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# Past, present, and future product modelling standards for the building and construction sector

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**Abstract**

The majority of industries have spent the last ten years creating standards for the electronic sharing and interchange of product model data. The building and construction sector continues to lag behind in this growth, unlike several adjacent industries, such as automobile and shipbuilding production, which have integrated electronic product models into their operations with some degree of success. The creation of a product modelling standard that enables electronic sharing, storage, and exchanging of project information is crucial for the building and construction sector to tackle the challenges of the future. This claim's justification is discussed in the report, along with the industry criteria for creating a product modelling standard. The report elaborates on the outcomes of past and present standardisation initiatives before analysing the state of development at the time in question. Personal opinions about the direction of information exchange development are then expressed. 

## 1. Introduction

The building and construction industry is facing an increase in demands. Stronger regulations on safety, energy consumption and environmental con- straints are combined with increased user demands for more complexity, better performance, lower costs and shorter lead times. The building and construction industry, saddled with its traditional paper-based in- formation system and its fragmented organizational structure, has difficulties in meeting these chal- lenges.

Many experts believe that the current lack of ‘integration,’ illustrated in Fig. 1, is one of the main factors leading to the unsatisfactory performance of the building and construction industry as a whole.

Design and construction processes are too expensive, time consuming and error prone. Furthermore, the designed artifacts typically do not perform as well as demanded and the reuse of knowledge is practically impossible.

Information technology is generally expected to solve a large number of these problems. Each disci- pline, company and professional currently possesses a variety of software applications that are tailored to their individual needs. However, open Žvendor inde- pendent., meaningful, electronic communication, sharing and storing of project information is cur- rently difficult, if not impossible. The current build- ing and construction project information paradigm is still primarily based on the use of traditional media and methods such as drawings, faxes, and meetings.

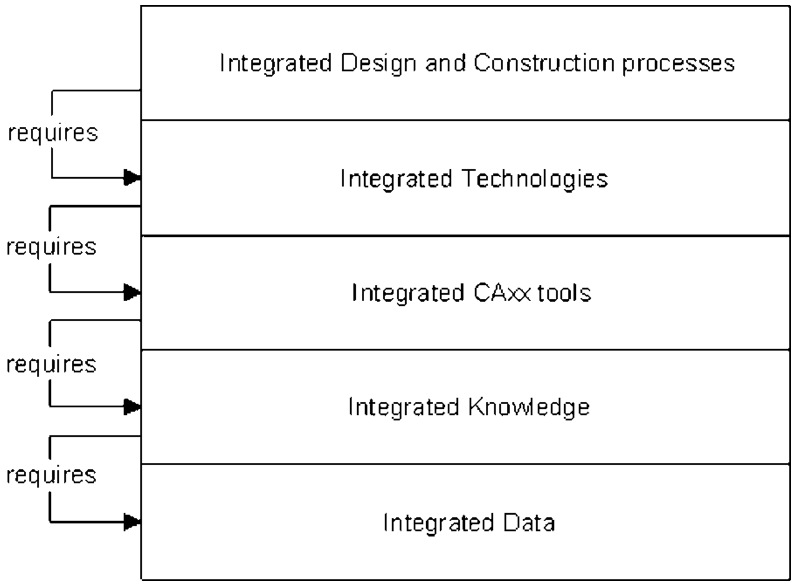


Fig. 1. Levels of 'integration'. Integrated design and construction processes are required to meet growing demands. Integrated design and construction processes require integrated technologies, which require integrated applications, integrated knowledge, and integrated data.

Consequently all the participants in a specific project process to a future computer-integrated construction are required to convert computer-generated, elec-

tronic information into paper-based output. Likewise, paper-bound information must be translated into electronic versions for use in the computer-based applications. This continual process of creating and translating information according to the design and presentation medium used creates several bottlenecks in the flow of information. Until recently, informa- tion logistics Žgetting the right information, in the right format, at the right time, in the right place. has not benefited from the growth in the information- technology field w10x.

As information is probably the most important construction 'material', it is clear that the building and construction industry requires a complete and adequate electronic project information system. The system should, for the present, support the possibilityof generating output in traditional paper-based for- mats as well.

As standards for project information sharing, stor- ing and exchange are generally seen as the first step in the evolution from the current paper-based infor- mation system to a future electronic information system, and thus from the traditional construction

massive standard development efforts. Why would the industry deny their clients and end-users the benefits of better design solutions for their buildings, plants, or infrastructure?

