Gamification of Education

Overcoming conflicting sustainability goals in a playful way

Panel: 06 EDUCATION CONCEPTS Less Routine, Breaking New Ground

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- **gamification**
- **lean construction**
- **multidisciplinary teams**
- **cross-disciplinary collaboration**
- **target sustainability design**
- **conflict of objectives**

Introduction

An examination of architecture in practice reveals that robust interdisciplinary collaboration is essential for effectively addressing the significant challenges posed by climate change. Therefore, it is crucial to prepare students for multidisciplinary collaboration. Previous research characterizes architecture and civil engineering education as disciplinary, fragmented, and adversarial, contributing to projects that are of low quality, delayed, and over budget. Integrating collaboration and sustainability principles into the curriculum will better equip students for contemporary, multidisciplinary building projects, leading to higher quality and more sustainable outcomes.[1] To adequately prepare professionals to tackle contemporary sustainability challenges, education through integrated and cross-disciplinary programs, emphasizing high student engagement with real-world applications, is recommended.[2]

A common sustainability challenge for multidisciplinary teams in construction projects is the conflict between minimizing costs and implementing social and ecological measures.[3] Target Sustainability Design (TSD) is a Lean Construction method developed to address this conflict by incorporating quality, social factors, lifecycle costs, an intergenerationally equitable CO_2 price, and the value of the urban mine into the value equation. The method is based on Target Value Design (TVD), which is a widely used approach in Integrated Project Delivery projects but does not account for social or ecological dimensions. TSD enhances this framework by integrating stakeholders—including clients, architects, specialized planners, builders, and users—throughout the tree step process: Set Targets, Design to Targets, and Build to Targets.[4]

In addition to the architect's workspace studio serving as both a physical space and a didactical method for developing design ideas, project courses play a significant role in the framework of architecture education. They enable students to synthesize knowledge across disciplines and simulate professional architectural and construction processes, thereby preparing them for complex, real-world challenges.[5] Given the extended duration of building projects, involving students directly in real-world project processes as case studies is not feasible. Consequently, alternative methods of student-involved teaching in courses are required. One effective approach is the use of simulation games to study project processes. Educators and researchers, particularly in the fields of Lean Construction and Integrated Project Delivery, have experimented with simulation games and serious games in education and training for teaching project delivery methods and have observed significant positive impacts.[6]

Thesis and Research Questions

The central thesis posits that teaching Target Sustainability Design (TSD) through a simulation game encourages students to work collaboratively in multidisciplinary teams throughout all project processes and motivates them to pursue sustainable goals in real-life projects.

To investigate this thesis, it is broken down into several subtopics and research questions:
RQ1: Developing sustainable solutions to contemporary climate change challenges necessitates interdisciplinary collaboration to resolve conflicts of interest. Can the effectiveness of methods such as TSD be evaluated within a course using gamification?
RQ2: Gamification is an effective approach for conveying methodological concepts. The suitability of the gamification approach can be assessed using criteria such as whether students retain the course content six months after the course and feel prepared to apply it. Can long-term retention of TSD knowledge be demonstrated through follow-up assessments with the student group?
RQ3: Gamification is an effective teaching method for illustrating the impact of interdisciplinary collaboration with stakeholders across all project phases, as well as for developing methodological competence. Do students report a positive effect from experiencing interdisciplinarity and cross-functionality in the game for their future practice?
RQ4: Can gamification, by engaging students' emotions, increase their motivation to invest in sustainability, particularly regarding ecological aspects, in practice?

