Creating Present-Day Solutions from Historical Knowledge

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Abstract—*Solutions for many present-day problems in the field of motion systems can be derived from historical knowledge. Unfortunately, large portions of this knowledge are difficult to access, since it is scattered over the world's libraries, museums, companies, universities, and other institutions. Also, it is stored in various forms, like textual descriptions, images, or diagrams.*

In recent years there have been efforts to digitalize sources of historical knowledge and make them available on the Internet. However, most of these repositories represent information in a way that does not meet the requirements of engineering designers concerning the retrieval of specific solutions.

The presented paper discusses methods and tools necessary to extract solutions from sources and to describe them with metadata based on terms and concepts of motion science.

Keywords: motion systems, digital libraries, historical solutions, solution principles, search techniques, metadata

I. Introduction

Designing complex motion systems solving kinematic and dynamic problems belongs to the fundamental tasks in[1] engineering design today and in the future. Therefore, mechanical solutions remain important. However, these solutions need to be adapted to meet new or more demanding requirements in the context of new technologies and applications. These include increasing reliability and accuracy, extending performance limits, ensuring environmental safety, lowering maintenance costs, modularization and miniaturization.

Although the knowledge about motion systems is essential not only to mechanical engineering, students of this subject only learn fundamental basics regarding structure, analysis and synthesis of mechanisms. There is no specific education of genuine motion systems experts. On the other hand, industry expresses an increased demand for access to the knowledge about motion systems in its entirety. Against this background, a project called "Digital Mechanism and Gear Library" (DMG-Lib, [1,15]) started to create a central information repository on motion science in 2004 (Fig.1). Recently, this growing collection became the starting point for the European thinkMOTION project on the same subject [16].

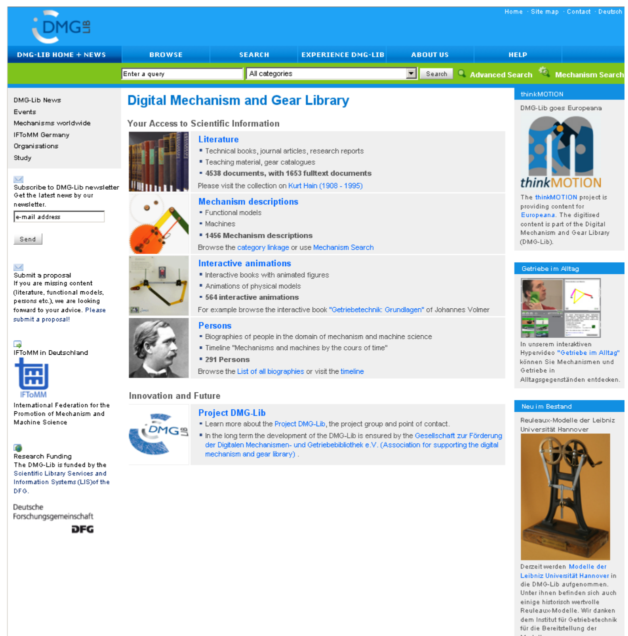

Fig. 1. Welcome page of the DMG-Lib web portal

DMG-Lib incorporates all forms of stored knowledge like books, educational material, technical drawings, photos, demonstration models, etc. Table 1 lists the source types and item numbers available in DMG-Lib.

Source type	Available online (Oct.2010)
Books	193 (full text)
Articles	1261 (full text)
Photos, Slides	ca. 2000
Animations, Videos	ca. 600
Mechanism descriptions	1458
Biographies	291

TABLE 1. Number of digital documents in DMG-Lib

As a method of abstraction, the DMG-Lib database stores the solution principle of each motion system. This results in a uniform description of solutions that exist in various forms of representation (verbal, graphic, model).

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Collecting large numbers of motion system descriptions in this unified form allows building a web-based repository that supports searching for suitable solutions to a variety of problems and speeds up information retrieval. Derived data like analyses or simulations also facilitate comprehension of kinematic knowledge (Figs. 2 and 3).

