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Daniele Villa · Franca Zuccoli
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Preface

For those who work in the field of education and professional development, a key figure in relation to the theme of image is John Amos Comenius (1592–1670), known as Iohannes Amos Comenius in Latin and Jan Amos Komenský in his native Czech. An eclectic character, Comenius was a philosopher, educationalist, theologian, and educator. He is considered to be the father of didactics because he concerned himself with the overall design of the human educational trajectory across the lifespan. Comenius believed that schools should be open to all: places where anything could be taught to anybody/by anyone, albeit via tailored offerings and methods [1] (Comenius 1658). His Orbis sensualium pictus (1658) was the first textbook to include pictures, which dominated over the written text. Here, he made targeted and intentional use of images, chosen with a view to fostering knowledge and learning in children [2] (Comenius 1658). Roberto Farné includes Comenius' approach in his rich overview of the diverse uses of images in the field of education, which he calls "didactic iconology"; explicitly drawing on the work of Erwin Panosfky (1939) [3], he defines this perspective as "[…] the study of images for educational purposes or, more narrowly, for the purposes of schooling. The term 'image' is the common denominator in an extremely broad and diversified range of visual and audio-visual repertoires, which primarily act as media and whose "iconic dimension" is key to the educational communication they are deployed for" [4] (Farné 2002, p. VIII). Since Comenius' day, despite encountering a host of difficulties and at times serious obstacles, images have become part of the world of school, and a crucial element of the teaching–learning process, during which they may be variously consumed, interpreted, produced, and manipulated. Images enhance all educational trajectories, from early years education with children as young as 0–3 years to university and educational and professional development research settings. Scholarly interest in the educational use of image and images themselves as a primary source of knowledge has inspired ongoing debates and processes of inquiry [5,6,7] (Calvani 2011); to be more specific, within the constantly evolving impact of the sphere of image on the world, substantial differences remain between those who understand images to be decorative rather than laden with meaning, and even at risk of distracting us from the sphere of words and numbers, and those who engage with images in all their possible forms. We should note here in passing that the iconic sphere underpins the visual thinking paradigm that was early theorized by Rudolf Arnheim, and whose enormous potential has been coming progressively to the fore [8]. Sometimes educational theory and practice still struggle to draw creatively from the multifaceted potential of constantly evolving and shifting representations and images. However, the suspension of in-person teaching and learning due to the COVID-19 health emergency and the announcement of a global pandemic by WHO (March 12, 2020) forced all forms of education to switch to distance-learning modes that involved exploiting digital instruments to the full. In this case, the world of images not only represented an aid to teaching and learning but also became the very place of possible educational encounter. Consequently, the use of images in education accelerated at a speed that would otherwise have been unthinkable [9]. The lessons that COVID has taught us, as Edgar Morin has aptly described this painful trajectory, can and must be transformed into challenges [10], which educational research and professional development must embrace and not overlook. Within the process of transformation that is currently underway, images—understood in plural and complex terms—must count among the foundational components of an alternative paradigm in which mindfulness, creativity, and openness in interpretation and production will all be essential characteristics. This conference, the first to take place as a physical encounter following a long hiatus, ably, and fully exploits the meeting of different disciplines that bring different understandings to bear upon images and use them for different purposes [11]. It is a point of interdisciplinary encounter, of enrichment and debate, and of real learning about other areas of knowledge in which images have become indispensable; it explores a shared pathway that we should never tire of pursuing.

Franca Zuccoli
Daniele Villa

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Contents

When the Artifact Becomes Image: Representing Geometrical Query with Tangible Tools. Catalogues Physical Models at the Turn of 1900

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Abstract. Traditionally, communication in mathematics passes through symbolic representations and visual ones, whether they are images, models or other artifacts, both in the theoretical speculation phase and in the transmission of knowledge with educational and disseminative aims. This dichotomy of representations has its roots in the epistemology of the discipline. In the European context, during the second half of the 19th century, a set of Catalogues of models for the study of geometry born. The contribution analyses their structures based on visual operations of a mathematical nature, with an indisputable aesthetic content, realized following the developments of mathematics at that time and the foundational studies by Monge, which explicitly identified the educational use of models for the geometry of surfaces. Catalogues are therefore tools for the promotion of visual artifacts of great impact, designed for the materialization of complex mathematical queries. Therefore, we propose a critical analysis of the images used in such Catalogues, of the modalities of model interpretation and of the possible repercussions in the current context of interdisciplinary studies.