Literature Review

A literature review was conducted to assess whether gamification is an effective teaching approach for Target Sustainability Design (TSD), which involves both a process and an equation for evaluating the sustainable value of a project across all three dimensions. Various combinations of the following keywords were used in scientific search engines to find relevant research papers: "simulation games," "serious games," "education," "sustainability," "architecture," and "construction." The literature review reveals that numerous researchers have explored gamification in education using diverse approaches. A selection of the most pertinent studies is discussed here.
In a meta-analysis Zhonggen displays, that serious games are increasingly being used for education purpose in various fields, among one is architectural education, where students practical and theoretical knowledge is positively enlarged by serious games.[7] Sustainability and circular economy are characterized by high complexity caused by the interactions of economic, social, and environmental systems. De La Torre et al. figured out in a qualitative study, that serious games are helpful for understanding the complexity of sustainability and circularity by involving emotions into the learning experience of students.[8] Alves demonstrates in experiments with students, that interdisciplinary teams achieved better results in a serious game focusing on decision-making for green building projects. The game illustrates how trade-offs between different stakeholders can help meet customer requirements and project goals. It shows that interdisciplinary collaboration leads to better sustainability performance but does not fully address the conflict between ecological and economic goals[9]. Rybkowski et al. illustrate in their first-run study the so-called marshmallow challenge and its effectivity in teaching basic Target Value Design (TVD) principles. The study has limitations in accounting for the social or ecological dimensions of sustainability, which is clear, since TVD does not cover social or ecological aspects.[10] To overcome this gap of TVD, TSD was developed, which integrates social

and ecological aspects into the method. TSD combines lifecycle cost with environmental cost, by monetizing the environmental cost of CO_2-eq and subtract cost that can be claimed from urban mine. Urban Mine is defined as difference from using secondary products to primary products. The price for the resource expenditure is set into ratio with the added value, which includes functionality, quality and social aspects especially regarding intergenerational justice. The sustainable value in TSD is defined according to the equation in Fig. 1.[4]

$$\text{Sustainable value} = \frac{\text{Added value}}{\text{Resource expenditure}} = \frac{(\text{functionality} + \text{quality}) * \textbf{social aspects}}{\underset{[\text{€/LC} * \text{LC}]}{\textbf{life cycle costs}} + \underset{[CO_2\text{-eq} * \text{€/t}CO_2\text{-eq}]}{\textbf{environmental impact costs}} - \underset{[\text{€}]}{\textbf{urban mine}}}$$

Fig. 1 equation of the TSD

Based on the literature review, it can be concluded that gamification is a suitable pedagogical strategy for teaching TSD. A TSD simulation game has the potential to enable students to experience and comprehend the complex interrelationships among the three dimensions of sustainability. Moreover, instruction in TSD provides students with a framework for managing these complexities and integrating all dimensions into real-world projects.

Methodology

A simulation game based on the marshmallow challenge was developed to teach Target Sustainability Design (TSD). Two teaching sessions were implemented and analyzed using a mixed-method approach to validate the thesis. Each session lasted for 2 x 90 minutes. The teaching session utilizing the simulation game was conducted twice as a case study to address the research questions.

The first teaching session involved 48 professionals organized into eight interdisciplinary groups, to address RQ1. Data collected from these groups, which operated under identical conditions, will provide insights into the effectiveness of Target Sustainability Design (TSD).

The second teaching session involved 11 students enrolled in an interdisciplinary master's program, divided into two groups. This session aimed to evaluate learning outcomes, specifically focusing on knowledge retention (RQ2), the learning experience, and motivation (RQ3 and RQ4). To assess the educational impact of the simulation game, semi-structured interviews were conducted with nine students six months post-session to evaluate their retained knowledge of TSD.

Structure and Implementation of the Simulation Game

The simulation game is played in two rounds. In each round, each team designs and builds a tower made from spaghetti, wooden coffee stirrers, and drinking straws that supports a marshmallow at a height of 60 cm. In round one, a fragmented process where owners and designers are separated from the builder is simulated. For round two, Target Sustainability Design is applied to stimulate an integrated design and construction process.

The following instruction was given to the teams, for both rounds:
"The aim of the game is to build a representative tower within 30 minutes. The requirements for the tower are: The tower should be able to support a marshmallow at a height of 60 cm as a viewing platform. Furthermore, the tower must be self-supporting, i.e. it must not be attached to the table."

