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# An innovative approach to building engineering and architecture BIM education

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**Abstract**

*Engineering education design and investigation is a current issue: BIM and IMM in architecture and building engineering education is becoming popular and widespread. Nonetheless, the general approach carried out in this sense lacks innovative features. Current curricula are based on single courses providing expertise on specific topics, missing a holistic approach that takes in to account the complexity of building design and management. This research provides an experimental approach to education, as a result of tests conducted together with professors and students. Some of these tests involved the application of Information Asymmetry) to problems, that reflect common issues of design and construction. Results from these tests are used to set an innovative practice-oriented methodology for teaching BIM and IMM, overcoming the traditional approach. The aim of this work is providing potential renovations of architecture and building engineering curricula, based on deep analysis of student's abilities, limitations and perspectives, setting the framework for a better integration of BIM.*

***Keywords:*** *BIM, IMM, innovative education, AEC curricula, information asymmetry.*

**Resumen**

*El diseño y la investigación de la enseñanza de la ingeniería es un tema de actualidad: el BIM y el IMM en la enseñanza de arquitectura y ingeniería de la construcción se están popularizando y generalizando. Sin embargo, el enfoque general llevado a cabo en este sentido carece de características innovadoras. Los planes de estudios actuales se basan en cursos individuales que proporcionan conocimientos especializados sobre temas específicos, sin un enfoque holístico que tenga en cuenta la complejidad del diseño y la gestión de los edificios. Esta investigación proporciona un enfoque experimental de la educación, como resultado de pruebas realizadas conjuntamente con profesores y estudiantes. Algunas de estas pruebas implicaron la aplicación de la Asimetría de Información a problemas, que reflejan problemas comunes de diseño y construcción. Los resultados de estas pruebas se utilizan para establecer una metodología innovadora orientada a la práctica para la enseñanza de BIM e IMM, superando el enfoque tradicional. El objetivo de este trabajo es proporcionar potenciales renovaciones de los planes de estudio de arquitectura e ingeniería de edificios, basados en un análisis profundo de las habilidades, limitaciones y perspectivas de los estudiantes, estableciendo el marco para una mejor integración de BIM.*

***Palabras clave:*** *BIM, IMM, educación innovadora, AEC planos de estudios, asimetría de información.*


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## Introduction

In last years, engineering industries have identified knowledge and skills that specifically respond to current issues; nonetheless, engineering education, besides providing a high level of expertise, lacks in providing the students with the capability to cope with complex issues (Kolmos and De Graaff 2015).

This aspect is related to the current setting of Architecture and Building Engineering Curricula. Those are mainly based on single courses providing expertise and knowledge on specific topics: structural design, building services, urban design, architectural history and composition, together with legislative requirements and standards. The consolidation of this expertise through the application to complex projects is needed; building design is in fact a complex task, as in many cases the requirements are conflicting, and it is particularly hard to find a balance.

A holistic approach is therefore useful to shape the ability of students and future professionals to (i) be able to understand complexity and to cope with needs and requirements, and (ii) to work in a team combining different skills.

Considering in particular construction, BIM is gaining remarkably importance in current times, due to the many advantages that it can provide to the entire industry (Azhar 2011). The proper features of BIM methodologies require an early application and a specific training (Peterson et al. 2011; Sacks and Barak 2010). For this reason, BIM teaching plays a central role in building engineering and architecture curricula.

The aim of this work is illustrating the approach to possible renovations of Architecture and Building Engineering curricula, based on deep understanding of students' ability, limitations and perspectives. Experiments with students are under development in order to test their current skills; a first case study is presented, with a reflection on the results.

## 1. Design teaching: architecture and building engineering

One of the main barriers related to design teaching, especially in higher grades when project complexity is particularly relevant, is the lack of time. To properly cope with complex issues in fact, students should first acquire all the methods and the expertise needed, and then apply them to projects. In many cases, this phase is carried out after graduation, in real-world profession as learning-by-doing (Thomas and Mengel 2008). In this context, the use of BIM in teaching project design has proven to simulate practical situations in a realistic way, and therefore could represent a valuable support for design teaching (Peterson et al. 2011).

