# Using Old Schröder-Reuleaux Models in Modern Kinematics Lectures

*Original*
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In the past, in the absence of these tools, teachers were creative in developing accurate real 3D mechanical models, both to help students visualize the complex motions of mechanisms and machines components, and to represent mathematical curves and functions. Robert Willis (1800-1879), one of the pioneers of kinematic and machine theory in England, used mechanical models as early as 1840, in Cambridge. In the same period, Ferdinand Redtenbacher (1809-1863) independently developed (there is no evidence of contacts with Willis) at least 100 models at Karlsruhe, documenting their realization in his texts. After his death, his student Franz Reuleaux (1829-1905) designed and built around 800 models in Berlin, which were lost during the Second World War [1]. Fortunately, the designs of Reuleaux's models have been preserved thanks to reproductions by Gustav Voigt [2, 3] (about 350 models) and J. Schröder [2, 4], both model producers according to both Redtenbacher and Reuleaux [1].

Several original collections have been preserved in excellent condition. Moon in [5, 6] reports a detailed list. Among the most important constituted by the Voigt/Reuleaux models we want to remember those of the Cornell University of Ithaca (230 pieces) and the University of Porto (130 pieces). As for Schröder's models, we remember the collection of the Fondazione Scienza e Tecnica of Florence (100 pieces) and, not mentioned in [5, 6], the collection of the Politecnico di Torino [7] (about 85 pieces). In Italy, at the Politecnico di Milano, there is also a collection of 40 pieces made by the Società di Incoraggiamento Arti e Mestieri (SIAM) [8]. Table 1 integrates the data published in [5, 6] with the collections of the Politecnico di Torino and the Politecnico di Milano.

The collections, in addition to having an important historical value [6], are still today a valid support for teaching activities, so much so that in some cases there are deterioration processes that require the development of restoration techniques [9], or it is suggested to replicate them by 3D printing [10].

The article deals with the use of historical Schröder/Reuleaux models in modern lectures of Automatic Machine Mechanics at Politecnico di Torino. After a brief introduction on the collection of the Politecnico di Torino, the four mechanisms, employed in the educational workshop, are presented. The teaching method, that provides, starting from a first qualitative analysis of the real models, the creation of virtual models using software, is finally presented and discussed.

**Table 1.** Model collections of kinematic mechanisms (Moon, 2007 with addition of the Politecnico di Torino and Politecnico di Milano collections)

| *Location* | *Institution* | *Approx. no.Models* | *Vintage* | *Designer* |
|---|---|---|---|---|
| Aachen, Germany | RWTH-Technische Hochschule | 300 | modern | |
| Berlin, Germany | Technische Universität | 40 | modern | |
| Boston, MA, USA | Boston Museum of Science | 120 | 1940s | Clark/Brown |
| Cambridge, UK | Cambridge University | 40 | 19th–20th C. | |
| Chemnitz, Germany | Technische Universität | ? | modern | |
| Columbia, PA, USA | Nat. Clock and Watch Museum | 80 escapements | 17th–20th C | |
| Columbus, OH, USA | Ohio State University | 50 | 1950s | Illinois Gear Co. |