The teams consist of 4-6 people and appoint 1 client, 1-2 planners and 2-3 builders. The following materials may be used to build the tower: Straws, Spaghetti, Wooden stirring sticks, Masking tape as a fastener, Marshmallow as a viewing platform. Each Building Material has monetized values for Lifecycle Cost, CO_2-eq, and Urban Mine according to the cost data given under 1) on the handed-out calculation sheet, Fig. 2. The given Lifecycle Cost, CO2-eq cost and Urban Mine are fictional. They are balanced the way that a low resource expenditure can only be achieved when the building material is chosen considerably. To simplify the simulation game Urban Mine is not specified into pre-use or post-use.

Before round one the instructor explained the factors of the TSD including the monetized values and the correlation of CO_2-Price and intergenerational justice.

Round one is played in two steps:
Step 1 – Design: The designer and client design the tower together on paper and fill in the calculation table "Project as-planned" with the needed amount of material on the calculation sheet. Which will give the as-planned resource expenditure. During the design period, the contractors familiarize themselves with the material at a different location and do not have contact to the client or planner. As soon as the design has been completed, the planners call in the builders. The builders collect the material listed on the calculation sheet.

Step 2 – Execution: The builders build the tower based on the design in step 1. If anything is unclear, a request for information is issued. If the builders wish to build differently than designed, a change request must be submitted. For clarification, communication takes place exclusively via the designer; the client's concerns must be considered. The calculation table "Project as-built" is filled in by the designer according to the actual execution giving the as-built resource cost. Additionally, the designer counts the number of change requests and requests for information.

1) cost data

€/g CO_2e		**2 €** 1% discounting			
social aspects		**63%** 100 years lifecycle duration = 1 - (100%-1%)^100			
building material	**amount**	**LCC [€]**	**LCA [g CO_2eq]**	**CO_2eq [€]**	**Urbane Mine**
Straws	1	20.00 €	2.0 g CO2e	4.00 €	-10.00 €
Spaghetti	1	10.00 €	2.5 g CO2e	5.00 €	0.00 €
Wooden stirring sticks	1	30.00 €	3.0 g CO2e	6.00 €	-20.00 €
Masking tape (per joint)	1	5.00 €	0.5 g CO2e	1.00 €	0.00 €
profit on LCC		10%			

2) Project as-planned

building material	amount	LCC [€]	LCA [g CO2eq]	CO2eq [€]	Urbane Mine	Sum [€]
Straws	10	200.00 €	20.0 g CO2e	40.00 €	- 100.00 €	140.00 €
Spaghetti	15	150.00 €	37.5 g CO2e	75.00 €	- €	225.00 €
Wooden stirring sticks	6	180.00 €	18.0 g CO2e	36.00 €	- 120.00 €	96.00 €
Masking tape (per joint)	18	90.00 €	9.0 g CO2e	18.00 €	- €	108.00 €
profit on LCC		62.00 €				62.00 €
Sum resource expenditure		682.00 €	84.5 g CO2e	169.00 €	- 220.00 €	631.00 €
quality						100%
sustainable value = quality*social aspects*1000/ sum ressource expenditure						1.005

3) Project as-build

building material	amount	LCC [€]	LCA [g CO2eq]	CO2eq [€]	Urbane Mine	Sum [€]
Straws	12	240.00 €	24.0 g CO2e	48.00 €	- 120.00 €	168.00 €
Spaghetti	16	160.00 €	40.0 g CO2e	80.00 €	- €	240.00 €
Wooden stirring sticks	10	300.00 €	30.0 g CO2e	60.00 €	- 200.00 €	160.00 €
Masking tape (per joint)	20	100.00 €	10.0 g CO2e	20.00 €	- €	120.00 €
profit on LCC		80.00 €				80.00 €
Sum resource expenditure		880.00 €	104.0 g CO2e	208.00 €	- 320.00 €	768.00 €
quality						90%
sustainable value = quality*social aspects*1000/ sum ressource expenditure						0.743
Amount Change Order						2
Amount Request for Information						5

Fig. 2 exemplary data sheet of round 1

After round one and before round two an average "as-build" resource expenditure for Lifecycle Cost, CO_2, and Urban Mine is set up. This average becomes the market price.