Another relevant limitation (that could seem prosaic and trivial, but in fact strongly influences teaching programs) is related to the tension between the need to provide comprehensive education and training, and the number of credits in degrees (Sacks and Barak 2010).

The chosen environment to carry out these tests is the faculty of Building Engineering and Architecture; it is a five-year program, including several high-level courses. The training provided in this Faculty reflects the multidisciplinarity of complex building projects, preparing students to the challenges of real-world projects. The current curriculum organization is the following:

Table 1. Building Engineering and Architecture curriculum

| year | Course (ITA) | Course (ENG) |
|---|---|---|
| 1st year | Analisi matematica 1 + Complementi di Algebra Lineare | Mathematical analysis 1 + Linear Algebra |
| | Diritto Urbanistico + Sociologia Urbana | Urban planning law + Urban sociology |
| | Disegno dell'architettura 1 + Informatica grafica + Laboratorio CAD | Architectural design 1 + Computer graphics + CAD lab |
| | Storia dell'architettura 1 | History of architecture 1 |
| | Fisica Generale | General Physics |



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| | | |
|---|---|---|
| 2nd year | Disegno dell'architettura 2 + laboratorio di rilievo fotogrammetrico dell'architettura | Architecture Drawing 2 + Architecture Photogrammetric Survey Lab |
| | Analisi matematica 2 | Mathematical analysis 2 |
| | Architettura e composizione architettonica 2 + laboratorio | Architecture and architectural composition 2 + lab |
| | Fisica tecnica ambientale | Environmental thermodynamics and heat |
| | Progettazione degli elementi costruttivi + laboratorio | Building elements design |
| | Meccanica Razionale | Rational mechanics |
| 3rd year | Architettura tecnica + laboratorio + laboratorio di servizi tecnologici | Technical architecture + lab |
| | Chimica + tecnologia dei materiali e chimica applicata | Chemistry + Technology of materials and applied chemistry |
| | Idraulica + costruzioni idrauliche | Hydraulics + hydraulics structures |
| | Estimo + economia del territorio | Estimate + spatial economics |
| | Scienza delle costruzioni | Structural mechanics |
| | Storia dell'architettura 2 + laboratorio | History of architecture 2 |
| 4th year | Tecnica delle costruzioni + laboratorio di costruzioni | Structure building constructions + lab |
| | Architettura e composizione architettonica 3 + laboratorio + storia e critica dell'architettura contemporanea | Architecture and Architectural planning 3 + lab + history and critical of contemporary architecture |
| | Geotecnica | Soil mechanics |
| | Restauro architettonico + laboratorio | Architecture restoration + restoration studio |
| | Tecnica Urbanistica + laboratorio | Urban engineering + lab |
| | Tirocinio | Internship |
| 5th year | Laboratorio di sintesi finale | Studio Lab |
| | Ergotecnica edile + laboratorio | Building ergotechnics + safety lab |
| | Progettazione e Innovazione Tecnologica + laboratorio<br>*or*<br>Recupero e conservazione + laboratorio<br>Consolidamento di strutture<br>*or*<br>Progetto di strutture<br>Progettazione urbanistica + laboratorio<br>Analisi e valutazione ambientale<br>*or*<br>Buildings in seismic areas<br>*or*<br>Energy efficient buildings<br>*or*<br>Gestione dei progetti complessi | Progettazione e Innovazione Tecnologica + laboratorio<br>*or*<br>Building reuse and conservation + lab<br>Structural retrofit + lab<br>*or*<br>Structural design + lab<br>Urban design + lab + landscape lab<br>Environmenal analysis<br>*or*<br>Buildings in seismic areas<br>*or*<br>Energy efficient buildings<br>*or*<br>Management of complex projects |

The current organization of the programme reflects the variety of fields and topics that a building engineer could face in his professional life. Nonetheless, it could be noticed that the first integrated design project appears at the 3rd year (Architettura tecnica). Other holistic design projects are the ones faced during the 5th year. This means that students do not have the possibility of facing many complex design projects during


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their educational path. The first issue to be addressed that acts as trigger of the experiment is understanding what is the students' approach to complex issues.

The chosen approach in this sense is an iterative one: once the problem is understood, experiments and tests of students' behaviors are carried out. The analysis of the results can lead to modifications of current curricula and evaluation of their success.

