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Use-Inspired Basic Research: Improved Understanding and Innovative Products - a Case Study

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Introduction

In the international debate about design research various approaches and perspectives have been described. Special interest aroused the practice-based design research. Referring to a case study -- the long-term research projects conducted at the C_Lab for customization design at the Academy of Art and Design Offenbach and funded partly by grants from the German Federal Ministry of Education and Research -- it can be pointed out how theoretical-philosophical basic research and conceptual-applied research can be combined with experimental design. The research complied wih the characteristics of "best practice" as stated by Nigel Cross (2000): it was conducted in a purposive, inquisitive, informed, methodical and communicable manner. The borders of reflection were extended by new knowledge and at the same time also on practical level by experimental design and a range of marketable products.

Furthermore this paper will demonstrate how the research covers basic research and applied research according to the definitions by Siegfried Maser (1987), Richard Buchanan (2001) and Ken Friedman (2003). Nevertheless the research work of the C_Lab contradicts the likewise widely accepted linear model: Curiosity driven basic research leads to new knowledge; the application of the knowledge comes later and is usually achieved by other people. More applicable to the research conducted at the C_Lab appears a concept of a use-inspired basic research presented by Donald E. Stokes (1997), which leads both to improved understanding and to innovative products and processes. Knowledge creation was never a self-sufficient l'art pour l'art, but had always possible and probable consequences and results in design practice in view. It should serve as guideline and point of reference for future design practice, so that professional designers can adjust to changing basic conditions in their field. In order to bridge the gap between theoretical discourses on the one hand and the design object "translating" the hypotheses into a visual language on the other, experimental design work accompanied knowledge creation.

Case Study: Customization Design at the C_Lab

The C_Lab at the Academy of Art and Design Offenbach (Germany) was founded by Jochen Gros and Friedrich Sulzer in 1995 with the goal of working on a specific subject throughout the next years -- the transition from industrial mass production to a computer-assisted, flexible manufacturing. Before it came to this institutionalization, Gros was engaged in this research field for years. The acquisition of a computer-controlled milling cutter by the Academy offered the possibility for intensified research. As main subject of the C_Lab, Gros and Sulzer defined basic research in the field of mass customization and product semantics, as well as the development of experimental furniture design, appropriate for the new CNC (computerized numerical controlled) manufacturing tools.

Starting point was the hypothesis that the digital info-technologies combined with the computerized manufacturing tools do not cause a continuation of the industrial production on a higher level, but that the computer tools are in its character a "post-industrial" technology. It will bring cultural and economic changes that are just as far-reaching as those that accompanied the industrialization of the world in the 19th and 20th centuries. Economists described this change from industrial mass production to computer-integrated, flexible manufacturing with new terms like "flexible specialization" (Piore/ Sabel 1984), "virtual production" (Davidow/ Malone 1992), "mass customization" (Pine 1993), and "customer-individual mass production " (Piller 1998). In the view of these authors, the advance of the digital production is mainly a technological and economical challenge, whereas Gros (1987, 1995, 1997, 2001) argued as one of the first that the technological change would also have serious consequences for industrial design. This discipline, which had gained its profile and its central principles during the industrialization, will change with and by the announced structural change: "Thus I imagine ... that a discipline, which calls itself industrial design must really count on it, to be shaken up, when the explicit point of reference, the industrial production, revolutionizes itself." (Gros 1987)

This hypothesis was based on a lesson from design history. Gros (1997a,b, 2001a) compared the challenge of the transition from crafts to industrial production at the beginning of the 20th century with the present task to interpret the transition from the industrial to the post-industrial production. The problem of adapting products to fabrication and of ensuring compatibility between product design and the system of production is basically the same. Those key questions in design, which were answered at that time by the German Werkbund, the Dessau Bauhaus and the Ulm School with historical validity, came up again due to technological change -- but now under reverse signs. Considering the industrial mass production for anonymous customers the modern avant-garde demanded, with logical consistency, a pure form purged of ornamentation and heraldic signs. Their claim for semantics of style that reflect the industrial production symbolically found an appropriate embodiment for many decades in functionalism and the so-called "Good Form". But today, argued Gros, the digital tools are once again encouraging the personalization of products made in small series or as one-off pieces.