In the last ten years, only a few researchers have been working on the issue of standardization. It is only in the past few years that some countries recog- nize the fact that their governments have a profound interest in funding efforts in the development of information sharing and exchange standards for the

building and construction ŽB–C. industry. The rea-

son is that competitive forces, as exist in the automo- tive and aerospace industries, are not really manifest in B–C. However, society continues to demand bet- ter roads, bridges, buildings and tunnels for less money, and with decreased impact on the health of the workforce, and the environment.

## 2. Industry requirements

In general, the difficulty with standards is thatthey are of limited value most of the time. If a

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standard is not adopted by a significant number of its intended users, it may solve some problems, but in turn creates a host of other problems. An example in the standards area are the so-called integrated sys- tems ICES and GENESYS from around 1980 w1,9x. These systems provided application integration for the users of the system as shown in Fig. 1. End user companies began to develop new applications for their own use, or subsystems, that dovetailed with the overall structure provided by the integrated sys- tem. The resulting ‘islands of automation’ grew and became ‘archipelagos of integration’ and, when the information technology of the integrated system be- came obsolete, their users were left with a severeloss of investment and faith.

Perhaps a more suitable solution for problems in the building and construction industry is an open Žvendor-independent. approach that allows each par- ticipant in a project to use the application systems of their choice and to build and maintain an open project database. A prerequisite of this open B–C database is that it must support the sharing, storing and exchanging of product models and project mod- els. Another requirement is that experts, such as structural engineers, and HVAC engineers, should be able to employ their own preferred systems utilizing the shared project data.

A method of addressing this issue of extracting different information from a single version of the data is to carefully design standards for the sharing, storing and exchanging of product models. There are several definitions of a product model, and conse- quently there are several thoughts about standards for product modeling. The definition of a product model used in this paper is as follows: A product model is an information model that implicitly con- tains data regarding form, function and behavior of a product and is able to describe the product throughits life cycle. A building model, as an example of a B–C product model, contains the data that captures the form Žgeometry and topology., function Žintent. and behaviour Žload resistance, etc.. of a building. The definition does not say that all the different behaviors of a product have to be captured explicitly, only that all the data required to establish form, function and behavior is available.

The role of the product model in this definition is in the current paper-based design and construction process. The complete set of drawings and related documents contains all the information required to establish form, function and behavior of a product.

With the definition of product model offered above, the standards we are seeking are neither standards for the exchange of electronic versions of traditional technical drawings, nor standards for the exchange of geometric data Žform is only one of the relevant aspects.. What is needed are standards that capture the project information in a semantical Žmeaningful. way, in the same notions also used in practice. From such a semantically rich information model other models, like a geometrical model, or an FEM Žfinite element model. can be derived automat- ically. Additionally, 2D-drawings, and other docu- ments could be generated from the same product model. Since it is easier to express the knowledge of a discipline in the notions Žentities, object classes, semantics. of the discipline than, for instance, in meaningless geometry, a semantical product model also supports the step from integrated data to inte- grated knowledge as shown in Fig. 1. Finally, the possibility that a product model could support the complete life cycle of a product compares to the current paper-based usage of technical documents with revisions, alterations, and so on.

Though the idea to explicitly include behavior in the product model is valid and can be realised with object-oriented technology, it is perhaps better to be somewhat less ambitious and start with a pure infor- mation model. Since the information model forms the core of any product model, extending the stan- dard in a later stage can be accomplished without the loss of investments made in the development.

Standards for product modeling should not only be expressed utilizing the jargon used in practice, they should also be open and international. With no leading CAxx vendor in the product modeling busi- ness able to develop and set an international stan- dard, there remains only a few possibilities for their development: Ž1. continue to develop an ISO stan- dard Žwhich is done in ISO 10303 STEP. w6x; Ž2. establish a consortium of vendors and influential clients, and develop a group standard Žwhich is done by AutoDesk, Bentley and others in the industry foundation classes. w5x; or Ž3. develop a national equivalent to the role of the technical documentation standard and hope that mapping to an international standard will become possible in the future Žwhich isdone in several countries, like Singapore·.

## 3. Semantical standards

The remaining sections of the paper will focus on semantical standards. After a brief review of the history and an overview of the current situation, the author expresses his personal views on the futuredevelopments.

*The history of semantical standards for theconstruction industry*

One lesson from the past, as already discussed above, is that we should be suspicious of standards developed by vendors. Vendor-developed standards Žand consortium standards, if the consortium is small· are potentially self-serving. Vendors are not in the business of standardization. Their interests lie pri-marily in profitability from sales.

