FROM DBT TO TDB – A NEW APPROACH TO DESIGN-BUILD PROJECTS

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ABSTRACT

CDIO emphasizes active and experiential learning. One of the characteristics of a true CDIO engineering programme is that it contains two or more design-implement projects (CDIO Standard #5). CDIO institutions therefore have well equipped laboratories available to their students. Academic development projects are often carried out in the sequence Design – Build – Test (DBT), resembling the prevalent industrial development process. In this, an early decision is made on which solution to the problem at hand should be developed, after which a prototype is built and tested while attempting to meet all conditions put up by the market and other stakeholders. One of several drawbacks associated with this approach is its haphazard selection of the best alternative among several unfinished designs. In recent years, an alternative development method has attracted positive attention. This "Lean Product Development" (LPD) philosophy implies that careful attention should be given to the earlier stages of the development process, in order to gain sufficient knowledge to solve the problem. To align academic design project with the LPD philosophy, we propose a shift in design-build experiences from the Design – Build – Test of today to the Test – Design – Build (TDB). By teaching TDB, the activities central to the process of developing new products and systems are enhanced. It provides a foundation upon which deeper conceptual understanding can be built, and is thereby well aligned with the CDIO principles. The proposed shift from DBT to TDB also makes design-build experiences applicable to engineering disciplines where size and cost of prototypes have previously been obstacles to implementation, such as architecture and civil engineering. However, a TDB approach put higher demands on the educational institutions, both in the form of resources in labs and workshops, and in the form of teacher competence, which is what this paper discusses.

KEYWORDS

LPD, Lean Product Development, TDB, DBT

INTRODUCTION

CDIO Standard #5 states that a true CDIO engineering programme contains two or more design-implement projects [1]. These projects can be described by [2]:

> *"A design-build-test experience is a learning event where the learning takes place through the creation of a product or system. The product that is created in the learning event should be developed and implemented to a state where it is*

operationally testable by students in order to verify that it meets its requirements and to identify possible improvements."

In academia, an often used acronym which designates the prevalent sequence in which these particular events appear in student projects is DBT [3] (Design-Build-Test). Judging from popular European and North American textbooks [4, 5], this is also their order in most industrial companies. Somewhat simplified and exaggerated, this development process often follows the pattern in figure 1. The development project begins with a detailed specification of the characteristics of the product to be developed, created through lesser or greater input from customers, followed by generation of different ideas of how to solve the problem. Proposed solutions are often based on existing ones, and the choice of the best alternative to develop among the solutions tends to be made fairly quickly, before the space of possible solutions has been explored. The chosen concept is then designed and a prototype is built to test if it fulfills the conditions set out in the specifications.

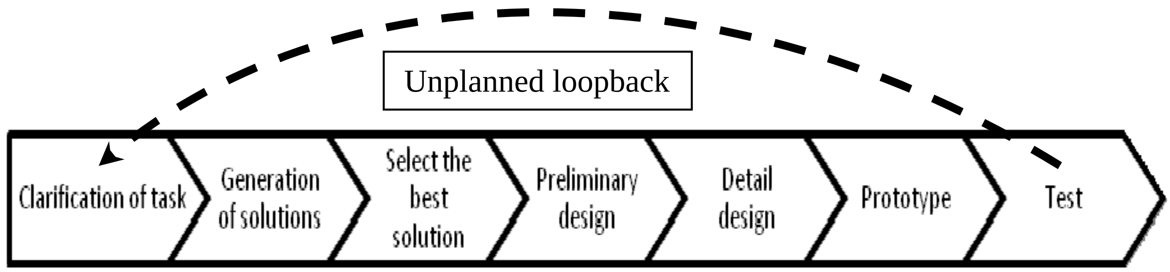

Figure 1: A generic product development process

Drawbacks of a traditional Product Development process

Despite the popularity of the DBT development process, it is easy to spot several weaknesses and potential sources of difficulties in the process which can easily make development projects run late and exceed budget limits. One reason for delays is that if detailed conditions that have to be met by an approved design are set out early in the project, there is an inherent risk that such a solution does not exist or at least is not possible to find within the time allotted [6].