Scenario of virtual production

Inspired by the remarks of the author team Davidow/ Malone (1992) on "the virtual enterprise" 1994/95 the C_Lab team developed a scenario, which transferred the model of virtual production to the specific conditions of the furniture making. It reflects the structural change, promoted by digital technology, using the example of furniture production and comprises the entire process chain -- from product development and customer communication to production and distribution. The scenario of virtual production (figure 1) presumed that the cards would be reshuffled and that new actors would take the stage in the typical interaction between designers, manufacturers, the trade and customers that had emerged in the course of industrialization. Moreover, product design and development would have to be adjusted to the new conditions. Emphasising the need for innovation new terms were coined like "technofactury", "product publisher", "product gallery" and "customer as co-designer".

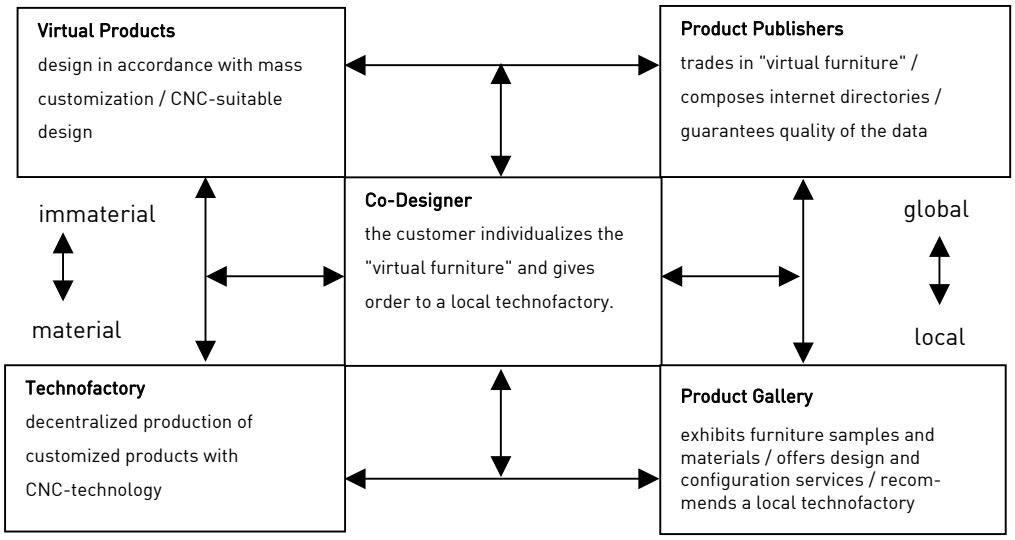

Fig.1: Scenario of virtual production

1. *Virtual products*: Given the fact that production technologies have a great impact on product design – at least in the field of furniture – computer numeric controlled technologies afford completely new CNC-suitable designs. Neither traditional trade design nor modern industrial design is suited to the new technologies and to mass customization (Gros 1995, 2001a, b) If this precondition becomes a fact, a "virtual product" – i.e., a ready-for-use dataset for machine control – can be "materialized" with computer-controlled tools, just as a text or graphic can be printed by a laser printer. Ideally, the furniture would be fully defined through its digital production program, thereby allowing it to be sent as a data file via the Internet and produced at any given location by a company that has CNC technology, but in countless versions according to the wishes of individual customers. Since the transportation of data via the Internet is cheaper and faster than the transportation of material goods via the highway, this will lend an impetus to a regionalization of production.

2. *Product publisher*: At the same time, however, the data network and the fact that the development of "virtual products" neither pays in a regional market nor can it be realized by small manufacturers, should tend to lead to a globalization of the trade with digital product design. This task could be fulfilled by the management of an "electronic directory" by a product publisher -- similar to traditional pattern books -- in order to mediate between the design offers of the designers, on the one hand, and the design demands of small and medium-sized producers, on the other.