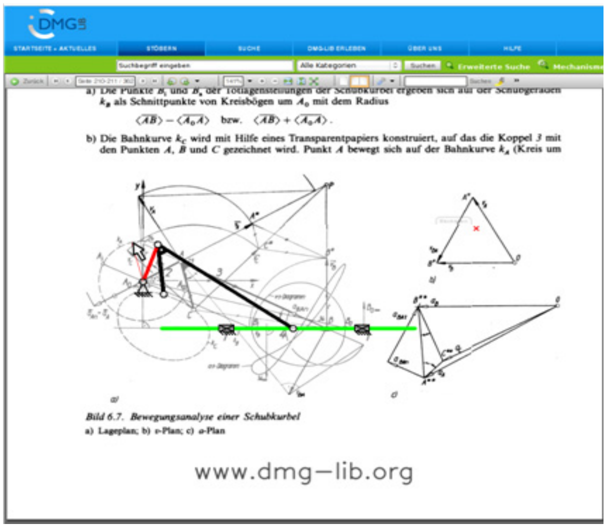


Fig. 2. Book page of [13] with overlaid interactive animation

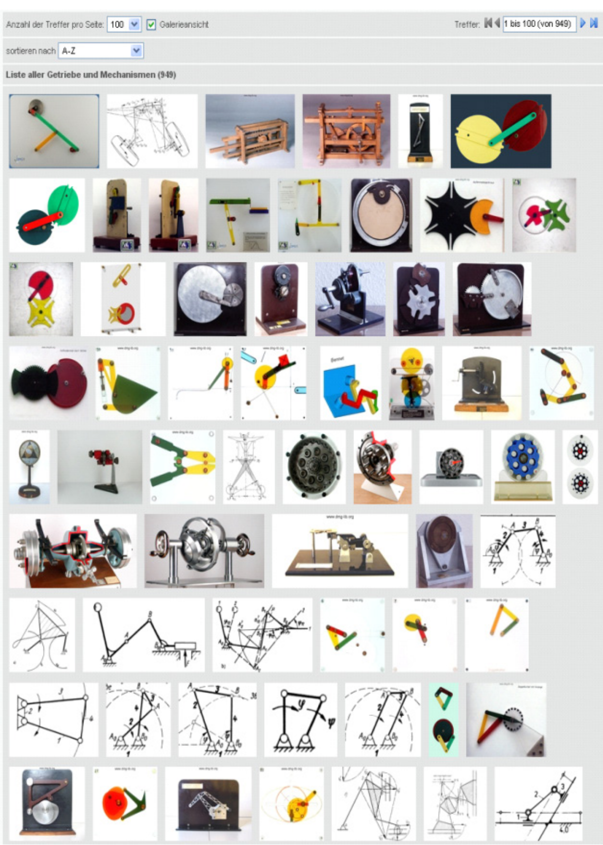


Fig. 3. Preview of mechanism in the solution repository

Currently, DMG-Lib provides more than 1400 descriptions of mechanisms and 564 interactive animations as a solution repository for design tasks.

II. Analysis of the problem

Besides the DMG-Lib project there are few other comprehensive projects that collect and present knowledge in the field of motion science using a web-based library. Noteworthy among them are KMODDL [7] and the Taiwanese collection of educational models [8]. Additionally there are a number of smaller projects [3, 4, 9]. In the future, this situation will change as digital processing and provision of technical solutions becomes more important. The main indicators are the greatly increased financial resources for the creation of digital repositories granted by national and international institutions (e.g. German Research Foundation, European Commission).

Today, the descriptions of technical solutions differ greatly concerning style and content, depending on the targeted user group and the editor of the metadata. Figures 4 to 7 show different examples that give an impression of the current variety found among web-based presentations of knowledge in the field of motion science.

The description of the technical solutions in Fig. 4 is a simple explanation of the design and the functionality of the displayed models. It aims primarily at interested laymen and visitors of museums. The example in Fig. 5 shows a lifting device explained by (and for) historians of technology in the Archimedes Project of the Max Planck Institute for the History of Science in Berlin [10]. The Archimedes database contains approximately 1800 described solutions of motion science from the 16th and 17th century. Fig. 5 also presents the set of metadata used for the solutions in the Archimedes database. While this kind of description bears valuable information for design engineers it cannot be considered a solution repository for design purposes.