Another drawback associated with this work model is that an early choice of the alternative to develop does not stimulate attempts to investigate the whole space of possible solutions [7], but rather the opposite, which means that better solutions are easily overlooked or even never discovered. A third disadvantage is the classic risk associated with putting all your money on only one horse. For if the chosen candidate does not to deliver what is expected of it, a loopback (see figure 1) is necessary in order to find a replacement solution which almost inevitably delays the project and increases the cost of it. In extreme cases it may be necessary to return all the way back to the fundamental question of what the task at hand is, if that for some reason was not clarified before design work commenced.

So, it is relevant to ask if there isn't a better way to develop new products than using DBT?

NEW INSIGHTS INTO THE PRODUCT DEVELOPMENT PROCESS

An alternative PD process which deals with the problems above and is attracting increasing interest is that of Lean Product Development (LPD) [6]. Originally, LPD was a generic name for techniques, methods and a philosophy used in some Japanese industrial companies, notably the car maker Toyota [8]. Now, the acronym also represents developments of these methods at Western companies and universities. The underlying idea in LPD is to use work methods and tools that help reduce all sorts of waste in the product development process, that is, unnecessary work, delays and everything else that slows down work and hampers efficiency.

From a CDIO point of view, the LPD ideas are well aligned with the CDIO framework for engineering education, not least in the design-build phase but also when it comes to testing. The LPD way of working has a learning focus that provides a foundation upon which deeper conceptual understanding can be built. It starts from the awareness of a problem and a rough idea of what the characteristics of a solution to it are, but no detailed conditions are set. The lack of precise requirements to be met stimulates a search for possible solutions that is not limited to and based on existing designs, rather the contrary. Experimentation and knowledge discovery, the importance of which is highlighted in CDIO, is natural if there aren't any precise conditions that restrain the imagination. It also becomes obvious and natural to proceed among more than one track and investigate different alternatives in parallel. On basis of knowledge gained by increasingly rigorous evaluation and comparisons – which always deserves to take precedence over preconceived ideas – inferior solutions are successively discarded and eliminated in the PD process until the most promising one is arrived at, securing that on the way all concepts have received proper attention.

The early LPD testing also reveals any remaining knowledge gaps that have to be closed. To commence detailed design before the technology employed is fully mastered is like introducing a time-bomb in the process which may go off at any time and create chaos. Closing the knowledge gaps greatly reduces the risk of an unpleasant later discovery that the chosen concept cannot be realized for one reason or another, and it also minimizes the need for loopbacks. The LPD approach thus avoids delays in the PD process caused by overoptimistic designs and lack of knowledge necessary to deal with the chosen technology. It is therefore fair to question whether the "standard" PD process model is really the best approach for learning design, or even if it is to be recommended at all.

The rediscovery of a product development process

The emerging interest for the LPD type of processes may indicate that LPD is a new type of product development method, but that is not the case at all. In the early 20th century, the Wright brothers employed an LPD type strategy when they designed their first pioneering airplane. The Wrights, who ran a bicycle repair shop and had taken an interest in aeronautics, very early realized that the three fundamental problems of lift, control and propulsion had to be solved if they would ever be able to fly something that wasn't just a pure glider, and they did not proceed into designing a complete system until they felt that they truly understood them and had the knowledge necessary to master them.

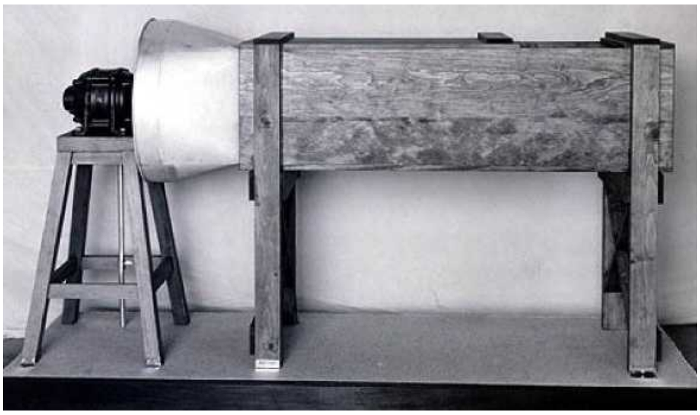

Figure 2: The Wright wind tunnel [9].