The first experiment was carried out with the students from the course of Ergotecnica Edile. The students did not know the date of the experiment, nor its content.

This experiment was intentionally based on a different field rather than construction; the goal was to give the students a general perspective of what a complex process is, pushing them out of their "comfort zone" that is the one related with building design.

Cooking is indeed a complex process that requires an accurate planning and balance of resources. In this sense, cooking can be seen as a process with some similarities with construction. Some reflections in this sense have leaded to the application of lean manufacturing principles to restaurants (CIT), with remarkable improvements in terms of waste management, time control and quality of the final product.

## 2. Information Asymmetry

Information Asymmetry (IA) is a condition that arises when information are not fully shared among individuals within the same economic process. Namely, a part of the agents concerned has more information compared to the rest of the participants, so the former can benefit from this discrepancy. In economical field, presence of IA is seen by participants as an opportunity, but they are acquired and used to get a benefit at the expense of the others. The arising of these mechanisms creates tensions, especially when the advantage is only to few people. It is therefore possible to state that in the real market information is distributed unequally among individuals.

As an example of adverse selection, Akerlof's Lemon Market Theory (Akerlof 1970), explain different behavior and reaction among people, who are in the marked of used car. These problems are the main cause of losses and risk phenomena that may occur during the procurement process and often their presence does not guarantee the fulfillment of the efficiency and quality standards established by the contract.

According to the literature (Billett, Garfinkel, and Yu 2017), the process allows the realization of a building through a procurement procedure. It is divided in two parts, the former is the bidding process and the latter is the construction. The three principal figures are characterized by an information asymmetry, and in particular: (i) the client knows the price of the construction, he is willing to pay, and his expected quality; (ii) the contractor, on the other side, has a clear idea of the quality of the product is going to build that reflex the requirement expressed by the owner, not the ones intended. Each information heterogeneity is linked with the subjects who take advantage of or disadvantage from this condition. This problem is deeply affecting the construction market (Bryson and Yetmen 2010).

Relationships established during the construction process, each subject pursues his own interest with the possibility of hiding or omitting some information to maximize his leading position. The success of the construction process is obtained if the various participants are able to face and manage the asymmetries themselves.

Facing this conflict, some subjects undertake the others, and sometimes the best strategy is to cooperate.

For a long time, contracts stipulated have been considered as a formal tool to govern and limit potential opportunistic behaviors. The signing of the contract is divided in two stages: at first the client is empowered because he has to entrust a contractor, and this perspective empowers the client during the selection process, providing him a leading position; after that, the contractor uses controversy to recover the discount used in the bidding process based on project incoherencies. These differences are seen as mechanisms to achieve cooperation in inter-organizational activities.

Researchers decided to apply Information Asymmetry to a practice exercise to help students in understanding the impact that a single decision has, if it is taken at a given moment or later. This factor is substantial if applied in a field such as construction, in which reworking have a substantial cost in the work. This factor leads to a detachment from Lean theories that should optimize the AEC compartment.

## 3. Experiment 1: a complex problem with IA

### 3.1. Setting of the experiment

The experiment was conducted dividing the class in two main groups, where the former has all the information from the beginning (even numbers), the others have just some initial information and, during the development of the experiment, they have received perturbations (odd numbers). Students were further divided into sub-groups.

The initial statement reports that all students have to plan a dinner for twenty people composed by two choices of appetizers, two first courses, two second courses and desserts, including drinks, within a 600€ budget. During the preparation, an average kitchen and home equipment is available. Groups received notes during the experiment to make them aware of all the instructions.

When this experiment was presented to the students, their initial reaction was of astonishment and surprise. General approach in this faculty teaching activities does not exclude active learning activities, but experiments and tests are not usually performed (Freeman et al. 2014).

A series of questions was submitted to the students, in order to understand their background and habits, especially related to cooking activities. In particular, over 54% of them used to cook almost every day during working days for an average of 2, 3 people, this means their behaviors are closer to a worker than a normal student. They usually, more than 62% of them go to a grocery shop more than once a week (the average is three times a month). They stated they generally have 2 guests (49%) per week.

