient: 0.3763

angle tolerance:  $\pm 0^\circ$

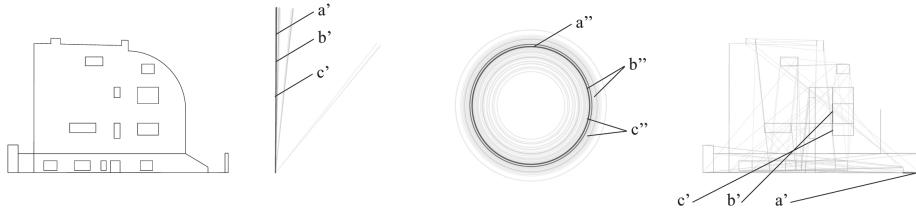
length tolerance:  $\pm 0\%$

angle tolerance:  $\pm 0^\circ$

angle tolerance:  $\pm 0.1^\circ$

length tolerance:  $\pm 0.1\%$

angle tolerance:  $\pm 0.1^\circ$

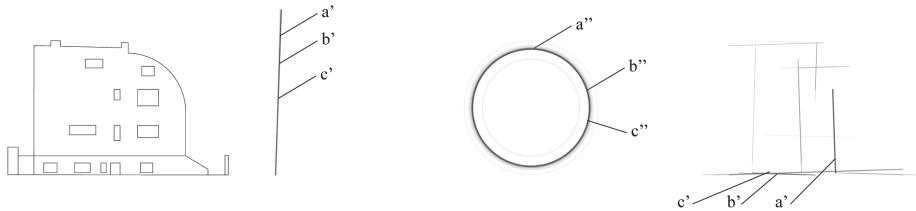


angle quotient: 0.0179  
length quotient: 0.1104

angle tolerance:  $\pm 0.5^\circ$

length tolerance:  $\pm 0.5\%$

angle tolerance:  $\pm 0.5^\circ$



angle quotient: 0.0049  
length quotient: 0.0331

angle tolerance:  $\pm 2^\circ$

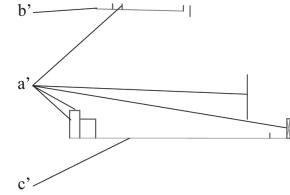
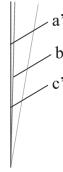
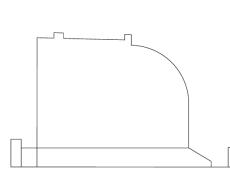
length tolerance:  $\pm 2\%$

angle tolerance:  $\pm 2^\circ$

Figure 5  
Analysis House Steiner, northern elevation. Architect: A. Loos (a=red ... most repetitions, b ... second most repetitions, c ... third most repetitions)

Figure 6  
 Analysis House  
 Steiner, northern  
 elevation, outlines.  
 Architect: A. Loos  
 (a=red ... most  
 repetitions, b ...  
 second most  
 repetitions, c ...  
 third most  
 repetitions)

A. Loos - House Steiner North - main (with the 20 most repetitions)

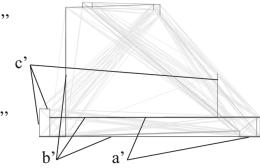
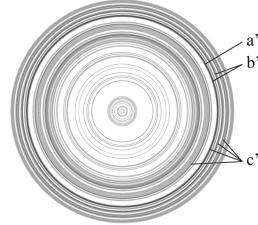
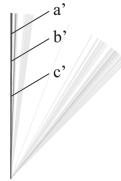
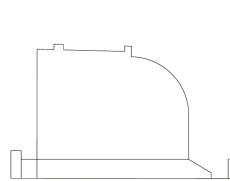


angle quotient: 0.9200  
 length quotient: 0.9900  
 angle quotient: 0.4633  
 length quotient: 0.7767

angle tolerance:  $\pm 0^\circ$   
 angle tolerance:  $\pm 0.1^\circ$

length tolerance:  $\pm 0\%$   
 length tolerance:  $\pm 0.1\%$

angle tolerance:  $\pm 0^\circ$   
 angle tolerance:  $\pm 0.1^\circ$

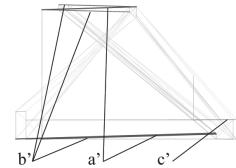
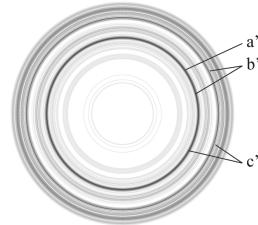
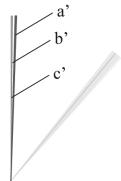
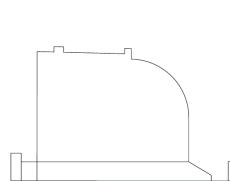


angle quotient: 0.1533  
 length quotient: 0.4333

angle tolerance:  $\pm 0.5^\circ$

length tolerance:  $\pm 0.5\%$

angle tolerance:  $\pm 0.5^\circ$



angle quotient: 0.0433  
 length quotient: 0.2200

angle tolerance:  $\pm 2^\circ$

length tolerance:  $\pm 2\%$

angle tolerance:  $\pm 2^\circ$

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