3. *Technofactury*: Furthermore, it can be expected that digitized furniture production will develop beyond the traditional joiner's or locksmith trade. Since a wide variety of materials like wood, wood-based materials, acrylic, glass, metal, etc. can be processed with the digital tools, the neo-craft production of the future will organize itself in a cross-material and cross-craft way. This "technofactury" will be equipped with cutting-edge technology but will function following the old model of manufacturing in a decentralized and custom-tailored way.

4. *Product gallery*: Since the technofacture produces only upon receiving an order and on site, the former furniture trade becomes superfluous. A combination of an Internet presence and a local product gallery that presents patterns, material samples, etc. and consults with customers with respect to the configuration of their furniture seems more favorable. The product galleries, which require less exhibition space and lower margins than a traditional furniture store, can be operated within cities. However, they can also be affiliated with a technofacture and offer all of the advantages that make sales outside the workshop attractive.

5. *Customer as co-designer*: Given the increasing possibilities of co-designing the production process, the customer has already been described as "co-producer" (Davidow/ Malone 1992). In order to express the increasing influence of the customer on the design, which not only comprises the measurements, materials and colors but also the artistic manner of surface design, the term co-designer was coined.

CNC-compatible furniture design

This scenario was basic for the further research at the C-Lab, which focused on the question of a CNC-compatible furniture design and a renewed change of semantics of style, which was both examined theoretically and explored with experimental products. Following the hypothesis of the virtual product, several research projects developed and tested wood joints. Traditional Japanese and European joints were modified in such a way, that they can be produced in a single pass of the piece of furniture via 3-axle CNC milling. These so-called digital wood joints replace special fittings, reduce production costs, and facilitate the assemblage of the furniture. As integrated joints, they become both constructive elements and design characteristics of the furniture form. (Figure 2a-d) A second construction principle is a so-called folding technique. It allows for the folding of coated panels into furniture bodies, similar to origami. The boards, which have a flexible, tear-proof coating, are milled in a V-shape via CNC and then folded; the coating serves as a connecting joint. (Figure 3)

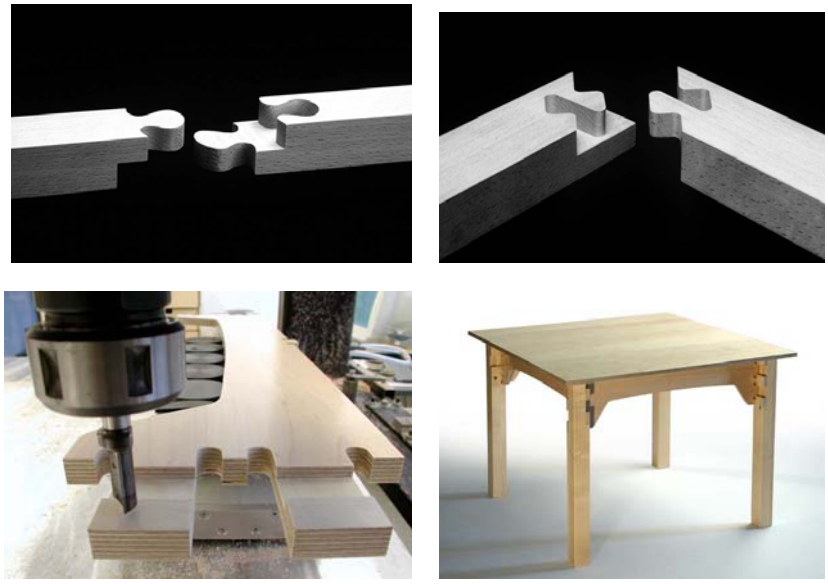

Fig. 2 a-d Digital wood joints, table with digital wood joints (design: Jochen Gros)