### 3.2. Development

Students were divided in random groups and have just one computer available. The experiment had three main deadlines, where they have to deliver all the material produced. During the first deadline, groups have to produce a menu and, consequently, a shopping list with its relative costs. During the first hour and half, they analyzed the problem, setting the quality they want to achieve and list all the needs in terms of material and means.

After one hour and half, groups delivered what they had produced. In the meantime, the odd groups received the perturbation: information related to the people who will attend the dinner and impose a change in the menu (i.e. 30% of guests suffer from celiac disease): considering most of the people have to be able to eat all dishes, students have to adapt their menu. This phase lasted forty minutes and groups delivered the final shopping list, which implied modification only to the group who has received later the information.

Last phase concerned the production of timetable and schedules for the activity and list of means.

## 4. Results and discussion

### 4.1. Experiment results

Data analyzed show how students used just a minimum part of the proposed budget, as shown in Figure 3. The unused budget, imposed by the structure of the menu, causes a low quality of the result. Analyzing the result, it is not possible to grasp real knowledge of the students and what they have produced. A boundary changes of an un-optimized result do not produce an over-budget, because students did not satisfy the owner requests.


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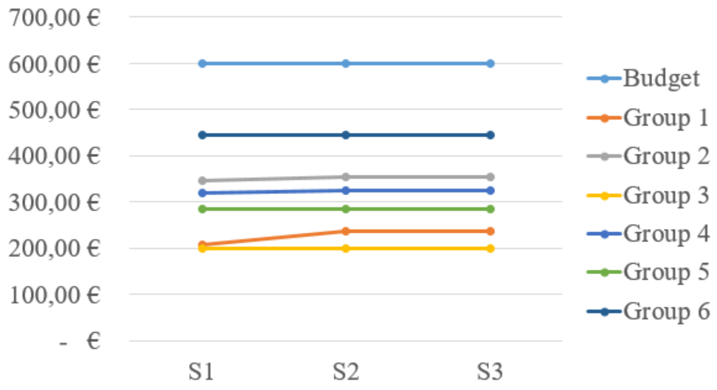


*Figure 3. Shopping amount*

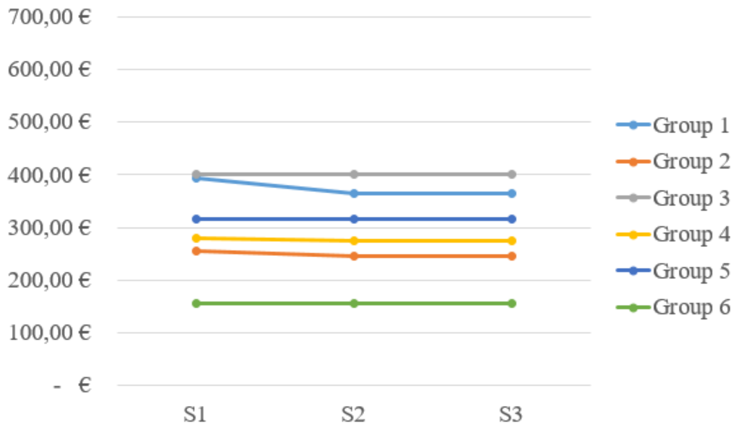


*Figure 4. Remaining part of budget provided*

In particular, according to the sample of students analyzed, there is no systematic use of the information provided by the client to understand the expected quality. The difference between expected and real quality produced a discrepancy of the results and a client's dissatisfaction.

In the early stages, qualitative parameters were not defined, nor legislation requirements are analyzed to provide a correct menu. Even if some information were provided (e.g. ordinary equipment of flatware), they were not taken into account in the process management; some groups do not take into account money required to buy cutleries or to rent chairs. The lack in searching information (e.g. some guests suffering from celiac disease) produced wrong choices in the cooking process. This fault originated a depreciation of the final result, theoretically implying that some guest could not be able to have a suitable dinner.

The presentation of the courses was not considered as a part of the activities, but a common chef should have taken it into account it: this result underline a lack in general view of the process.

The difference between legislation requirement and information provided was not well defined by the students. This consideration reveals its result when the odd groups received perturbation and this action did not have any deep implications on the final budget of the event. The application of perturbations on projects, which are globally understood and optimized, should produce changes. During the experiment, on the contrary, perturbations did not produce modification to the entire project, but just a slight variation of the menu.