Before round two the instructor explained the process and project organization of the TSD to the participants.

Round two is played in three steps:
Step 1 – Set Targets: The designer, client and builder determine the market price and set the target resource expenditure below the determined market price and record it on the calculation sheet for round two. The target resource expenditure is below the market price. Setting the target resource expenditure below market price intends to spur innovation.

Step 2 - Design to Target: Designers, the client, and builders design the tower together on paper. The design needs to be below or equal the target resource expenditure. The number of elements is filled in the calculation sheet "Project as-planned".

Step 3 - Build to Target: The builders build the tower based on the design from step 2. If anything is unclear, a request for information is issued. If the builders wish to build differently than designed, a change request must be submitted. For clarification, communication takes place with the designer and client together. The designer fills in the calculation table "Project as-built" according to the actual execution giving the as-built resource expenditure. Additionally, the designer counts the number of change requests and request for information.

After both rounds the entire group rated the quality of the towers to be able to calculate the achieved sustainable value. Teams received 80% of quality by achieving 60 cm height. The next 20% were influenced by quality of design (subjective impression of all participants) and quality of execution, which included e.g. nicely crafted junctions or no leaning.

Data Collection, Analysis, and Results from Simulation Games
In the session with the professionals the as-planned and as-built resource expenditure in both rounds was counted and noted by the participants. To check and, if necessary, correct the number of elements and junctions the elements in the design and executed towers were counted by the instructor after the simulation game, based on the drawings of the teams and pictures of the towers.

The results of the simulation game session are presented in Table 1. In the mean the resource expenditure as-build lays 8% above as-planned in a fragmented process. Whereas in an TSD-process we can see savings of 4% between as-build and as-planned. Additionally, the ratio between round 2 and round 1 regarding the as-planned resp. as-build resource expenditure shows savings of 41% resp. 42%. Those numbers allow for the conclusion that the biggest influence on a low resource expenditure lay in step 1 Set Targets and step 2 Design to Target. At the same time, the quality rose by 5% under the TSD method. Respecting the equation for sustainable value a ratio of 216% shows that the sustainable value could be more than doubled under TSD. Team 5 delivered a design in round 1 which was not executable, thus the builders decided to build a tower without design. For this reason, the mean is calculated once with team 5 and once without team 5.

Regarding change orders and requests of information only one team reported two change orders and two teams one change order and no request for information in the first round. After the first round the instructor of the simulation asked for more careful consideration of counting change and information requests. In the second round 5 teams reported one and one team reported 2 change requests. The answer of the teams to the instructor, why they only counted so few was that the dynamics of the building process took so much attention, that counting change orders or requests of information was a neglected task as it seems not to add value to the project. Therefore, no results regarding this topic can be presented.

	round 1 resource expenditure ratio = as-build / as-planned	round 2 resource expenditure ratio = as-build / as-planned	resource expenditure as-planned ratio = round 2 / round 1	resource expenditure as-build ratio = round 2 / round 1	quality ratio = round 2 / round 1	sustainable value = added value / resource expenditure ratio = round 2 / round 1
team 1	96%	103%	67%	72%	105%	147%
team 2	100%	100%	77%	77%	106%	137%
team 3	157%	108%	62%	42%	106%	250%
team 4	104%	69%	38%	25%	101%	407%
team 5	35%	96%	19%	52%	114%	220%
team 6	100%	100%	69%	69%	106%	154%
team 7	125%	105%	110%	93%	100%	108%
team 8	77%	87%	30%	33%	103%	309%
mean value	99%	96%	59%	58%	105%	216%
mean value w/o team 5	108%	96%	65%	**59%**	104%	**216%**

Table 1: Results of simulation game with professionals

In the teaching session with students, they received the same data and calculation sheets, as an Excel-sheet instead of paper print. Since the focus of the data analysis lays on the learning outcome of the students, the data of the round of the simulation game is not presented here. However, the students showed comparable results like the professionals.