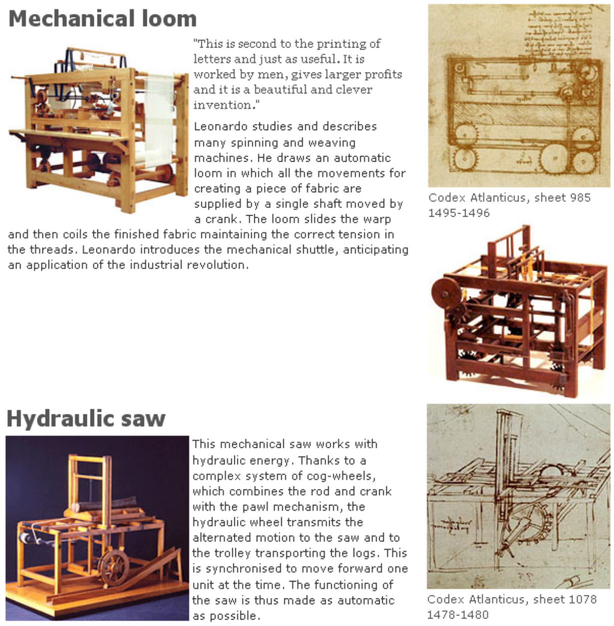
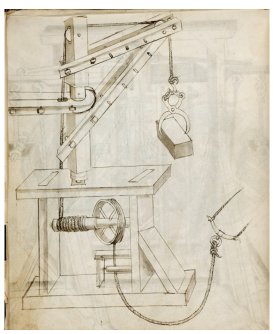
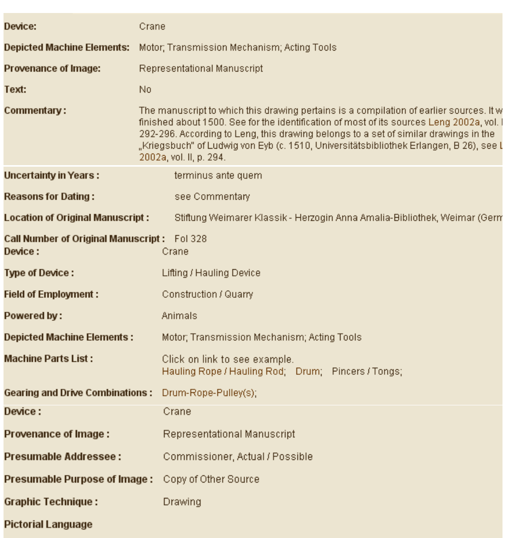


Fig. 4. Examples fort he description of motion systems of the virtual model collection "The Leonardo Gallery" of the Museo Nazionale della Scienza e della Tecnologia [2]





Overview	Device:	Crane
	Depicted Machine Elements:	Motor; Transmission Mechanism; Acting Tools
	Provenance of Image:	Representational Manuscript
	Text:	No
	Commentary:	The manuscript to which this drawing pertains is a compilation of earlier sources. It w finished about 1500. See for the identification of most of its sources Leng 2002a, vol. I 292-296. According to Leng, this drawing belongs to a set of similar drawings in the „Kriegsbuch" of Ludwig von Eyb (c. 1510, Universitätsbibliothek Erlangen, B 26), see L 2002a, vol. II, p. 294.
Source	Uncertainty in Years :	terminus ante quem
	Reasons for Dating :	see Commentary
	Location of Original Manuscript :	Stiftung Weimarer Klassik - Herzogin Anna Amalia-Bibliothek, Weimar (Germ
	Call Number of Original Manuscript :	Fol 328
Device	Device :	Crane
	Type of Device :	Lifting / Hauling Device
	Field of Employment :	Construction / Quarry
	Powered by :	Animals
	Depicted Machine Elements :	Motor; Transmission Mechanism; Acting Tools
	Machine Parts List :	Click on link to see example. Hauling Rope / Hauling Rod; Drum; Pincers / Tongs;
	Gearing and Drive Combinations :	Drum-Rope-Pulley(s);
Image	Device :	Crane
	Provenance of Image :	Representational Manuscript
	Presumable Addressee :	Commissioner, Actual / Possible
	Presumable Purpose of Image :	Copy of Other Source
	Graphic Technique :	Drawing
	Pictorial Language	
	Complete Device :	Pre-Perspective View

Fig. 5. Example for the description of a lifting device from "Ingenieurkunst- und Wunderbuch" (author unknown) ca. 1500, presented by the Archimedes project [10], technical drawing and metadata

The example of a worm gear (Fig. 6) described by the student project group "Leonardo da Vinci" of the Bielefeld University of Applied Sciences serves well for self-study of engineering students at the beginning of their education.

Fig. 6. Example of the description of a worm gear from the model collection of the project group "Leonardo da Vinci" of the Bielefeld University of Applied Sciences

On the contrary, the virtual Model Collection of the Delft University of Technology forms a true solution repository for engineers. It contains the necessary functional descriptions that support solving design tasks (Fig. 7).