Fig. 3 Milling and folding of a table

Art Customization

The feasibility study "Art Customization, New Arts-n-Crafts with computer-controlled tools" (Gros et al 2001) extended the question concerning CNC-compatible furniture design. Jochen Gros examined the challenge of customer-specific design and individual design processes that perceive the customer as co-designers. Since a first generation of mass customization enterprises offered only superficial product variations, without symbolic commitment and real plurality, Gros suggested the concept of art customization and a "New Arts-n-Crafts" movement. In order to gain more authentic forms of product differentiation and individualization, he referred to the potential of the applied arts as a source for aesthetic segmentation with a purposeful and identity-creating meaning. Applied arts, he argued, could embody the highest degree of expressing individualism and personality. (Gros 2003) One of the first experiments in this direction was the making of a chest decorated with a relief designed by the Frankfurt sculptor Frank Reinecke. Both chest and ornament were made entirely by computer-assisted tools. The starting point was a photo of motifs carved on rock in Africa by Reinecke for the Trixel Planet project. The photo was scanned, with dark and light parts converted into volumes and then formatted in triangular DXF format (using AutoCAD software). The polygonal product was then configured for the lathe that cut the design onto a laminate. (Figure 4) Of course, this experiment is only a beginning. "Yet the creative use we make of the new tools still lags far behind the technical developments. It is comparable to a concert grand on which somebody is bashing away at "Three Blind Mice", argued Gros (2001a).

Fig. 4 Chest, decorated with a relief by Frank Reinecke

Decentralized technofactury and the pilot project Newcraft

This scenario of virtual production was also basic for the question, whether the industry or the trade will approach the goal of a custom-tailored furniture production based on digital technology. While the economic science analysed the technological change from the perspective of strategic changes in industry, Gros opposed this point of view with the hypothesis that the digital tools -- for the first time since the industrialization -- will increase the competitiveness of decentralized production in joiner's trade. The Arts and Crafts movement at the end of the 19th century, the alternative handicraft in the 1970ies and finally the "New Design" in the

1980ies, which argued for different reasons for a crafts production, mainly failed because of the inferior productivity. But nowadays around 15 percent of the trade is equipped with the same computer tools as the furniture industry. Seen from this perspective, the technological change opens up the chance for "socio-cultural hopes", such as holistic forms of human work and an ecological decentralized manufacturing of products, which are for manufacturers and users meaningful and significant, argued Gros.

For deeper analysis Willy Bierter, Christine Ax and Dagmar Steffen (Gros et al 2001) investigated into regional-economic, ecological, work-sociological and design-historical aspects of the trade production. As has been shown, this time the technological change is also in unison with ecological demands and the goals for a sustained regional development. All decentralized production, service and marketing possibilities are of special importance. For the regions the achievement of being prepared for the future means, above all, less imports and exports of materials and an increase of the local economic cycle, and thus the preservation of the substance of the natural potentials. In addition, a decentralized furniture production in joinery workshops or technofactories offers a societal meaningful perspective to the "working society" which could run out of work. Manual labour always has a high ranking in alternative working worlds. The trade and the craftsman's work often prove to be the kind of work people takes up if they do "what they really, really want". To summarize, a decentralized new form of digital "Arts-and-Crafts" production might contribute to solutions, urgently needed in a country with a high unemployment rate.

Encouraged by this perspective the C_Lab and the Craft Union of Joinery in North-Rhine Westphalia initiated a co-operation between ten large CNC-experienced joinery workshops. A range of experimental products developed at the C_Lab was improved with regard to costs and market conditions. Under the registered trademark Newcraft the joinery workshops offered these pieces of furniture in custom-tailored versions for private customers.

Analysing the case study: Basic research on the foundations of design history

On the basis of Siegfried Maser's (1987) and Richard Buchanan's (2001) definitions of basic research the research work at C_Lab covered questions and hypotheses, which can be assigned to this level. The discourse on a radical change of production technology, on its product-semantic implications, on the roles of designer, user and producer during the product development process, finally also the discourse on the social, cultural and ecological responsibility of the designer beyond product design -- these issues interlace the history of handicraft and industrial design for more than 150 years, as can be shown by lots of historical texts. (Breuer 1998, Conrads 1970, Die Neue Sammlung 1975, Fischer/ Hamilton 1999) Research questions concerning these issues certainly belong to the "fundamental questions of a field of knowledge" addressed by Maser; following the definition of Buchanan the hypotheses formulated by Jochen Gros might be "in their implications important and extensive".