The Wright brothers designed a simple pine box wind tunnel, see figure 2, which they used for advanced aerodynamic experimentation with model airfoils, measuring lift and drag on them with balances made of worn out hacksaw blades and discarded bicycle spokes [9]. The data they gained was remarkably accurate and one result of it that relates to the propulsion issue is the propeller they designed to power their aircraft, figure 3. It is surprisingly good for its age, especially considering the limited resources that their designers could devote to development of it, and it is in fact competitive even by today's standards.

Figure 3: The Wright propeller, a near optimal design based on knowledge acquired through testing [10].

The Wright propeller has near optimal design and was superior to their competitors' designs [11], which relied on existing heuristics for steam-boat propellers that worked well in water but not in air, see figure 4.

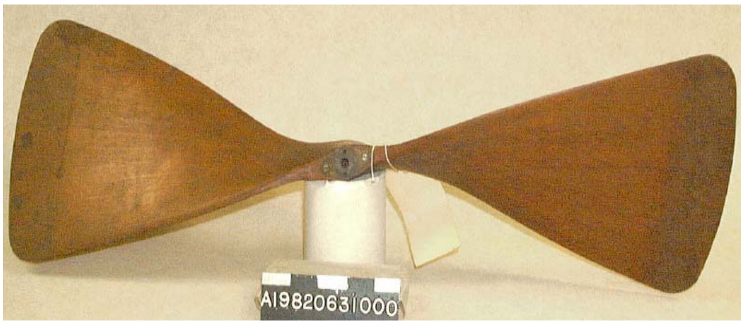

Figure 4: The Langley propeller, designed by knowledge from boats [12].

DESCRIPTION OF THE TDB PROCESS

In the CDIO context, the proposed sequence of events for Design – Build experiences is Test – Design – Build, TDB, rather than Design – Build – Test, and somewhat simplified this resembles the design process used by the Wrights. Having the T in the beginning instead of at the end does not imply that TDB does not contain late tests, it does, but then much more in order to verify than in order to learn. The process is seen in figure 5, where most of the learning is made in the beginning with simple devices, when it is inexpensive, and not at the end with expensive prototypes.

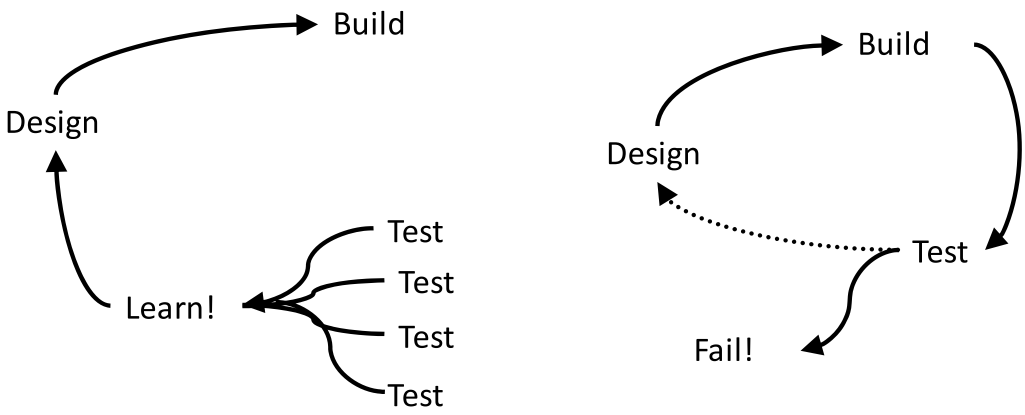

Figure 5: The T-D-B sequence and the D-B-T sequence

The proposed sequence TDB indicates that the process starts with tests, but to be able to perform experiments, there must be a computer model or prototype to test. The main difference between this approach and a traditional development process is the purpose of the test. However, compared to a “standard” PD process a larger share of the total experimental work is dedicated to early investigations and simple and inexpensive experiments, but it does not imply that TDB excludes testing at the end, or that it becomes unnecessary.