Keywords: Representation, Geometry, Algebraic Surfaces, Didactic, Models.

1 Introduction

The production of tangible models of mathematical objects, in particular of algebraic surfaces, was a cultural phenomenon which had its golden age between the second half of the 19th century and the beginning of the 20th century, involving in particular European universities and polytechnics in France, Germany and Great Britain [1], creating fruitful interactions between research and teaching, not only with regards to mathematical sciences. The spread of models was supported by the preparation of Catalogues born from the scientific collaboration between eminent mathematicians and publisher, [2].

Today, these Catalogues represent a cultural heritage, because they propose a systematization of knowledge linked to production and dissemination of models, according to the critical thinking of their time. In fact, they summarize the useful data for professionals to immediately identify the model of their interest through few elements and, only occasionally, a descriptive image. Connections between the practical needs of Catalogues, the synthetic characteristics of models, their iconic images and the mathematical language, both written and visual, characterize their structure to the point of being a distinctive element.

2 Critical reading of some Catalogues of models

An analysis of these works, focused on socio-scientific context and visual culture, leads to a critical reading of them as a medium for communication/sharing of mathematical results with an implication on mathematical visual thinking [3], when investigating the connections between written images and drawn words.Nonetheless, they inspire a look towards the real object, between physical and digital collections such as, for example, the collection of the Biblioteca G. Peano of the University of Torino and a more recent production by the Authors, focused on models for understanding the architectural shape [4] (Fig. 1). Thus, within an interdisciplinary approach it is possible to observe the evolution of the narrative sequence, over time and intentions, to identify their semantic values while respecting the different communicative registers. So, some of these Catalogues (also accessible online) are analysed in chronological order, thus studying them not only as such [7], but also as a corpus of images of models and investigating their semantic and synthetic values.

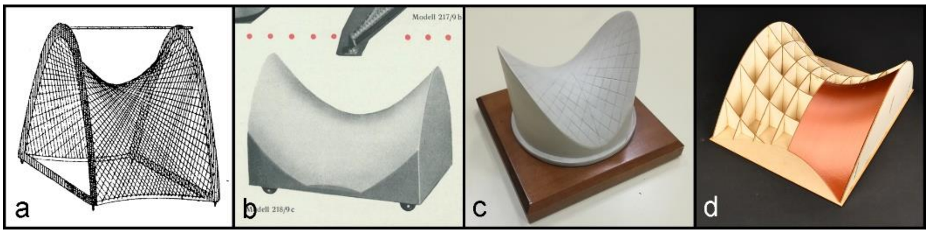

Fig. 1. Different hyperbolic paraboloids: **a)** [5] p. 260 fig. 4; **b)** [6] p. 105; **c)** Biblioteca Peano Collection; **d)** Authors' 2020.

2.1 1872, A catalogue of a collection of models of ruled surfaces…

The Catalogue [8] presents 45 models built by F. de Lagrange and an appendix on the study and classification of ruled surfaces written by C.W. Merrifield, rector of the Royal School of Naval Architecture and Maritime Engineering. Models represent ruled surfaces, introduced by the synthetic description typical of descriptive geometry as generated by the movement of a straight line in space. Given their great interest in the geometry of industrial arts, the choice of this type of surface is explained in the curator's introduction. The same happens for rotation surfaces (related to lathe work), in fact the author states that, from this point of view, the most important surfaces are plane, cylinder and right cone, ruled helicoid (common screw) which belong to both types of surfaces. These models are dynamic and made of silk wires, moreover their shape can be changed by moving their metal structure so as to illustrate a great variety of configurations. The author also underlines their fragility [8, p. 3], as well as the imperfect correspondence to the geometric rigor of the surfaces to which they refer.