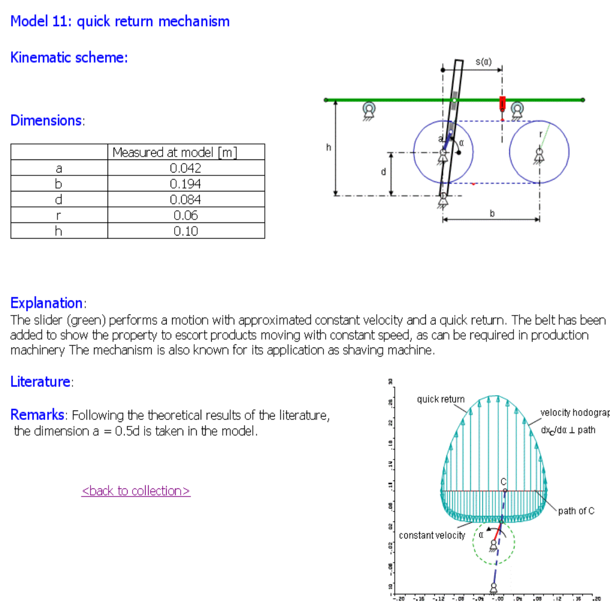


Fig. 7. Description of a "quick return mechanism" from the model collection of TU Delft [4]

Currently, the description of historical solutions for motion tasks is usually limited to stating a specific application and the origin of the source (historian's perspective). This prevents a target-oriented search for design solutions although there are a large number of technical solutions freely available on the internet. The same applies to (re-)publication and (re-)patenting of known solutions since previous publications and other original sources remain unnoticed. Also, information about solutions in motion science is scattered broadly (there is no integrative platform) and stored in meta descriptions that differ greatly in content and quality. Currently, there are no uniform standards for the description of technical solutions. However, this is one of the main requirements for target-oriented searching. The languages used for metadata descriptions form another possible obstacle when locating solutions. As an example, the model collection of the Moscow State Technical University (excerpt in Fig. 8) remains inaccessible to most internet users. Also, a description as shown in Fig. 6 would benefit from an English translation. In this context, activities for a web-based workflow and infrastructure for the maintenance of the IFToMM Dictionary (as described in [17]) could lead to a more general tool for the translation of textual information in online repositories for motion systems solutions.

Recently, the issue of locating motion science solutions set off first discussions about requirements for building digital collections in the IFToMM Permanent Commissions “Standardization of Terminology” (Workshop Lyon, 2007) and “History of the Theory of Machines and Mechanisms” (Workshop Tainan, 2008) [14]. The aim of these considerations is the definition of minimum standards for the description of motion systems. Altogether, the access to digitally available knowledge about motion science is considerably restricted.

Fig. 8. Examples from the model collection of the State Technical University

III. Applications

Design methodology sources estimate that approximately 20 percent of the engineering designer’s working time is consumed by the search for information [12]. In this context, building solution repositories is an important measure for shaping a more effective design process. As a part of his work, the designer seeks inspiration in solution examples and their description that help him to complete his design task. Among others, this includes assistance with the following activities:

- Dimensioning,
- Reducing diversity of solutions by comparing advantages and drawbacks of different solutions,
- Deciding patent disputes,
- Avoid patents and property rights,
- Gaining legal certainty,
- Conduct feasibility studies,
- Estimation of trends (How did solutions change over the time?),
- Verification of own design results,
- Model making,
- Customer information.

Solution collections may also serve as a source of inspiration for own solutions or solution variants.

Such an engineering-oriented solution repository also creates positive synergies for other user groups like authors of scientific publications, patent researchers, historians of technology, or engineering students. Patent researchers who evaluated the degree of novelty of a solution only by a few descriptors and classification classes using patent databases or literature databases may gain useful instruments to decide about the inventive step.

Historians of technology may find interesting interrelations to interpret technological advance or the spreading of ideas in connection with societal developments, to classify and honor technical inventions and developments, to find primary sources, or to identify connections to present-day solutions.

All these applications raise one central question: How to structure available knowledge to allow finding it using common text-based search techniques?

IV. Requirements for indexing historical solutions

The requirements for indexing historical solutions depend on the designated use that was outlined in section III. They not only include specifications regarding content, but also organizational and technical demands that need to be addressed when building a solution repository.

Content-related questions are:

- Should only implemented, well-proven solutions be included in a collection or may academic concepts,

untested solutions or even depictions of Perpetuum Mobile become part of such a repository?
- How should solutions be presented? Should illustrations or descriptions from historical sources be included?
- Which references to methods of calculation, norms, guidelines, or further literature should to be incorporated?
- How to solve issues concerning the use of synonyms (regional, lingual, time-related, or author-specific synonyms)?