Semantical standards development for the B–C industry started around 1986 with the STEP AEC group. At the time, a product modeling standard was undefined and open. The first contributions came

with entities such as system, system input, system component, source and path in the core of the prod- uct model. Clouds of specialised entities were pro- vided for all the different types of distribution sys- tems. When it became clear that the benefits of a general systems model in the core were minor, and the systems approach was only a research idea ŽJim Turner changed his model every 3 months· the inter- est in this approach soon vanished.

Gielingh proposed a model called the general AEC reference model ŽGARM·. Parts of GARM have been used in the development of a model for roads. GARM was also used as the basis for the integration core model ŽICM· from CAM-I. Despite the relatively limited use of GARM in practical modeling, it has been rather influential for a number

of years. GARM proposed the notion of orthogonal dimensions, such as life-cycle stage, level of detail, level of concretisation, etc. Orthogonal dimensions allowed GARM to elaborate the relations between any pair of dimensions in a one-page model. This mechanism made it possible to present the rather complex subject in a seemingly simple model. Two parts of GARM were of particular interest. The first was the concretisation dimension, i.e. the distinction between ‘requirements’, called function unit ŽFU·,

from Jim Turner w15,16x and Wim Gielingh w3x.

and ‘solutions’, called technical solution ŽTS·

Turner proposed to use a general systems model, ŽFig. 2·.

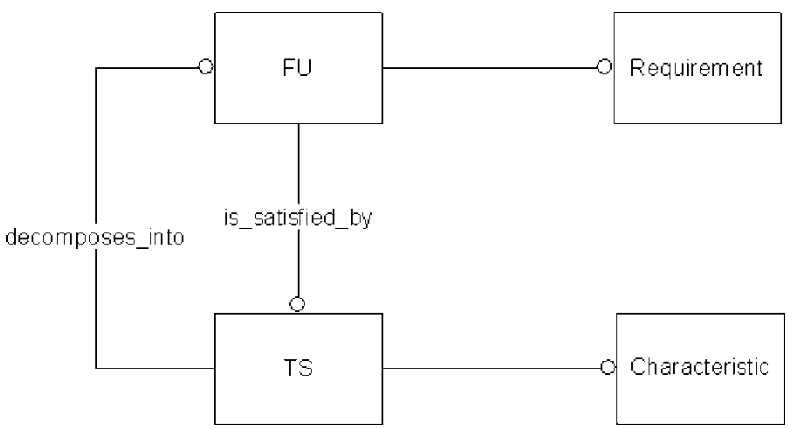


Fig. 2. FU–TS decomposition in Express-G. Functional units have ‘requirements’. Technical solutions have ‘characteristics’. An FU can be satisfied by one or more TSs. A TS decomposes into one or more FUs Žof a lower order·. Like a housing demand ŽFU· of a company can be satisfied by a building ŽTS·, where the building decomposes into a demand for office spaces ŽFU·, production facilities ŽFU·, parking facilities ŽFU·, etc.

This typical FU–TS decomposition results in highly structured Žlayered• product models. GARM also adds the notions of 'alternative technical solu- tion', and 'ports and ends' Žplaces where different FUs and TSs can be connected• to enable a further modularization.

The second important part of GARM was a con- tribution by Peter Willems w17x concerning the trans- lation of semantical connectivity data into a non manifold topology model. Earlier efforts showed that the topology of a building requires a non manifold topology model, but preferably not at the core of the product model. Willems' meta-topology scheme sup- ported the automatic translation of product models in non manifold topology models. In his PhD study w18x Willems extends his meta-topology scheme to in-clude also semantical geometry.

The ideas of GARM have been extended and refined in the PISA project w4x. After some years, however, it became clear that solutions like GARM or PISA were not acceptable to the standardization community. The reason is that this type of solution is only useful if a large part of its intended users are willing to apply it. GARM, in fact, can be seen as a product-modeling language in which generic product type models for specific classes of products Žroads, tunnels, buildings.• can be written. Such a language is only useful if a, more or less complete, set of product type models becomes available, which clearlywas not going to be the case.

After GARM was refuted, the AEC group lost its momentum and interests shifted elsewhere. In 1990 a number of researchers proposed a new model, the 'integration reference model architecture' ŽIRMA• w7x. Through the contribution of Bart Luijten w8x the IRMA model still contained some influences of GARM. In 1993 Thomas Froese w2x organised the first e-mail conference w2x to try to enhance the IRMA model and to develop international consensus.