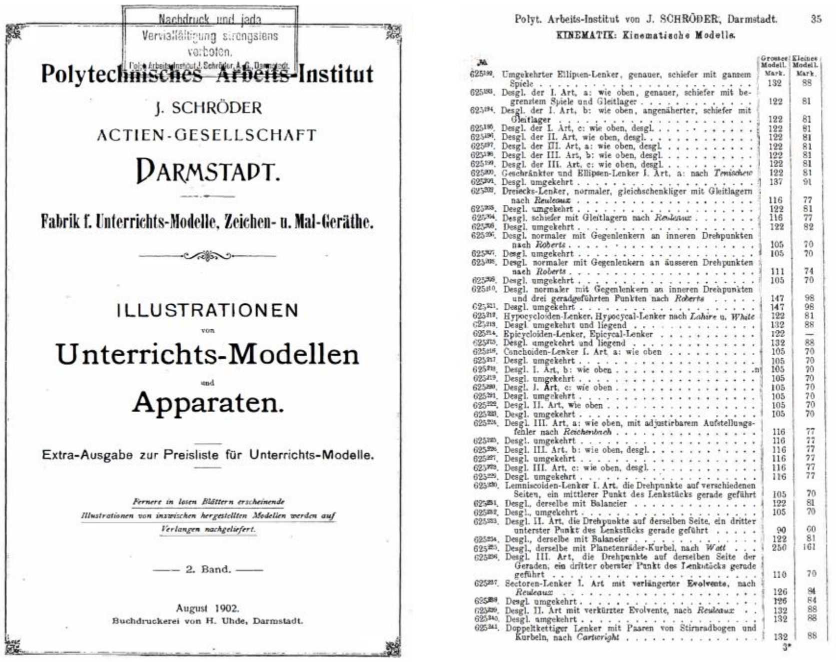
| | | | | |
|---|---|---|---|---|
| Denmark | Hauck Foundation | ? | 18th C | |
| Dresden, Germany | Technische Universität | 120 | 19th–20th C. | |
| Florence, Italy | Fondazione Scienza e Tecnica | 100 | 19th C. | Schröder |
| Hannover, Germany | Technische Universität | 20 | 1880 | Reuleaux |
| Hannover | Technische Universität | 200 | modern | |
| Ithaca, NY, USA | Cornell University | 230 | 1882 | Reuleaux/Voigt |
| Ithaca, NY, USA | Cornell University | 20 | 1869 | Schröder |
| Karlsruhe, Germany | Universität Karlsruhe | 100 | c.1866 | Redtenbacher |
| Kyoto, Japan | Kyoto University Museum | | c. 1890 | Reuleaux/Voigt |
| London, UK | Science Museum | 20 | 19th C. | Schröder |
| London, UK | Victoria and Albert Museum | Escapements | | |
| Milan, Italy | Science Museum | | 20th C. | Leonardo copies |
| Milan, Italy | Politecnico di Milano | 40 | 1920-30 | SIAM |
| Moscow, Russia 500 | Bauman State Tech. Univ. | 19th–20th C | | |
| Munich, Germany | Deutsches Museum | 100 | 19th C. | Reuleaux |
| New York, USA | IBM | ? | 1950–1970 | Leonardo copies |
| Newark, NJ, USA | Newark Museum | 160 | 1930s | Clark/Brown |
| Paris, France | Musee des Arts et Meteir | ? | 19th C. | Schröder |
| Porto, Portugal | University of Porto | 113 | c. 1890 | Reuleaux/Voigt |
| Prague, Czech Rep. | Technical University | 23 | | Schröder |
| Riga, Latvia | Technical University | ? | | Schröder? |
| Rome, Italy | University | 20 | | |
| Stockholm, Sweden | Science Museum | | 18th C. | Polhem |
| Tainan, Taiwan | Nat. Cheng Kung Univ | c. 60 | | Japanese maker |
| Turin, Italy | Politecnico di Torino | 85 | end 19th C. | Schröder |
| Vinci, Italy | Leonardo da Vinci Museum | 20th C | | Leonardo copies |
| Zurich, Switzerland | ETH | 10 | c. 1880 | Voigt/Reuleaux |

## 2 The Schröder-Reuleaux collection and models

The Regio Museo Industriale of Turin was formally established in 1862 with the aim of "promoting industrial education and the progress of industries and commerce" on the momentum of the Great London Exposition of the same year [11]. At the Institute of Mechanics of the Museum there was a cabinet of Composition of Machines, "intended to make known the shape and proportions of the different parts constituting the machines" with an attached laboratory in which, among others, there were "constructive models of all the components and elements of machines [*omissis*] partly provided by the renowned Company Schröder of Darmstadt and partly made in Italy by mechanical workshops on the basis of drawings supplied by the professor of Composition and Construction of Machines " [11, 12]. In 1906 The Museo Industriale and the Scuola di Applicazione per Ingegneri (established with the Casati Law in 1859) merged, forming the original nucleus of the Politecnico di Torino [7].