The first two illustrations of the book show that string surfaces have a level of approximation equivalent to that of a dashed curve or an envelope of straight lines used to describe a curve (Fig. 2a, b). To reinforce the concept, the author inserts a direct reference to two models, hyperbolic paraboloid and cylinder with helix and developable helicoid (Fig. 2c, d) which exploit the same approach illustrated in Fig. 2b. The Catalogue contains only 5 images: 2 in the introduction, 3 in the appendix and none in the detailed descriptions of models. 12 photographs of artifacts preserved at the naval museum in South Kensington complement the publication but were probably added later. Each model is described in the Catalogue via construction method, dynamism, some specific geometric property, and possible/essential architectural and engineering applications. Also, a summary of the reference bibliographical sources is inserted,which includes Monge, Bradley, Leroy, to integrate everything that is not expressly described in the Catalogue, [8, p. 4].

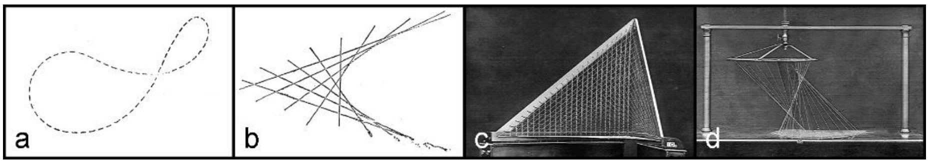

Fig. 2. Examples from [8]: **a)** p. 3 fig. 1; **b)** p. 3 fig. 2; **c)** Table III; **d)** Table VI.

2.2 1892, Katalog Mathematischer und mathematisch-physikalischer Modelle, Apparate und Instrumente

The Catalogue [5] is the result of a series of preparatory operations in order to create an exhibition of models planned for 1892. Similarly to the current situation, in which the COVID-19 pandemic has forced us to question teaching and research methods, on that occasion the epidemic situation in Germany caused the cancellation of what had been planned and favoured the publication of the Catalogue. Here, the German Mathematical Union leaded by W. Dyck provided a fundamental contribution. In fact, many mathematical, physical, technical-mechanical, and geodetic institutes of German universities were involved, framing themselves in wider network, with contributions from Great Britain, France, Italy, the Netherlands, Norway, Austria-Hungary, Russia, Switzerland and America [5, pp. III-VI]. In the foreword, the Catalogue curator introduces its contents, starting from the analysis of its structure: a series of essays with a synthetic content - by his colleagues such as Klein, Voss, Brill, Hauck, Braunmühl, Boltzmann, Amsler, Henrici - precedes the «exact description» complete with «numerous illustrations» of the individual models ranging from arithmetic, algebra, function theory and integral calculus, geometry, mechanics, mathematics, physics and various technical applications such as geodetic and nautical ones. Dyck underlines the growing interest in these disciplines and the consequent evolution of aids useful for their teaching and more, since «the aims of teaching are expressed alongside those of research». Not all the introductory scientific essays make use of graphic descriptions, nonetheless it is to observe that the representations within F. Klein's paper propose examples with the declared purpose of facilitating geometric intuition, even if they deal with problems such as counting the real roots of an algebraic equation from a general point of view and with highly specialized language (Fig. 3).

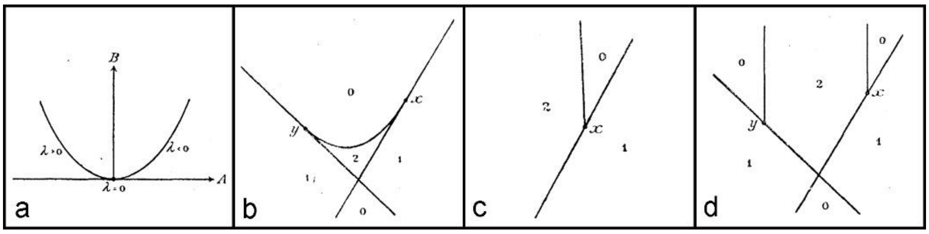

Fig. 3. Counting roots of an algebraic equation [5]: **a)** p. 5 fig. 1; **b)** p. 11 fig. 3; **c)** p. 12 fig. 5; **d)** p. 13 fig. 6.

A. Brill emphasizes the metamorphosis of the role of drawing supporting mathematical investigation, stating that the use of images may be superfluous in the development of the general theory of projective curves, but it regains importance in the study of real curves (with specific properties). Brill is also the author of many of the models represented in the second section - see for example the models in Fig. 4 which will later become the backbone of Schilling's catalogues, analysed in detail in [3]. In his essay he inserts drawings made by a student of mathematics at the technical University of Munich [5, p. 34] that make use of a deliberately essential graphic language but enriched with textual information such as to make it effective for aware users. This language is completely different from the one used in the Catalogue where artifact images are not descriptive but iconic, opening to possibly unspecialized users (Fig. 5).