### 4.2. Feedback analysis and lesson learned

After having collected tests, students were required to express their thoughts about the answering to pre-defined questions, without providing a scientific explanation of the phenomena used to develop the test.

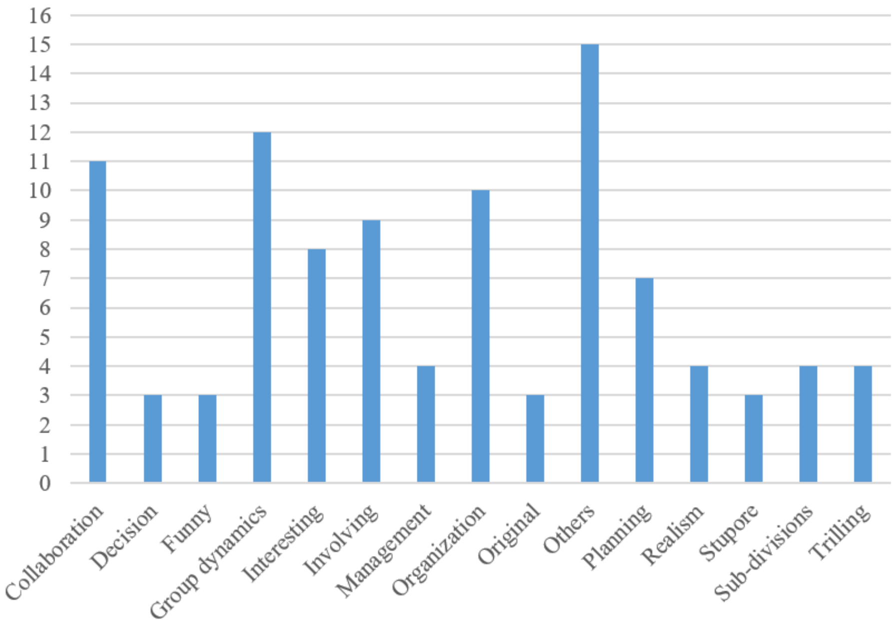


*Figure 5. Keywords categories*

Students produced a report from which we obtained feedback on the experiment. After the analysis of the student's report, results were explained them in order to have a deep understanding of the scope and results of the experiment. Probably some change will be applied in the setting of the initial request to better provide them a holistic view of the problem and misunderstanding.

## 5. Discussions

The experiment was developed to analyze the ability of architecture and building engineering to understand and manage complex problems. The principle was to check if their curricula are suitable to provide them these abilities.

We chose a field in which no student has a complete control, but, according to Santorella (Santorella 2011), they are so close and used to cook that they can have a holistic view of the problem.

The moments of synthesis, after having acquired all the basics among various disciplines, is necessary and indispensable. The modification of their academic curricula aims at providing students with the necessary tools to put the acquired knowledge in an interdisciplinary perspective over the years. This evaluation is useful for professor as a tool.

Analyzing a cut across different project, a common feature was detected. All groups show a deep focus on the specific pot to use, but not the flatware needed to serve the course. It means that they focused on the recipes and on what is in it, not on the consequences of what they prepare and if they have the means to apply it. Generalizing the incorrect consideration of means (flatware) explain a lack of resources management in the complexity of the construction field.

What students proposed are not alternatives, but slight changes of the principal choice, namely they do not provide guests a choice among two different solutions but a variance of the course. Generalizing to a bigger scale, it implies they provide to clients a selected technology that follow the project from the beginning to the end of the project. It means there is no possibility for a Design Optioneering technique, because the choice is already taken in the first place, without thinking about the entire project.

Generally speaking, the experience was positive both for the students and for the professors. Namely, some students understood some of the error they committed during the simulation. This aspect reveal that the competences, acquired during their university path, are enough to be prepare to outside university, but they have to reorganize their knowledge in a more efficient way to embrace a holistic view of the problems.

This experiments reveals some problem in students' curricula, students' approach reveals the main problem: if there is no question there cannot be a project that responds adequately to it. This consideration requires a more general reflection on the design dynamics. The research is just a first step in the resolution of the problem.