As has been shown in the presentation of the research, central hypotheses, i.e. the scenario of virtual production, the concepts of customization design and art customization, not only question the aesthetic concepts and business models of the design profession. They also promote a change of the more

comprehensive contexts. Neither a continuation of past trends is suggested, nor the strategy of mass customization as described by economists was transferred uncritically to the field of furniture production. Instead alternative possibilities were reflected, which could give a conclusive answer to acute problems in society. If Victor Margolin (1998) argued that William Morris' "arguments are still persuasive as we struggle to make sense out of current turbulence of technological innovation", he addressed substantial motives of the work of the C_Lab. Apart from an approach to the idea of an holistic work aspired by the Arts and Crafts movement, later by the alternative handicraft and the New Design it seemed possible to contribute to the maintenance or even to the creation of qualified jobs in a high-wage country and to a sustained regional development.

Thus the basic research reflects future design practice in a larger societal context without losing sight of design specific questions. Gros' hypotheses contribute to design knowledge, by which the discipline cannot only distinguish itself from other disciplines, but which was also acknowledged by them. Thus for example the term Art Customization was taken up by the economists with interest (Tseng/ Piller 2003), because they had not been recognizing that the success of the mass customization will depend substantially on a design concept, which does not offer a simple and arbitrary variety of products to the customer, but which translates the specifics of the new technology into adequate product semantics. Neither the economists were competent to develop a suitable aesthetic concept.

Broadly speeking Jochen Gros picked up with his hypotheses -- post-industrial customization design, neo-crafts art customization, and the scenario of virtual production -- important issues of design history and spun out hypothetically with view at the present technological developments and basic cultural and societal conditions. The coinage of new terms focused the perception and the discourse on design in radically changing contexts, to which Nigel Cross (2001) contributed his considerations on "Post-Industrial Design Education" and John Heskett (2002) his text "Waiting for a new Design".

Applied research and experimental design

Parallel to the basic research the C_Lab accomplished applied research, which is -- according to Buchanan (2001) -- "directed towards problems that are discovered in a general class of products or situations", with the goal to "discover some principles or even rules-of-thumb". It focuses on questions about the concrete effects of the digital technologies on furniture design, i.e. generalizable design criteria and concepts for a CNC-compatible design. On the basis of the found characteristics of the digital technology and principles described in the economic literature, hypotheses were proposed, as for instance the demand for digital wood joints and "100% CNC". In a next step the verbal hypotheses were "transferred" into experimental furniture design. Gros and the C_Lab team developed objects, which embodied the cognitive content of the hypothesis and thus have to be regarded as an equivalent component of the design research. Hence the research confirms an argument made by Michael Biggs (2002): "... design is advanced using both text and artefacts. ... Neither writing alone, nor making alone, are sufficient to represent a whole concept."

It is obvious that the design and realization of the experimental furniture aimed at different goals than a professional design process. Considerations such as production costs or preferences of certain target groups were ignored at this stage. Rather the role of the products in the context of design research might be compared with the role of experiments in the experimental sciences, such as physics, chemistry, biology or psychology: They serve as proof of hypotheses, which they verify or disprove. Both in their function as proof or refutation of hypotheses they contribute to knowledge.

Knowledge creation and experimental design practice took place in iterative hermeneutic circles, while mutually inspiring and correcting. First a design, which aims to explore the specific possibilities and borders of a new tool, presupposes inductive speculations and provisional hypotheses. That is, that the specific formative qualities of a new technology are to be interpreted creatively on the basis of previous knowledge. Without such an interpretation by the designer it is very likely that the technology is only used for the rationalization of the manufacturing of conventional product designs and constructions. Historical examples such as the machine punched and pressed ornaments in historicism demonstrate this as well as current examples: those industrial and trade enterprises, which use the digital tools only for manufacturing box furniture, variable in size and material. The specific qualities and formative potentials of the digital tools are in no way exhausted with such designs, which still correspond with the characteristics of the industrial production. In order to develop a new CNC-compatible product design, first hypotheses are to be made, which in the next step need to be interpreted by an appropriate design and embodied in an experimental product. If professional designers may work mostly on the basis of implicit hypotheses -- is it, because they regard theory formation not to be their task, is it, because they miss terms and theoretical frameworks, on which the hypotheses has to be based -- the underlying hypotheses in the research work of the C_Lab were stated explicitly in principle, justified comprehensibly and published (Gros 1995, 2001, Steffen 2003). Certainly the coherence of the artifacts designed at the C_Lab is due to the fact that the design criteria were clearly defined at the beginning and re-defined if necessary.