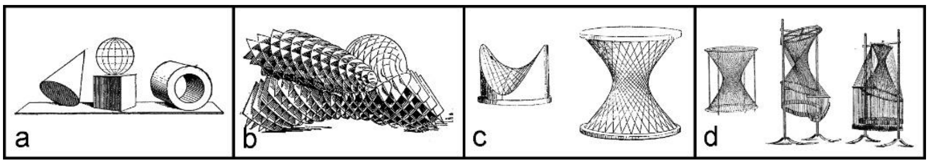

Fig. 4. Models for basic lectures on trigonometry, planar, solid and descriptive geometry [5]: **a)** p. 245c Obj. 127; **b)** p. 258c Obj. 155; **c)** p. 259c Obj. 156; **d)** p. 259c Obj. 157, figg. 1-3.

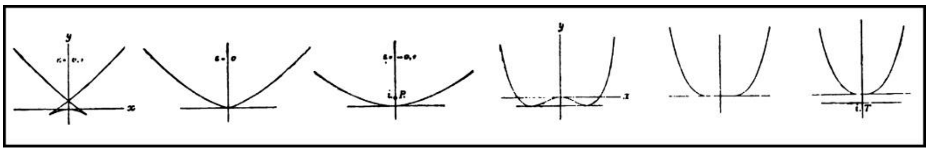

Fig. 5. Singularities of algebraic curves from [5]: p. 36.

The contribution makes use of graphic descriptions to support textual narration for the visualization of constructions for teaching Geometry (Fig. 6): they allow the reader to easily follow the thread of speech because they highlight the single passage using a dedicated type of line, independently from the graphic conventions: in fact, they don't give any line a semantic value and make the single images of dubious interpretation if detached from the text.

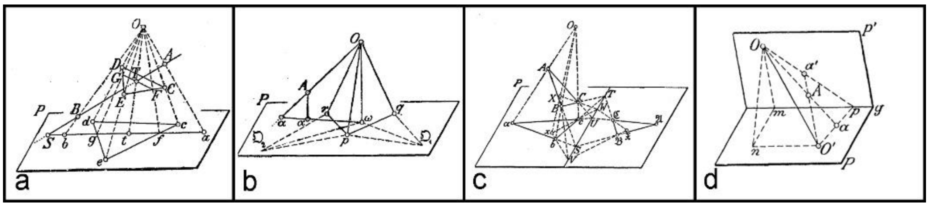

Fig. 6. Constructive postulates of Euclidean and modern geometry from [5]: **a)** p. 45 fig. 2; **b)** p. 46 fig. 3; **c)** p. 47 fig. 4; **d)** p. 51 fig. 5.

A. Braunmühl reports on machines for mechanical generation of curves, from antiquity to the end of the 18th century. He highlights practical and reproduction limits of such tools [5, p. 56] and Descartes' fundamental role in describing all plane curves as a result of the movement of a point and in observing that every movement of a point in the plane can be produced by instruments [5, p. 67] (Fig. 7).

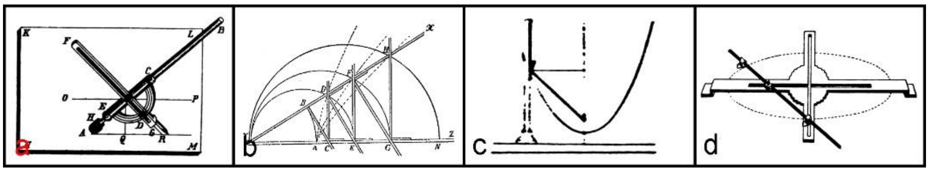

Fig. 7. Generation of curves [5]: **a)** p. 65 fig. 6; **b)** p. 67 fig. 8; **c)** p. 70 fig. 13; **d)** p. 70 fig. 14.