As explained, there are similarities between Building Information Modeling and cooking. Both activities are a process, and implies a good choice of ingredients, a recipe to be followed, and collaboration among actors taking part in the process (Andersson et al. 2016). Creating a connection between BIM and other activities with which students are more familiar and at ease provides a valuable starting point for teaching BIM in an innovative way.

## 6. Strategies to improve collaboration in existing curricula

A better integration of BIM teaching would result in increased collaboration in the presented curricula; BIM application could help in simulating realistic scenarios, and in learning how to cope with those (Peterson et al. 2011). Several researches have addressed this theme, analyzing the state of diffusion of BIM related activities teaching and their effectiveness, and proposing changes in curricula and better ways to successfully integrate BIM teaching in existing courses.

Building Engineering and Architecture is, as presented, a complete design course that integrates technical skills and architectural design capability. During the study course, twelve design studios are proposed, but only some of those are explicitly presenting a synthetic summary of other disciplines. Most of these projects are only referring to specific aspects of building architecture. This could be a cause of the lack of holistic collaboration underlined by the proposed experiment. Several strategies can be performed in order to increase collaboration, BIM consciousness, and ability to cope with complex issues in Building Engineering and Architecture as it is. These strategies are here presented, based on previous cases, experiences found in literature, and personal discussions with professors related to the school.

a. Introduction of a project course for each year of learning, combining the skills acquired in the corresponding year, in a BIM perspective, increasing the collaboration among disciplines. This strategy would require an intense change in current setting of the course, involving all the professors in a collaborative process (Aldeanueva-Fernández et al. 2017);

b. Introduction of specific BIM-based courses, teaching both technical skills (use of BIM software and collaboration tools) and theoretical basis (Hu 2018);

c. Incorporation of BIM-skills in existing courses (Piedecausa-García et al. 2017);

d. Engagement of students' in the evaluation, by means of self-evaluation sessions, public critics, encouraging active learning (Freeman et al. 2014);

e. Engagement of students' in extracurricular activities, such as competitions, hackathons, workshops, to encourage collaboration with students' from other Countries with different backgrounds (Agulló-deRueda, Jurado-Egea, and Inglés-Gosalbez 2018); this option would be particularly interesting when combining students with different skills, e.g. studying in different courses (Becerik-Gerber, Gerber, and Ku 2011);

f. Engagement of PhD Candidates, and industry representatives, in existing courses (Becerik-Gerber, Gerber, and Ku 2011; Sacks and Barak 2010);

g. Increase in use of collaboration tools (such as communication tools, social media, etc), among students and for deadlines and homework delivery (Cos-Gayón López et al. 2018; Becerik-Gerber, Gerber, and Ku 2011).

These strategies can be synthetized in a matrix, showing the level of impact that they have on existing curricula in terms of efforts or modifications to be performed (vertical axis) and the impact that they have in terms of increase in collaboration.

Table 2. Strategies to increase collaboration in Building Engineering and Architecture curricula

| Efforts | | Impact 1 | Impact 2 | Impact 3 |
|---|---|---|---|---|
| | 1 | Seminars<br>Meeting with professionals | Self-evaluation sessions | Collaboration tools use<br>Role-play games |
| | 2 | - | Students competitions | Workshops, hackathons |
| | 3 | - | Interaction with PhD candidates and researchers | Introduction of new BIM courses<br>Integration of BIM in existing courses |

The matrix can help in prioritizing the actions to be undertaken, depending on the available resources and the expected outcomes. It could be possible to combine some of these strategies to obtain the best result; it could be useful for instance to combine the use of BIM skills with the introduction of a theoretical course on BIM methodologies, so that the students could (i) learn what BIM is, and how does it work, and (ii) experience active learning of BIM methods, with a hands-on approach on their projects.

## 7. Conclusions

The presented experiment proposed some hints for changes in the current Building Engineering and Architecture curricula, based on an increase of collaboration among students and professors. Some strategies in this sense have been presented, and would be introduced in next years to evaluate the effectiveness of this approach. The matrix of strategies proposed could be implemented and kept as a useful tool for future strategies, to be discussed together with all the professors involved in this field.

Teaching experiments like the one proposed will be carried out as a continuous evaluation of students' engagement and satisfaction.

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