Regarding the role of the experimental design projects within the research work, two functions can be mentioned. On the one hand they serve to illustrate or concretize the ideas and -- as described above -- to "translate" the hypotheses into a descriptive visual form. Thus for example the chest illustrates the concept of art customization. In place of the relief, created particularly for this purpose by Reinecke, certainly other motives or completely different design concepts could concretize the hypothesis of product individualization and personalization with means of the applied art; the experimental design was only an exemplary representation. Nevertheless such experiments run the risk to be misunderstood: for example, if the audience picks up the concrete example, without noticing the underlying hypothesis or theory. Gros (1987) was quite conscious about this risk: "Visual thinking and discussion about the concrete design example is important for the linkage of design theory and practice, but it also has its disadvantages. The assessment of the underlying ideas and hypotheses easily narrows on what the examples show obviously, instead of also including, what could still develop from it."

Apart from this illustration function the experimental product design at the C_Lab had a second function, i.e. the investigation and testing of the technical possibilities. This was clearly the case with the engraving of the relief onto the chest. Another example is the C_stool. Ten years ago, this piece of furniture was a first proof that completely digitised so-called virtual furniture is able to travel via Internet, to be made according to the wishes of the customer in any joinery workshop or technofactory equipped with numerical tools. The successful realization of the experiments validated both, the basic as well as the applied research. The extent, to which the experiments correspond with the theory, confirmed the experimental products and the hypotheses.

Not all experiments run successfully. So the pilot project to establish with Newcraft old-established joiner's workshops as technofacturies and distributers of furniture for customers failed. Although they succeeded in the final step from experimental products to competitive prototypes they failed in market entry. The analysis showed that the missing marketing experience of the trade was a serious hurdle. Do we have to conclude from this failed experiment that the underlying thesis of a regionalization of the furniture manufacturing is wrong? Contrary to that is the fact that there are several active enterprises in this field, which come close to the idea of a technofactury. Also the later research on decentralized mini factories conducted at the Technical University Munich contradicts. Therefore the failure of Newcraft might be due to interference factors, unfavourable surrounding field conditions, and last not least the fact that other components of the scenario of virtual production, such as the product publishers and product galleries, are still missing.

Conceptual framework of use-inspired basic research

The presentation and analysis of the design research conducted at the C_Lab proves that the case study combines a quest for fundamental understanding and knowledge creation with applied goals, experimental design and last not least marketable product development. The interest of independent university-based design researchers in applied goals and current technical and societal developments has not precluded an interest in fundamental understanding and design history. On the contrary, design history and design semantics helped to frame the currant challenges more clearly. Thus, the case study confirms Donald E. Stokes (1997) view of the relationship between research for understanding and research for application should be cooperation, not opposition. He declared: "The belief that the goals of understanding and use are inherently in conflict, and that the categories of basic and applied research are necessarily separate, is itself in tension with the actual experience of science." (Stokes 1997, p.12) As proof for his argument Stokes refers to Louis Pasteur's late work, which represent an impressive synthesis of the goals of understanding and use. For the purpose of clarifying the relationship of understanding and use goals of research he suggests a two-dimensional conceptual framework with four quadrants. (Figure 5)

Stokes stated that the upper left-hand cell comprises "basic research that is guided solely by the quest for understanding without thought of practical use". This cell he called "Bohr's quadrant" since Niels Bohr's quest of a model atomic structure was a purely curiosity-driven voyage of discovery at that time. The lower right-hand cell "includes research that is guided solely by applied goals without seeking a more general understanding of the phenomena of a scientific field". Stokes named this cell "Edison's quadrant", in mind Thomas Edison and his research team, who developed the commercially marketable electric lighting, while

wholly uninterested in the deeper scientific implications of their discoveries. The upper right-hand cell "includes basic research that seeks to extend the frontiers of understanding but is also inspired by considerations of use". According to Stokes, it deserves to be known as "Pasteur's quadrant" in view of how clearly Pasteur's drive toward understanding and use illustrates this combination of the two goals.