In the Catalogue section, model presentations are enriched with heterogeneous, synthetic or descriptive information, rarely supplemented by images of small dimensions, usually without precise captions. In machines description, whether they are for drawing or computing, the representation is enriched with expedients for sizing the artifact, a fundamental element to show its functioning [9] (Fig. 8). On the other hand, the models of algebraic surfaces are graphically described with a specific language to make their geometric properties recognizable. To do so, surface infinite theoretical model is truncated; this is made explicit with a hatched borrowed from technical drawing and shows the limit of representation.

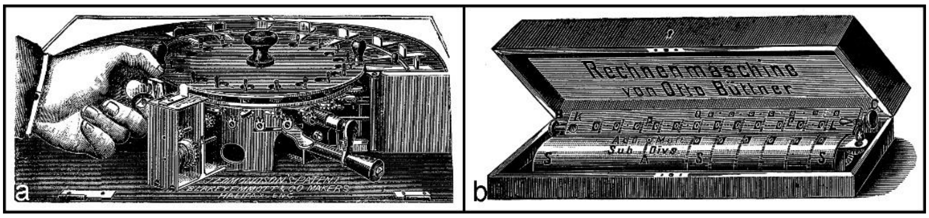

Fig. 8. Tools for computing [5]: **a)** p. 151 Obj. 33; **b)** p. 151 Obj. 35.

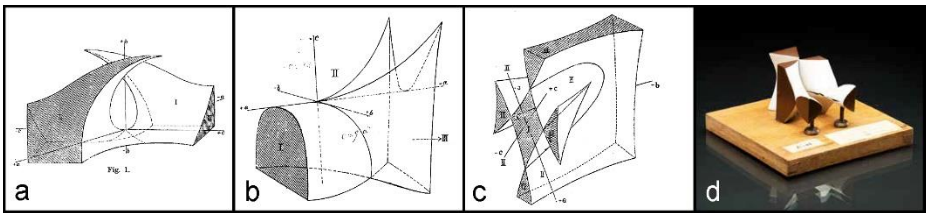

Fig. 9. Models and drawings for the study of algebraic surfaces [5]: **a)** p. 169 fig. 1; **b)** p. 171 fig. 2; **c)** p. 173 fig. 3. [10] physical model from the Museum Universität Tübingen: **d)** p. 9 fig. 181.

Fig. 9 shows a comparison with a physical model from the MUT Tübingen collection and makes this fact explicit [see 11]. Fig. 10 illustrates tools and methods for the perspective representation of simple architectural volumes: the author uses a technical language and makes use of the relationship between texts and images, with the insertion of capital letters for identifying points, to make the contents accessible to more users in the dual intention: visualizing the geometric problem that can be solved with the use of a drawing machine, associating technical terms and graphic representations.

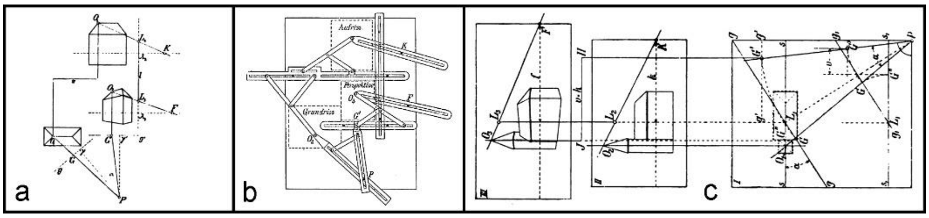

Fig. 10. Geometry [5]: **a)** p. 235 fig. 1; **b)** p. 235 fig. 2; **c)** p. 238 fig. 3.

2.3 1907, Abhandlungen zur Sammlung mathematischer Modelle

The purpose of this Catalogue [12] is to provide lessons of mathematics with a set of models suitable to strengthen the ability to see through their simplicity and clarity and to spread the knowledge of geometric shapes through a variety of choices. Among all the presented material subjects considered elementary appear, such as the Platonic solids, which however the author studies from an algebraic point of view, using the language of group theory; he states that regular polyhedra are important material not only for elementary teaching or for the study of shadows, but also in the research field, where at the time the concepts of function and group of functions had become of great interest. Only 5 figures are inserted: Fig.11a shows the vertices and edges of adjacent faces of a polyhedron while Fig.11b, c illustrate the proof of a result concerning the transformation groups of a polyhedron. Wiener deals also with the problem of correctly designing second-order surfaces, with a very critical position towards figures that appear in contemporary books and treatises, both mathematical and physical, some of which, according to him, reveal uncertainty in the evaluation of means used and even leave doubts about the author's intentions. To provide instructions on how to draw the surfaces of the second order, he proposes a set of models, and above all, he suggests tackling the problem starting from their principal sections to easily construct arbitrary points and contact planes, in a similar way to what can be done in the case of central conics (Fig. 11b), using principal axes and line at infinity, (Fig. 11c); in the drawing he distinguishes the real elements from the others with the use of continuous lines. Subsequent editions of the Catalogue edited by Wiener will add new illustrations, including photographic ones [see 13].