The definition of metadata for motion systems requires profound knowledge in this field. Therefore, the content-related indexing is also a process of scientific editing with tasks including:
- Estimation of the areas of application and the possible function,
- Detection of inconsistencies, conflicts, or flawed depictions,
- Handling of difficult-to-interpret, ambiguous technical information,
- Identification of perspective and scale,
- Definition of the degree of reliability/correctness/ trustworthiness (assumption, proven fact, part of patents or norms),
- Determination of the degree of editing/abstraction (unedited primary source, abstract and formalized, problem-oriented),
- Deriving models for simulation (with different degrees of abstraction and visualization details),
- Enhancement of sources with functional verifications (e.g. simulation results) and calculation methods (e.g. for dimensioning).

The latter two items also help to implement a graphic search for structural or functional properties of motion solutions in the future.

The knowledge of experts is also necessary if the quality or the abstraction of a technical illustration complicates interpretation, or if the function can only be recognized in a particular context (Fig. 9).

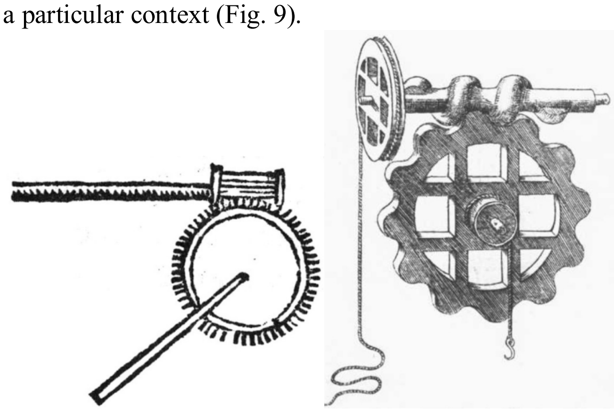


Fig. 9. Technical illustrations of worm gears from the 16th century

In addition to the mentioned content-related aspects indexing also concerns organizational and technical requirements. This not only includes developing the software implementation of an online database but also issues of data storage (backup system, choice of storage media and location), of user rights management, ensuring data consistency, logging of changes, or of the selection and extent of sources.

To address the demands of the engineering designer, as outlined in section II, it is necessary to consider a great number of (extensible) descriptors. According to their semantics they can be divided into structure-related, function-related and application-related, as well as formal and administrative identifiers. The aim is to allow the unambiguous and high-quality description of motion systems.

V. Example

This section illustrates the description of a solution using the example of a Peaucellier–Lipkin inversor from the collection of educational models of the Technische Universität Dresden. Metadata is gathered according to a web-based form developed by the DMG-Lib project. The form was derived from [11] and has been extended by adding various entries. Figs. 11 to 14 show the current state of the form, displaying the metadata of the Peaucellier–Lipkin inversor from Fig.10. The language used in the screenshots is German. However, translation to other languages including English progresses in the thinkMOTION project which raises DMG-Lib to a European level.

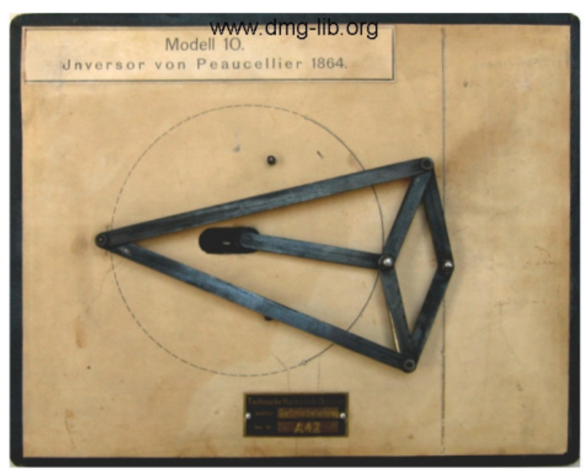


Fig. 10. Photo of a model of a Peaucellier–Lipkin inversor on which the metadata description in Figs. 11 to 14 is based on

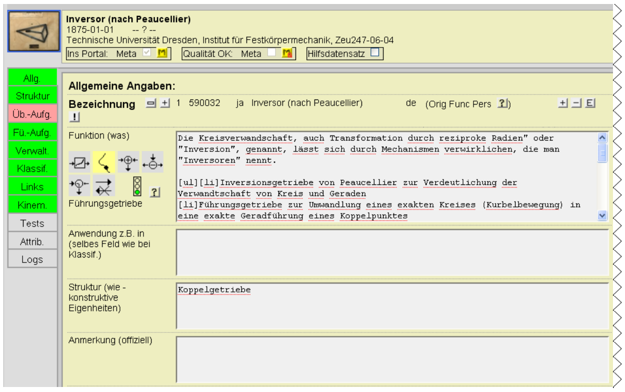


Fig. 11. Web-based working environment fort he description of motion systems, form “General Information”