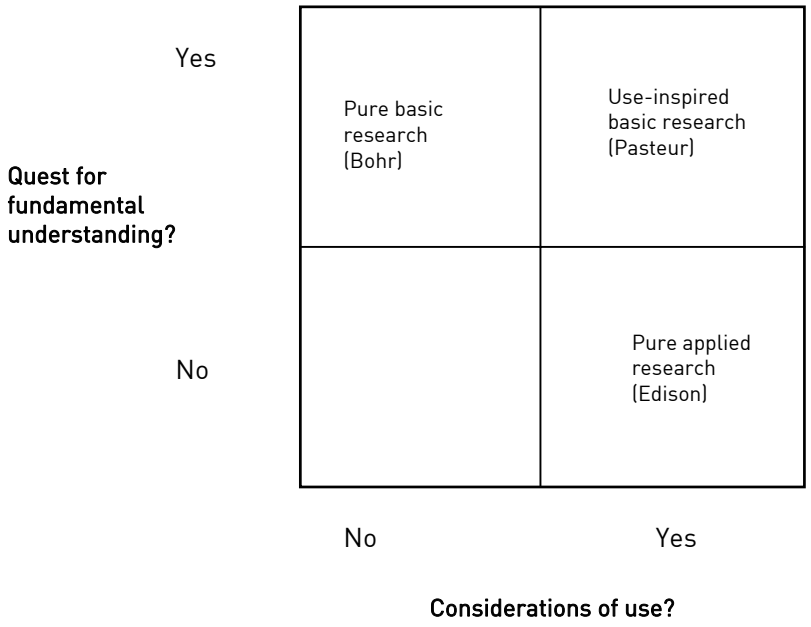

Figure 5 Quadrant Model of Scientific Research (Stokes, 1997)

Applying this framework to the above-presented case study it seems appropriate to place the research conducted at the C_Lab in the upper right-hand "Pasteur's quadrant". Furthermore, it questions the linear model of innovation, the so-called "chain of innovation". (Bonsiepe 1995) Stokes stated his framework to research in all scientific fields such as physical sciences and engineering, the biological and biomedical sciences, and the social sciences. As has been shown, design is a further field for research that is related to problems of application and use; and without doubt it is also concerned with fundamental understanding and interpretation of societal concerns.

References

Biggs, Michael (2002) "The Rhetoric of Research", in: Durling, David/ Shackleton, John (eds.). *Common Ground*, Proceedings of the Design Research Society, International Conference at Brunel University, Stoke-on-Trent, Staffordshire University Press.

Bonsiepe, Gui (1995) "The Chain of Innovation. Science, Technology, Design", in: *Design Issues*, Vol 11, No 3, pp. 33-36.

Breuer, Gerda (ed.) (1998) *Ästhetik der schönen Genügsamkeit oder Arts&Crafts als Lebensform*, Vieweg & Sohn Verlagsgesellschaft, Braunschweig, Wiesbaden.

Buchanan, Richard (2001) "Design Research and the New Learning", in: *Design Issues*, Vol 17, Nr. 4, pp. 3-23.

Conrads, Ulrich (ed.) (1970) *Programs and Manifestoes on 20th Century Architecture*, Cambridge. MA: MIT Press.

Cross, Nigel (2000) "Design as a Discipline", in: David Durling and Ken Friedman (eds.) *Doctoral Education in Design: Foundations for the Future*, Conference Proceedings La Clusaz. Stoke-on-Trent: Staffordshire University Press, pp. 93-100.

Cross, Nigel (2001) "Post-Industrial Design Education", Conference Proceedings, International Congress of Societies of Industrial Design (ICSID), Seoul, Korea.

Davidow, William H. / Malone, Michael S. (1992): *The Virtual Corporation*, *Structuring and Revitalizing the Corporation for the 21st Century,* Harper Business, Harper Collins Publishers, New York.

Die Neue Sammlung (ed.) (1975) *Zwischen Kunst und Industrie: Der Deutsche Werkbund*, Munich, Die Neue Sammlung.