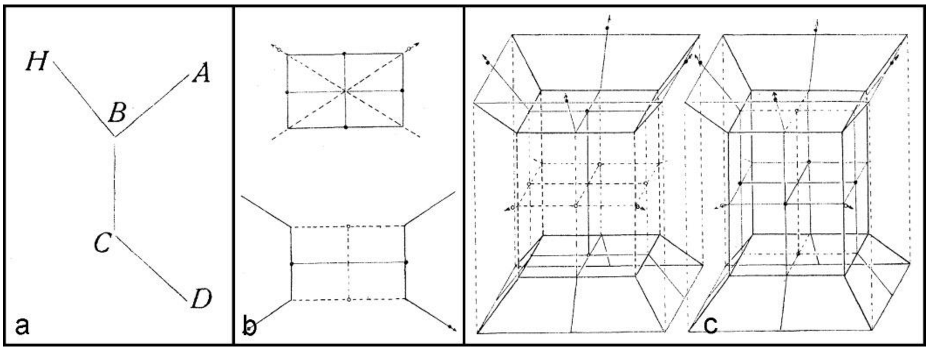

Fig. 11. Examples from [12]: **a)** p. 33; **b)** p. 57 figg. 1, 2; **c)** p. 60 figg. 3, 4.

2.4 1918 Geometrisches Zeichnen, Projektionslehre, Flächenmessung, Körpermessung

This Catalogue [14] presents itself as an opportunity to disseminate basic knowledge for professional practice; starting from its index we find, for example, the practical mathematics section for professionals, and chapters dedicated to projection theory and to graphic representation. Moreover, there are math games and chess with its strategic principles. The volume is richly illustrated by 133 figures and its second part is dedicated to geometry. The section dedicated to drawing is emblematic: it starts from the theoretical foundations offered through a series of very elementary practical but 'useful for learning' experiences. In this regard, Fig. 12a illustrates the use of set squares and ruler to answer the question of knowing how to draw a line parallel to the base one passing through a point not belonging to it. This image portraits a moment of construction which is described in words to the extent that image presence is not strictly necessary. The text also lists the specificities of useful materials for pursuing a good drawing, starting from the type of pencil leads suitable for geometric drawing.

By comparing descriptions of parables with what presented in Brill's essay we recognize different communicative registers directly connected to the possible user: in this case the user is the high school student, thus the mathematical information is obviously basic, and it does not require dedicated preparation in order to be shared. On the other hand, Brill presented his considerations to his Colleagues with a specialized language, both graphic and textual (Fig. 12b, c).

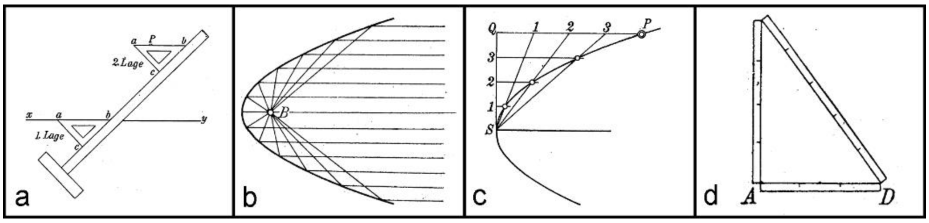

Fig. 12. Practical geometry [14]: **a)** p. 9 fig. 14; **b)** p. 15 fig. 28; **c)** p. 16 fig. 29; **d)** p. 21 fig. 40.

The attention to basic practices is also captured by the representation in Fig. 13d which illustrates the right-angled triangle of simple reproducibility also in the field during the survey practices, to verify orthogonality between cathetuses (Fig. 13d).