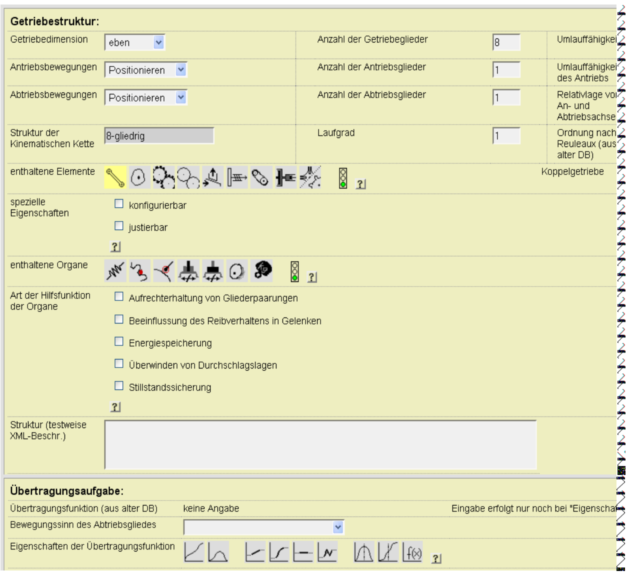


Fig. 12. Forms “Mechanism Structure” and “Transfer Function”

(Author’s comment to the reviewers: the final version of the paper will include screenshots translated into English.)

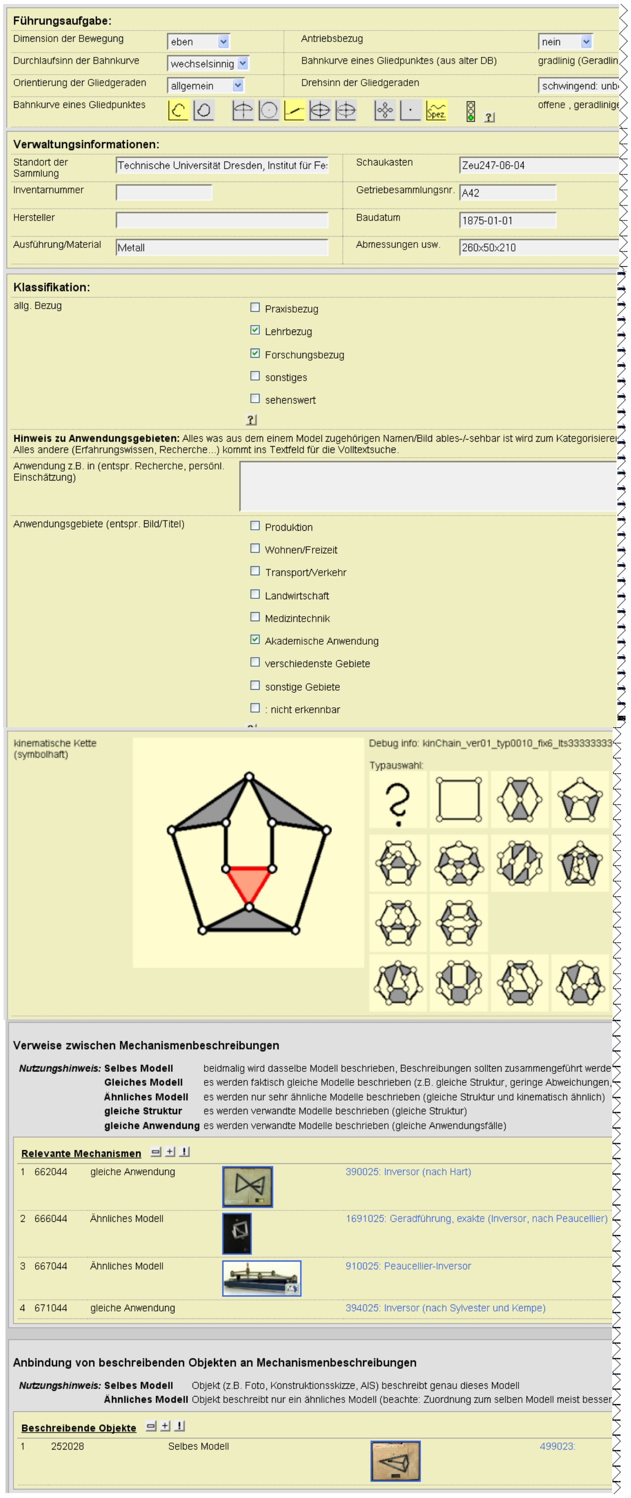


Fig. 13. Forms “Guidance Function”, “Administrative Information”, “Classification” and “Links”