The collection of models, about 85 mechanisms and power transmission components, fortunately has come almost entirely to us, and is currently kept at the Department of Mechanical and Aerospace Engineering -DIMEAS- of Politecnico di Torino. On each piece of the collection there is the Schröder brand and the catalogue number (Fig. 1), corresponding to the Schröder catalogue (Fig. 2, [4]). As stated by the same manufacturer, these are kinematic models based on the works and lessons of Professor Reuleaux [13], built in two series of different sizes: the largest are about 40 cm high, the smallest are about 25 cm high, in accordance with the models made by Professor Reuleaux in Berlin.

**Fig. 1.** Proprietary brand (trademark) and Schröder catalogue number



Nachdruck und jede
Vervielfältigung strengstens
verboten.
Polyt. Arbeits-Institut J. Schröder A.-G. Darmstadt.

Polytechnisches Arbeits-Institut
J. SCHRÖDER
ACTIEN-GESELLSCHAFT
DARMSTADT.

Fabrik f. Unterrichts-Modelle, Zeichen- u. Mal-Geräthe.

ILLUSTRATIONEN
von
Unterrichts-Modellen
und
Apparaten.

Extra-Ausgabe zur Preisliste für Unterrichts-Modelle.

*Fernere in losen Blättern erscheinende*
*Illustrationen von inzwischen hergestellten Modellen werden auf*
*Verlangen nachgeliefert.*

— 2. Band. —

August 1902.
Buchdruckerei von H. Uhde, Darmstadt.