One aspect of design-build experiences is that they are differently hard to implement in different engineering disciplines. For architecture and civil engineering, the cost and size of prototypes have previously been obstacles to implementation of DBT-projects. These disciplines have, with few exceptions, been relying on digital representations or scale models of products and systems. In the TDB approach, students could make simple prototypes to evaluate different versions of a window layout, to experience firsthand the effects of alternative exterior design.

The TDB process focuses on learning

The TDB process reinforces the design-build experience as described in [2]: *“A design-build-test experience is a learning event … The product … should be developed and implemented to a state where it is operationally testable by students in order to verify that it meets its requirements and to identify possible improvements.”*

Comparing to the Wrights development practice, they did fly only after mastering all the individual technical challenges in the form of propulsion, lift and control. Their testing and experimental work was extensive but carried out early. When they finally flew, after 22 months of work over four years [13], they had spent only about USD 1000 on their airplane project [14]. This is in stark contrast to the USD 70.000 and 17 years of development work [15] that their US Navy financed competitor Samuel P. Langley invested in his much less efficient and more traditional process of “build, test and try”, which may in when it comes to early flight experiments equally well be described as “build, test and crash”. Another very notable and important difference between him and the Wrights was that despite Langley’s vastly superior resources, he never managed to get his design airborne.

The TDB approach intends to focus on learning about the alternatives in order to find out which of the conceived solutions to the problem that are possible to realize, what works or not, and to close the knowledge gaps. Since the technology employed has already been thoroughly investigated in earlier tests, the final testing is focused on verifying what is basically already known, which means that the level of confidence that things will work at this stage is much higher than what is common in the DBT process. The main differences between ”ordinary” DBT and TDB are summarized in table 1:

Table 1.
Comparison between DBT and TDB projects

	DBT	*TDB*
Alternatives tested	Few (or only one)	Many
Time frame	Tests are carried out late in the process	Tests are carried out early
Reason for tests	Verify compliance with requirements	Exploratory testing in order to learn and find design limits
Models used	Detailed prototypes and advanced models	Simple experiments
Cost	High	Low, initially
Test characteristics	Nondestructive testing	Testing to failure

DISCUSSION OF ACADEMIC IMPLICATIONS, AND CONCLUSIONS

This paper proposes an approach to the design-build experience that is different from the most common one. It emphasises engineering science based on discovery and knowledge of the fundamentals, and a sound, fact-based development methodology in which advancement to the next stage is only made when there are no longer any unclear circumstances.

We know that practical experience of design and manufacturing in a workshop greatly motivates many students for their further engineering studies, so from this point of view a design-build experience is well worth the extra resources needed to carry it out. By employing the learning focus of TDB, we on top of that return to the roots of engineering design and the activities central to the process of developing new products and systems.

The proposal to shift from DBT to TDB in engineering education is based on insights from research in Lean Product Development. Many early tests in order to learn and explore are well aligned with CDIO’s ambition to let engineering students have active learning experiences. However, the TDB philosophy puts even higher demands on the educational institutions compared to the present situation.

If we want to move from today’s DBT projects to projects run according to the TDB sequence, it is important to try to determine what the implications are in terms of time needed, laboratory and workshop resources as well as teacher competence. It should be expected that

- The courses need to be adapted to the new process in that more time will be devoted to lab work
- The total volume of experimentation and testing in a course will increase
- The longer time spent in labs and workshops by students makes it likely that they will demand more supervision there and put extra strain on teaching resources as well as infrastructure
- More tools and machines will be needed, perhaps also more lab space
- The consumption of materials for building purposes will go up
- Lego type or similar equipment for experimentation might be needed
- Safety courses for the students before they are allowed into the labs must come earlier and perhaps also run faster

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