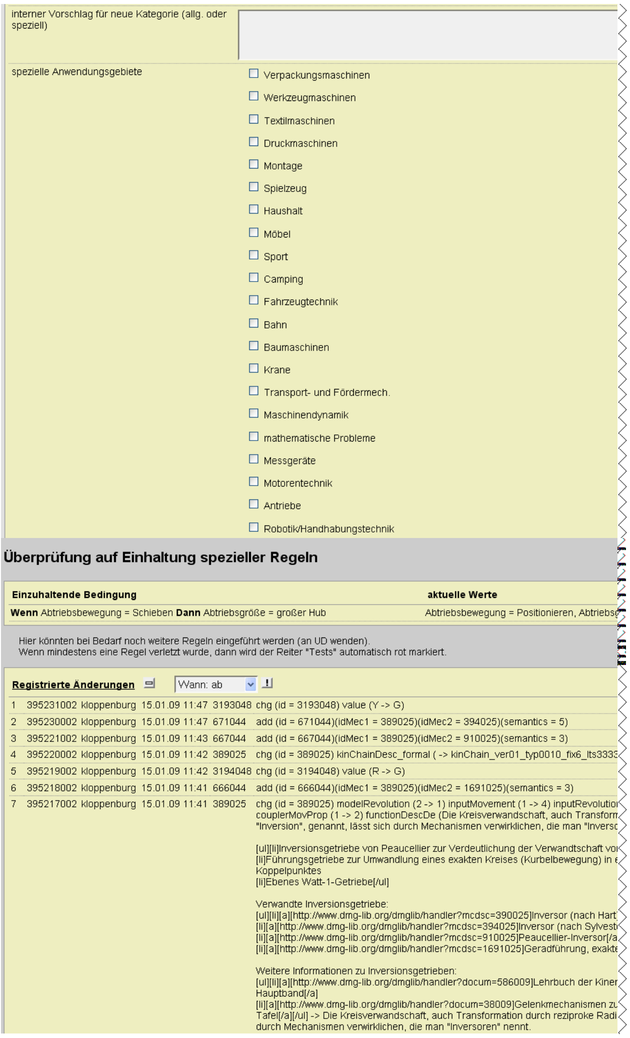


Fig. 14. Form „Fields of Application“, and information regarding consistency and change logging

On submitting the search term “inversor” the DMG-Lib database returns the result list shown in Fig. 15. Selecting the entry “Inversor according to Peaucellier” from the list leads to a presentation of the complete metadata set which includes links to further information (Fig. 16).

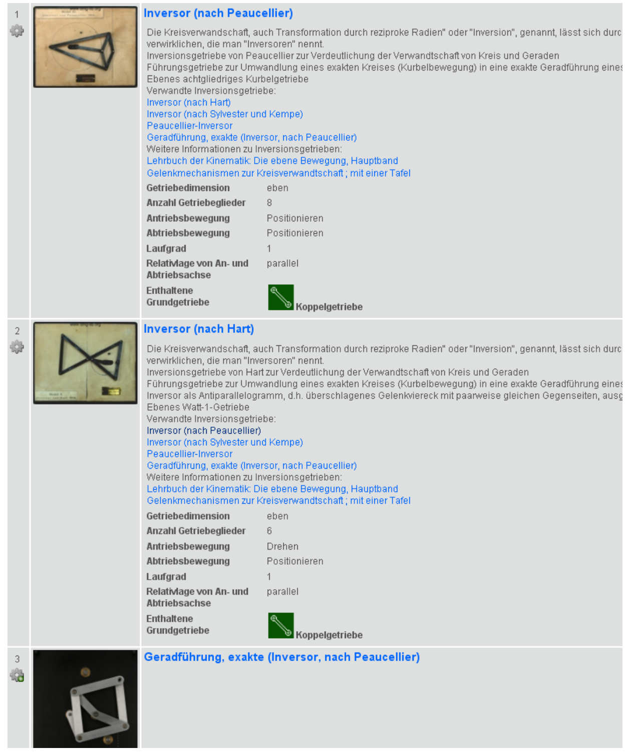


Fig. 15. Excerpt from the result list for the search term “inversor”