Polyt. Arbeits-Institut von J. SCHRÖDER, Darmstadt. 35

**KINEMATIK: Kinematische Modelle.**

| № | | Grosses Modell. Mark. | Kleines Modell. Mark. |
|---|---|---|---|
| 625$^{192}$. | Umgekehrter Ellipsen-Lenker, genauer, schiefer mit ganzem Spiele | 132 | 88 |
| 625$^{193}$. | Desgl. der I. Art, a: wie oben, genauer, schiefer mit begrenztem Spiele und Gleitlager | 122 | 81 |
| 625$^{194}$. | Desgl. der I. Art, b: wie oben, angenäherter, schiefer mit Gleitlager | 122 | 81 |
| 625$^{195}$. | Desgl. der I. Art, c: wie oben, desgl. | 122 | 81 |
| 625$^{196}$. | Desgl. der II. Art, wie oben, desgl. | 122 | 81 |
| 625$^{197}$. | Desgl. der III. Art, a: wie oben, desgl. | 122 | 81 |
| 625$^{198}$. | Desgl. der III. Art, b: wie oben, desgl. | 122 | 81 |
| 625$^{199}$. | Desgl. der III. Art, c: wie oben, desgl. | 122 | 81 |
| 625$^{200}$. | Geschränkter und Ellipsen-Lenker I. Art, a: nach *Tenischew* | 122 | 81 |
| 625$^{201}$. | Desgl. umgekehrt | 137 | 91 |
| 625$^{202}$. | Dreiecks-Lenker, normaler, gleichschenkliger mit Gleitlagern nach *Reuleaux* | 116 | 77 |
| 625$^{203}$. | Desgl. umgekehrt | 122 | 81 |
| 625$^{204}$. | Desgl. schiefer mit Gleitlagern nach *Reuleaux* | 116 | 77 |
| 625$^{205}$. | Desgl. umgekehrt | 122 | 82 |
| 625$^{206}$. | Desgl. normaler mit Gegenlenkern an inneren Drehpunkten nach *Roberts* | 105 | 70 |
| 625$^{207}$. | Desgl. umgekehrt | 105 | 70 |
| 625$^{208}$. | Desgl. normaler mit Gegenlenkern an äusseren Drehpunkten nach *Roberts* | 111 | 74 |
| 625$^{209}$. | Desgl. umgekehrt | 105 | 70 |
| 625$^{210}$. | Desgl. normaler mit Gegenlenkern an inneren Drehpunkten und drei geradgeführten Punkten nach *Roberts* | 147 | 98 |
| 625$^{211}$. | Desgl. umgekehrt | 147 | 98 |
| 625$^{212}$. | Hypocycloiden-Lenker, Hypocycal-Lenker nach *Lahire* u. *White* | 122 | 81 |
| 625$^{213}$. | Desgl. umgekehrt und liegend | 132 | 88 |
| 625$^{214}$. | Epicycloiden-Lenker, Epicycal-Lenker | 122 | — |
| 625$^{215}$. | Desgl. umgekehrt und liegend | 132 | 88 |
| 625$^{216}$. | Conchoiden-Lenker I. Art a: wie oben | 105 | 70 |
| 625$^{217}$. | Desgl. umgekehrt | 105 | 70 |
| 625$^{218}$. | Desgl. I. Art, b: wie oben | 105 | 70 |
| 625$^{219}$. | Desgl. umgekehrt | 105 | 70 |
| 625$^{220}$. | Desgl. I. Art, c: wie oben | 105 | 70 |
| 625$^{221}$. | Desgl. umgekehrt | 105 | 70 |
| 625$^{222}$. | Desgl. II. Art, wie oben | 105 | 70 |
| 625$^{223}$. | Desgl. umgekehrt | 105 | 70 |
| 625$^{224}$. | Desgl. III. Art, a: wie oben, mit adjustirbarem Aufstellungsfehler nach *Reichenbach* | 116 | 77 |
| 625$^{225}$. | Desgl. umgekehrt | 116 | 77 |
| 625$^{226}$. | Desgl. III. Art, b: wie oben, desgl. | 116 | 77 |
| 625$^{227}$. | Desgl. umgekehrt | 116 | 77 |
| 625$^{228}$. | Desgl. III. Art, c: wie oben, desgl. | 116 | 77 |
| 625$^{229}$. | Desgl. umgekehrt | 116 | 77 |
| 625$^{230}$. | Lemniscoiden-Lenker I. Art, die Drehpunkte auf verschiedenen Seiten, ein mittlerer Punkt des Lenkstücks gerade geführt | 105 | 70 |
| 625$^{231}$. | Desgl., derselbe mit Balancier | 122 | 81 |
| 625$^{232}$. | Desgl., umgekehrt | 105 | 70 |
| 625$^{233}$. | Desgl. II. Art, die Drehpunkte auf derselben Seite, ein dritter unterster Punkt des Lenkstücks gerade geführt | 90 | 60 |
| 625$^{234}$. | Desgl., derselbe mit Balancier | 122 | 81 |
| 625$^{235}$. | Desgl., derselbe mit Planetenräder-Kurbel, nach *Watt* | 250 | 161 |
| 625$^{236}$. | Desgl. III. Art, die Drehpunkte auf derselben Seite der Geraden, ein dritter oberster Punkt des Lenkstücks gerade geführt | 110 | 70 |
| 625$^{237}$. | Sectoren-Lenker I. Art mit verlängerter Evolvente, nach *Reuleaux* | 126 | 84 |
| 625$^{238}$. | Desgl. umgekehrt | 126 | 84 |
| 625$^{239}$. | Desgl. II. Art mit verkürzter Evolvente, nach *Reuleaux* | 132 | 88 |
| 625$^{240}$. | Desgl. umgekehrt | 132 | 88 |
| 625$^{241}$. | Doppeltkettiger Lenker mit Paaren von Stirnradbogen und Kurbeln, nach *Cartwright* | 132 | 88 |

3*

**Fig. 2.** J. Schröder catalogue (version 1902)

The real mechanism models used in the experimental teaching lab are approximate or exact straight-line mechanisms, originally developed for steam engines, pumps and various working machines, as reported in the catalog [4]:

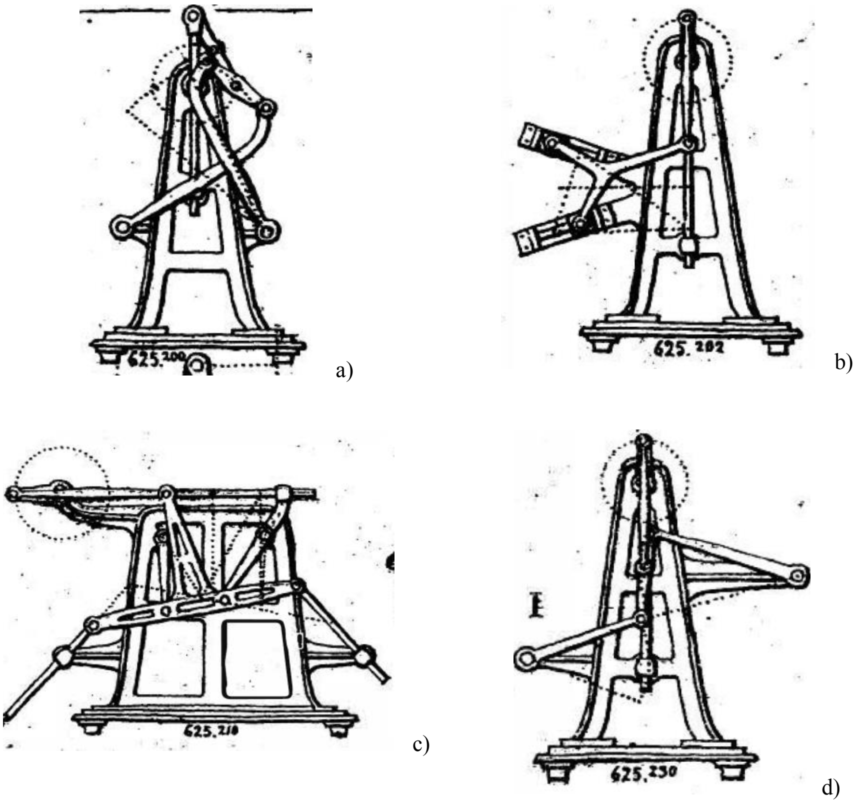
a) n. $625^{200}$ Chebyshev four-bar approximate straight-line mechanism (Geschränkter und Ellipsen-Lenker I. Art, a: nach Tenischew);

b) n. 625$^{202}$ Reuleaux four-bar slider-crank straight-line mechanism (Dreiecks-Lenker, normaler, gleichschenkliger mit Gleitlagern nach Reuleaux);

c) n. 625$^{210}$ Roberts four-bar approximate straight-line mechanism (Desgl. normaler mit Gegenlenkern an inneren Drehpunkten und drei geradgeführten Punkten nach Roberts);

d) n. 625$^{230}$ Watt four-bar approximate straight-line mechanism (Lemniscoiden-Lenker-1.Art, die Drehpunkte auf verschiedenen Seiten, ein mittlerer Punkt des Lenkstücks gerade geführt).

Figure 3 shows the drawings of the models of the Schröder catalogue [4]. Figure 4 shows the images of the same models of the Politecnico di Torino collection.



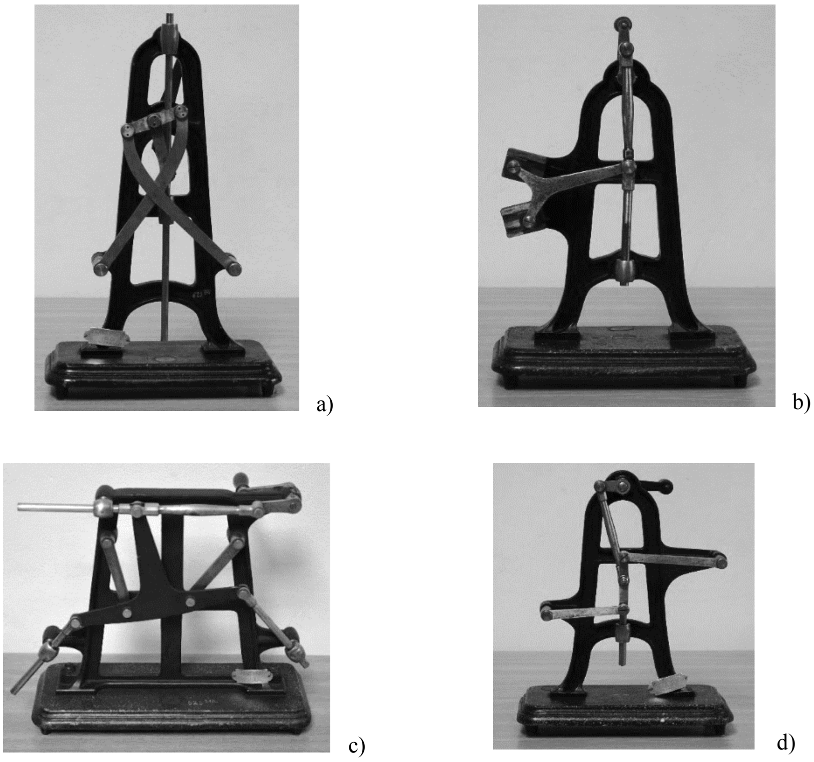
a)

b)

c)

d)