Fischer, Volker/ Hamilton, Anne (eds.) (1999) *Theorien der Gestaltung, Grundlagentexte zum Design*, Verlag form GmbH, Frankfurt am Main.

Friedman, Ken (2003) "Theory construction in design research: criteria: approaches, and methods", in: *Design Studies,* Vol 24, Nr. 6, p.507-522.

Gros, Jochen (1987) "High-Tech-Avantgarde", part 1, 2, 3, in: *form, Zeitschrift für Gestaltung*, No. 117, No. 118, and No. 119.

Gros, Jochen (1987) "Designvielfalt durch Roboterhandwerk", in: Lucius Burckhardt, Internationales Design Zentrum Berlin (eds.): *Design der Zukunft*, DuMont Buchverlag, Köln.

Gros, Jochen (1995) Virtuelle Alternativen, in: Dagmar Steffen (ed.): *Welche Dinge braucht der Mensch?*, Frankfurt am Main, Anabas Verlag, pp. 176-183.

Gros, Jochen (1997a) "Semantic of Style, The Ornament in the Age of new Technologies", in: *formdiskurs, Journal of Design and Design Theory*, No. 3, Vol 2, 1997, pp.82-93.

Gros, Jochen (1997b) "Design Postindustriale/ Postindustrial Design", in: *Domus, Architecture Design Art Communication*, No 799, December 1997, Editoriale Domus Spa, Rozzano Italy.

Gros, Jochen (2001a) "Customization Design and Art Customization", in: *Design Report*, No. 10, October 2001.

Gros, Jochen (2001b) "Furniture Industry Has to Reconsider all Products – Call it Customization Design", Proceedings of the Mass Customization and Personalization Congress 2001, Hong Kong, October 2001.

Gros, Jochen/ Steffen, Dagmar/ Ax, Christine/ Bierter, Willy (2001) *Art-Customization, NewArts-n-Crafts mit computergesteuerten Werkzeugen*, Feasability study, conducted at the Academy of Art and Design Offenbach, commissioned by the German Federal Ministry of Education and Research.

Gros, Jochen (2003) "Art Customization, Individualization and personalization are characteristics of art", in: Mitchell M. Tseng/ Frank T. Piller (eds.) *The Customer Centric Enterprise, Advances in Mass Customization and Personalization*, Springer, New York, Berlin.

Heskett, John (2002) "Waiting for a New Design", in: *form. The European Design Magazine.* No. 185, September/ October 2002, Birkhäuser Verlag GmbH, Berlin.

Margolin, Victor (1998) "History, Theory, and Criticism in Doctoral Design Education", in: Buchanan, Richard et al. (eds.) *Doctoral Education in Design*, Proceedings of the Ohio Conference, Pittsburgh, Pennsylvania: The School of Design, Carnegie Mellon University, p. 197-206.

Maser, Siegfried (1987) "Form and Vision", speech at the UIAH Helsinki, 1987; published under the title "Design als Wissenschaft", in: Böversen, Fritz (ed.) *Lehrerausbildung in Wuppertal.* Vol 2, Wuppertal 1989.

Piller, Frank T. (1998) *Kundenindividuelle Massenproduktion, die Wettbewerbsstrategie der Zukunft*, Hanser, München, Wien.

Pine, Joseph B. (1993) *Mass Customization, The New Frontier in Business Competition*, Harvard Business School Press, Boston.

Piore, Michael/ Charles Sabel (1984) *The Second Industrial Divide, Possibilities for Prosperity,* New York: Basic Books.

Steffen, Dagmar (2003) *C_Moebel, Digitale Machart und gestalterische Eigenart*, Anabas Verlag, Frankfurt am Main.

Steffen, Dagmar/ Gros, Jochen (2003) "Technofactory versus Mini-Plants: Potentials for a decentralized sustainable furniture production", in: Piller, Frank/ Reichwald, Ralf/ Tseng, Mitchell (eds.) *Leading Mass Customization and Personalization from an Emerging Stage to a Mainstream Business Model*, Proceedings of the Mass Customization and Personalization Congress, Technical University Munich.

Stokes, Donald E. (1997) *Pasteur's Quadrant, Basic Science and Technological Innovation*, Brookings Institution Press, Washington, D.C.