2.5 1960 circa, Lehrmodelle für Mathematik

Produced in the early 60s of the 20th century [15], the Catalogue [6] contains texts in three languages: German, English and French, making it more accessible to a general public (if compared with the previous ones). Its index is an advanced tool for critical synthesis, since the models are grouped according to macro-topics, elementary mathematics, geometry, analysis, however deemed representative of more than one topic. Its structure is based on a set of sheets made up of an introductory page of images, which is the real visual description of models, briefly described in the following textual pages. Each model is displayed by means of one or more black and white representations, be they drawings or photographs. The illustrated pages contain: Stoll logo at the top right; b/w figures and a set of coloured graphic elements, that can be evocative of geometric properties of the models. The figures are sometimes elaborated to evoke the possible geometric genesis of models they refer to, as in the case of 2/182, 3/182 b, 4/182 c, 5/182 d, 6/182 e (Fig. 13a). The synthesis carried out by the authors in the phase of descriptions realization is limited almost only to the name of the subject and it is interesting to note how the illustrations become the means to communicate the physical specifications of each artifact: created on the basis of 19th century projects (Fig.13d), both with new material interactions between materials already used (Fig.13b) and with the addition of new materials, such as plexiglass, especially in artifacts dedicated to problems of projective geometry or geodesy, such as 231/159 b (Fig.13c).

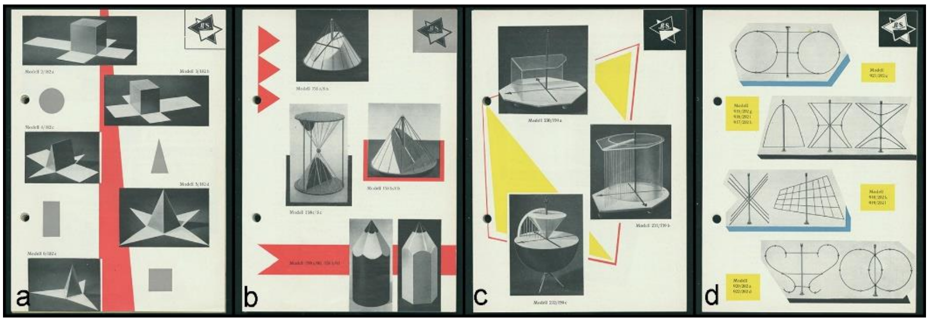

Fig. 13. Examples from [6]: **a)** p. 39; **b)** p. 85; **c)** p. 119; **d)** p. 187.

3 Discussion and Conclusions

By comparing contents, declined between texts and images, supporting model descriptions, it appears that different authors, in their Catalogues, offer very different descriptions of the same mathematical object. In order to grasp useful clues for the formalization of a *modus narrandi* of models properties, it has to be noted that not all Catalogues include information dedicated to selling functions (size, weight, price, portability) which are typical, for example, of Schilling's. These Catalogues were produced to become tools for the promotion of visual artifacts of great visual impact [16], designed for the materialization of complex mathematical questions. This set of procedures suitable to visually express the concepts of the disciplines themselves, are united by principal eidetic values, even if they are not clearly explained. This is evident while analysing models and images attributed to them as visualizers of the cultural category [17] of doing Geometry through a material representation.

Thanks to the interdisciplinary approach, we highlight the interaction between texts and images in relation to author/user, recognizing multiple registers of communication mediated by representations that are not always rigorous, while often iconic. Given the variety of models described, the scientific/applicative contexts and therefore the different professional figures involved, analysed representations offer a variety of tools and methods that could be traced back to the geometric specificities of the artifacts. The absence of shared graphic standards could be a limit if the use of Catalogues had to be guided by their sets of images, but users were usually 'experts' and were able to read texts in the absence of images so that a uniformity of (graphic) language was not required. Descriptive representations and symbols are distinguished, geometrically constructed and non-geometrically constructed drawings, 3D views and projection planes, pictures and drawings constructed as traces of the same offering a diversified panorama of images. These visual aids are combined to create an atlas of representations of mathematical models, whose visualization through the drawing is not formally codified. In all cases, the choice not to represent all the models in listed in Catalogues, but only those considered to be significant, follows communication purposes and problems related to the construction of shared mathematical knowledge within a community.

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