**Fig. 3.** The models used in the laboratory lectures: a) Chebyshev four-bar approximate straight-line mechanism; b) Reuleaux four-bar slider-crank straight-line mechanism; c) Roberts four-bar approximate straight-line mechanism; d) Watt four-bar approximate straight-line mechanism



a) b) c) d)

**Fig. 4.** The models of the Politecnico di Torino collection used in the laboratory lectures

## 3 The teaching method

Although today's students have at their disposal very effective calculation and visualization tools, the analytical and virtual models alone do not allow the student to have a complete understanding of the general functioning of mechanism or machine components. A physical didactic model enables an immediate and intuitive experimental visualization of: (i) the type of motion of the single links and of the whole mechanism; (ii) the design solutions adopted to avoid geometric interference between links during operation (for example the choice between the cantilever and straddle-mounted revolute joints); (iii) the dynamic physical meaning of the toggle positions; (iv) the effect of the backlash within kinematic pairs.

In addition, the use of a real model allows students to practice the sequence, non-obvious, between the real model and the virtual model: (i) to carry out a mechanical relief; (ii) to draw a kinematic scheme starting from the real model by isolating the significant physical phenomena and neglecting the secondary ones; (iii) recognizing redundant constraints.

Last but not least, we believe it is positive, fascinating and exciting for the student to handle kinematic models conceived and built more than a hundred years ago, testifying that current knowledge is however based on solid roots grown and developed over the centuries. Evidence of this fact is that the same exercise conducted with recent models, or with 3D printed copies of the original models, does not arouse the same interest.

Based on these considerations, starting from 2015 we have designed and started the experimentation of a three-hours didactic laboratory which involves the use of historical models. The laboratory is part of the course of Automatic Machine Mechanics aimed at second year students of the MSc in Mechanical Engineering and is addressed to a total of 140 students, divided in small group of 4-5 people.

The following activities, for each mechanism analysed, are proposed:

*Experimental functional analysis*. It consists in verifying the functioning of the mechanism by observing the types of motion of the links, the role of the joints, including the reasons that determined the choice of the position of the joints and the dimension of the links. The student is asked to divide the mechanism into a series of sub-mechanisms, identifying three different functions: the *input* (or motion generation) *mechanism* constituted by a crank and connecting rod; the *main mechanism* aimed at realizing the desired motion (straight-line or approximate straight line coupler curve); the *visualization mechanism* devoted to show the straight-line coupler curve. By way of example, Fig. 5 shows a detail of the viewer mechanism of the Roberts four-bar approximate straight-line mechanism, with which, the model manufacturer chose to highlight the almost rectilinear trajectory of the coupler point. It consists of a prismatic joint, whose members are respectively connected to the frame, and to the point whose rectilinear trajectory must be shown. Obviously, by adding the viewer member and two full joints to the original Roberts four bar mechanism, its mobility should drop to zero. In the case of approximate straight-line mechanism, this type of viewer does not lock the mechanism, that maintains one degree of freedom, thanks to the backlashes in the joints. Instead, in the case of exact straight-line mechanism, the viewer mechanism introduces a redundant constraint.

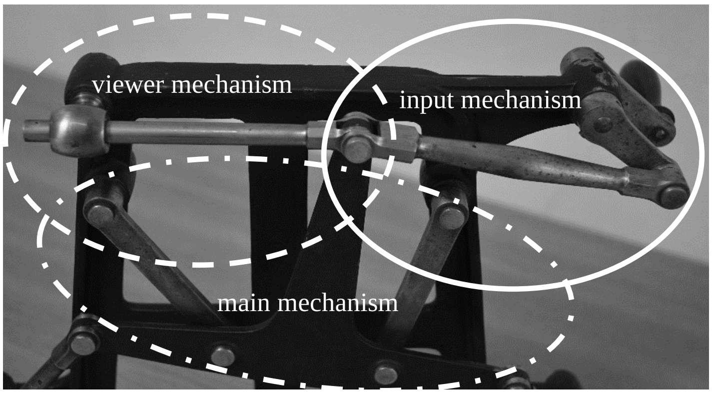


**Fig. 5.** Detail of the Roberts four-bar mechanism: an ingenious straight-line viewer

*Geometric relief and schematization*. Starting from the physical model, the student must obtain a functional scheme, possibly in different configurations, using the correct symbolism and respecting the geometric congruity and proportions. Furthermore, it must introduce the reference systems and variables needed for the kinematic analysis and geometric parameters for describing the dimensions of the mechanism.