Since the students' class is organized as inverted classroom, the students received a video about the theory of Target Value Design and a scientific paper about Target Sustainability Design as preparation. In class a teaching-format called "we are presentation" was used to recall the prepared input. Then the simulation game was carried out in the teaching session. To answer RQ2 the students' long-term learning outcome is examined in semi-structured interviews six months after the teaching session. To minimize potential biases, students were explicitly instructed not to prepare for the interviews, ensuring the results accurately reflect their retention and understanding provided in the teaching session. All students confirmed this. The first question was to tell everything they remember about TSD.

The retained knowledge was evaluated with the following 10 characteristics of TSD:

- C1) TSD is method from the field of lean construction and based on TVD.
- C2) TSD and consists of factors and a process.
- C3) TSD includes the environmental, social and economic dimension respecting the sustainability priority model.
- C4) The equation of TSD.
- C5) CO_2 price depends on the time preference rate and thus influences the social benefit mirroring the intergenerational equity.
- C6) TSD process has 3-steps: Set Targets, Design to Targets, Build to Targets.
- C7) Only if the team meets the target resource expenditure, the next step can be taken.
- C8) Work is carried out in multidisciplinary clusters.
- C9) Set Target and Design to Target is conducted together by users, owners, designers and builders.
- C10) In the TSD, the resource expenditure is determined first in the Set Targets step and then moved on to steps 2 and 3, where the target is set below the market price.

The evaluation of the knowledge was rated according to the following scheme:
0% = student does not remember this characteristic if mentioned indirectly
50% = student remembers when characteristic is mentioned indirectly by interviewer but cannot provide context or wording
60% = student remembers when characteristic is mentioned indirectly by interviewer and can provide some context or wording
70% = student remembers independently with some context or wording
80% = student remembers independently with mostly correct context or wording
90% = student shows deep understanding of topic with minor mistakes in context or wording
95% = student shows deep understanding of topic with minor mistakes in wording
100% = student shows full understanding of characteristic in context including correct wording

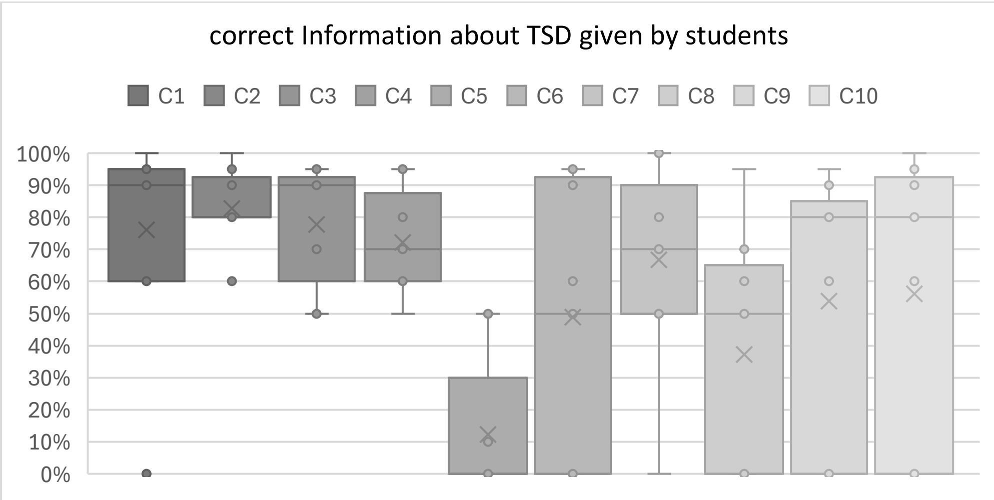

Fig. 3 students' retained knowledge after six months

Fig. 3 shows the results of the interview concerning the retained knowledge of the characteristics of TSD. In summary, there is considerable variability in the level of knowledge among the students. Anyhow, all students indicated that they learned the importance of setting targets before construction for successful achievement. Additionally, they gained an understanding of the complexity of the interrelationships among the dimensions of sustainability and the necessity for careful consideration of this complexity. However, the degree of learning is significantly influenced by the students' individual prior educational background.