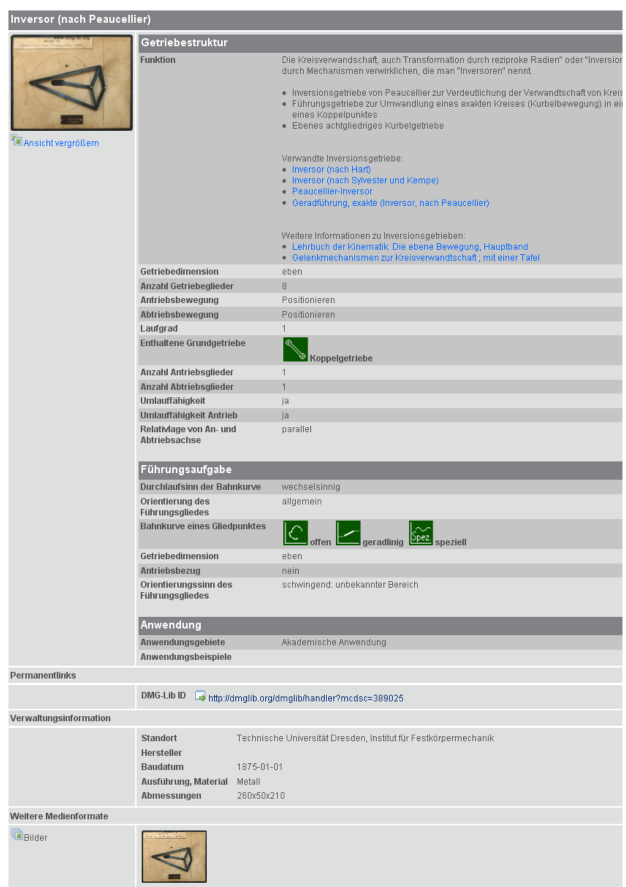


Fig. 16. Metadata set of the Peaucellier–Lipkin inversor (DMG-Lib)

Examples found in the solution repository can be the starting point of real applications. Fig. 17 shows possible implementations of the Peaucellier–Lipkin inversor. They demonstrate how historical designs and ideas may inspire solutions for present-day tasks and support the comprehension of kinematic knowledge.

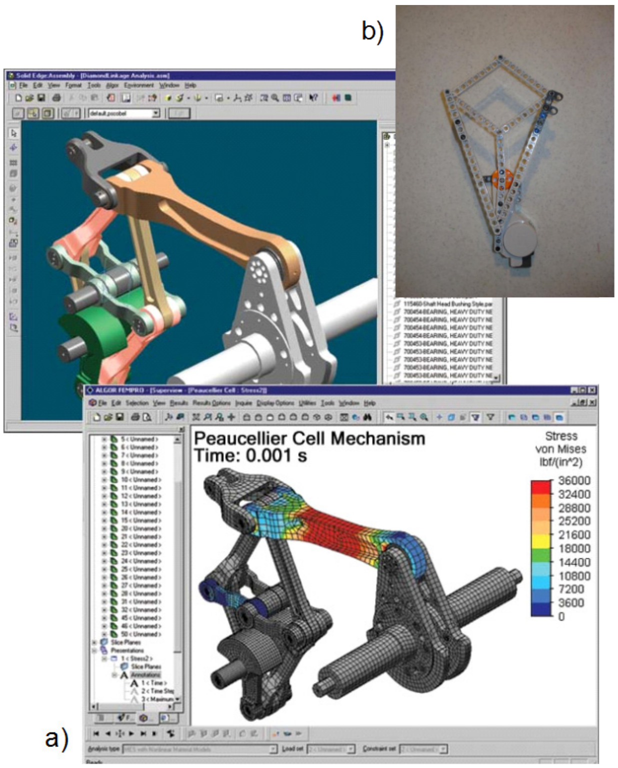


Fig. 17. Example applications of the Peaucellier–Lipkin inversor
a) Mechanical engineering application [6]
b) Example from the Lego Mindstorms website [5]

In the future, the specification of a unified, basic metadata set may simplify the description of solutions for motion systems. This applies particularly to current solutions. The basic metadata set would also help solving the problem of lacking cross-linking between existing digitalisation projects in the field of motion science.

VI. Conclusion

Without doubt, digital solution repositories are important for motion science. This certainly applies to historical solutions whose value for the engineering designer shows in many aspects of the design process. In recent years there have been a number of projects trying to implement the idea of a freely accessible solution repository, typically on a smaller scale. However, they scarcely fulfil the requirements and expectations of engineering designers concerning content and accessibility. There is no uniform way of describing motion systems and linking between existing repositories. This complicates the search for information on motion systems. The DMG-Lib project implements and proposes a metadata set that also considers the engineer's view on information access. Providing accurate and trusted metadata of motion systems is a scientifically demanding task. Using a sub-set of the tools described in [18], DMG-Lib developed a web-based database that allows collaborative work of all interested experts who wish to expand the collection. Such a tool is a necessary prerequisite to achieve the aim of a high-quality solution repository.

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