*Determination of degrees of freedom*. Using Grubler's equation, the student must calculate the degrees of freedom of the mechanism starting from the kinematic scheme obtained and understanding the origin of any redundancy of the constraints as discussed above.

*Modeling.* Using a software for kinematic analysis, like GIM [14], the student must create a model of the mechanisms. To do this, the student is called to identify and neglect rightly all the redundancies. As an example, Fig. 6 shows the GIM model of the Chebyshev four-bar approximate straight-line mechanism.

*Kinematic analysis.* The student must perform the kinematic and parametric analysis of the mechanism by means of simulations aimed at visualizing the functioning of the mechanism, representing the trajectories, speeds and accelerations of specific points, assessing the effect of the variation of the geometric parameters. The GIM model allows to calculate easily the coupler curves, the fixed and moving centrodes, the position, velocity and acceleration of points of interest etc., and to evaluate the effect of the mechanism parameter change (Fig. 6).

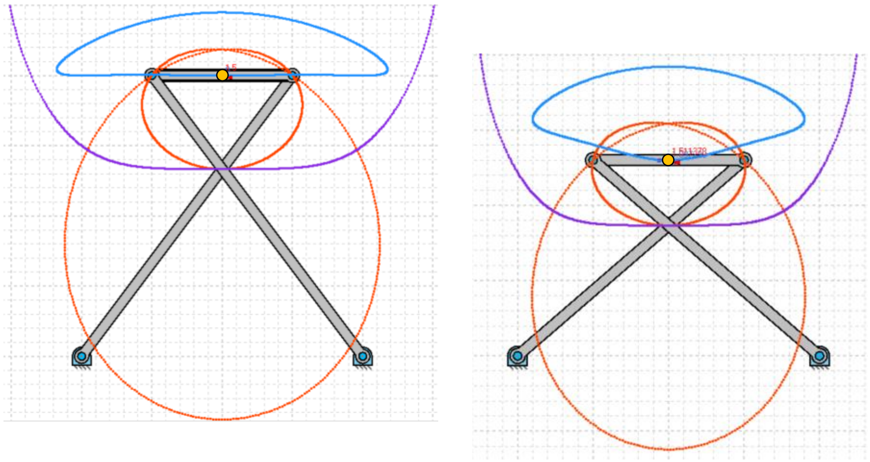


**Fig. 6.** Educational software tool GIM models: coupler curve (blue), fixed centrode (violet) and moving centrode (red). a) Chebyshev four-bar approximate straight-line mechanism of the collection; b) a modified mechanism

## 4 Conclusions

A collection of Schröder / Reuleaux models, among the most important in the world, is kept at the Politecnico di Torino. Some models are still used in kinematics practical lectures of a Mechanical Engineering MSc course, Automatic Machine Mechanics, aimed to develop knowledge of the main types of mechanisms for the transmission and transformation of motion.

The students, during the experimental laboratory, are invited to: (i) make an experimental functional analysis of the real historical models; (ii) detect its geometry and sketch a mechanical scheme; (iii) calculate the d.o.f; (iv) study the influence of the main parameters by a software model.

From the beginning of the didactic experimentation, the students have shown interest regarding the activity. In particular, they appreciated the possibility to check their ability to put into practice the knowledge learned during the theoretical lessons. Indeed, the students can exercise and test their skills in carry out an in-depth kinematic performance analysis of a real mechanism.

The historical models conceived more than a hundred years ago, at the beginning of the Science of Mechanisms and Machines, demonstrated their effectiveness in reproducing mechanical parts, allowing students of today to play an active role in learning the mechanisms and machine components with a pleasant and interactive methodology.

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