Fig. 4 presents the students' perspectives on three hypotheses:
T1) The gamification teaching format is suitable for instructing TSD.
T2) Participation in the TSD simulation game enhances attitudes toward multidisciplinary collaboration.
T3) Participation in the TSD simulation game increases motivation to engage in sustainability efforts.

The median scores for all three theses ranged between 7 and 8 on the assessment scale, indicating strong support for each hypothesis. The presence of downward outliers for theses T2 and T3 was attributed to students who reported already having a high interest in interdisciplinarity and sustainability prior to the study. These students noted that while the TSD simulation game reinforced their existing interests, it did not significantly alter their attitudes or motivations.

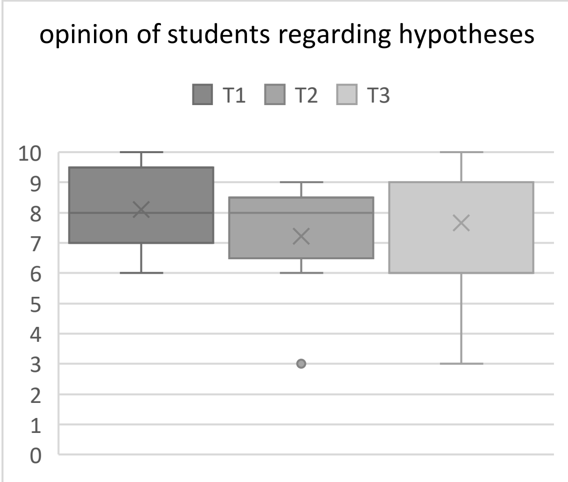

Fig. 4 opinion of students to hypotheses rated on a scale 1-10 (10 = very much)

Limitations

The study involved a limited number of teams and students, which constrains the generalizability of the findings. A larger sample size would enhance the accuracy of the results. Systematically the simulation game allows for team building and experience with the material in round one which could have an influence on the quality of design and execution in round two. This effect might be acceptable, since in real world TSD projects early integration of the experience of the builders will allow for early team building as well. Right after the simulation game professionals and students reported additional positive outcomes of TSD including shorter planning and construction times. Furthermore, the participants reported that joint learning through iterations led to better results and that the collaborative flow within the group fostered a calmer atmosphere. Those effects were not measured and cannot be evaluated by the presented study but could be subject of further research.

Discussion and Conclusion

The discussion of the results will be organized according to each research question.

RQ1: The results of the teaching session with the professionals illustrate the effectiveness of the TSD method. The TSD simulation game allows to experience the positive effect of integrated collaboration of all stakeholders by reaching better project results in both resource expenditure and quality.

RQ2: The interviews with the students show long-term-knowledge about TSD and its characteristics after the teaching session. Nevertheless, the students' knowledge is mostly too basic to be ready to apply the method in practice. Students argued that the topic is very complex and therefore should be tackled in more than one teaching session.

RQ3 and RQ 4: Students report positive effects of TSD teaching session on both multi-disciplinary collaboration and their motivation to engage for sustainability in practice.

The study underscores that the successful achievement of sustainability goals in projects is fundamentally dependent on two key factors: the establishment of clear, measurable targets and the facilitation of effective multidisciplinary collaboration. This collaboration must encompass all stakeholders, including project owners, end-users, building builders, designers, and specialized planners. The interplay among these diverse groups is crucial to aligning objectives and ensuring the successful implementation of sustainability initiatives. Gamification is a suitable teaching approach for collaborative methods to motivate students to pursue sustainable goals in real-life projects.

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