The conference mainly showed that e-mail is not the most effective medium for a conference. Few were reading what others had to say, and focusing the discussions proved impossible. However, two things that came out of the IRMA e-mail conference had some impact. There was consensus about the need to extend the scope of product modeling to project modeling, and to include basic entities for activities Žor processes•, resources, and controls. The 'control' type of entities were especially heavily debated, but the fact that these four entities Žproduct, process, resource and control• formed the basic objectifica- tion of the IDEF-0 or SADT paradigm, made accep- tance easier. The second concept was that the build- ing and construction industry would require a num- ber of standards that, together, would serve the whole spectrum of AEC applications. The four basic enti- ties can be seen as the root entities of the complete set of applications in the building and construction area. The 'product' entity is the root for the tradi- tional product model oriented type of applications. The 'process' entity is the root for all the activity-re- lated software, like scheduling software. Resource is the root entity for resource-related software, like site planning. And 'control' is the root entity for project management and decision support software.

Shortly after the IRMA e-mail conference the European Commission funded the first Ž50 man– year• EU project in the B–C and process plant area. This project, called ATLAS, focused on the develop- ment, implementation, demonstration and dissemina- tion of semantical project information models, taking the IRMA results as its starting point. The author was the editor of the ATLAS model architecture, the ATLAS LSE Project type model, and the ATLAS building project type model. The model architecture developed under ATLAS w11–13x supported project information sharing, storing and exchange on four different layers ŽFig. 3•.

The carefully designed ATLAS layered model architecture supports cooperative design of technical buildings, where the installation is an important part of the project. Plant designers and building designers can use the CAxx systems of there choice and exchange information about heat sources, piping connections, etc., that influence both parties. About 12 application systems from eight different disci- plines, including project managers, were involved in the final demonstration.

After the completion of the ATLAS project the STEP AEC group initiated the AP planning project, which, in the 1994 Dallas meeting, resulted in the plan to develop a layered model architecture for AEC. The core model hierarchy researched in AT- LAS formed the basis of the plan. Below an AEC core model, five sectors would develop a 'sector core' model surrounded by 'discipline' models.

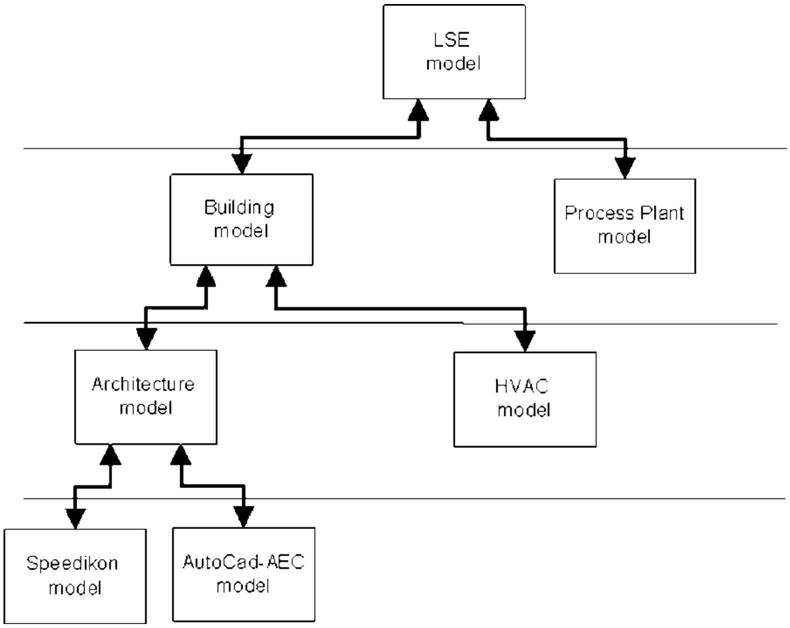


Fig. 3. The ATLAS model hierarchy. Boxes denote a model, or schema. Arrows denote mappings, or translators. Higher in the hierarchy entities are more abstract ŽSeparationObject, instead of OuterWall.. In the top layer the large-scale engineering ŽLSE. model provides an integration mechanism between different sectors of the LSE industry. One layer below, the building model and process plant model provide an integration mechanism between disciplines of their own sectors. Again one layer lower a number of discipline models ŽArchitecture, structural engineering, HVAC engineering in the building case. provide an integration mechanism between different applications of the discipline.

discipline model contains a 'discipline core' model. The B–C core model ŽBCCM. project edited by the author for two years, was the first sector core model development to start. w14x Development projects for discipline models for HVAC, steel structures, andarchitecture followed shortly thereafter ŽFig. 4..

*The present deÕelopment of semantical stan- dards*

Presently the two main standardization efforts are the continuing development of STEP and the re- cently started development of the industry founda- tion classes ŽIFC. by a consortium formed by Au- toDesk and Bentley, called the industry alliance for interoperability ŽIAI..

The ongoing development of the STEP AEC model architecture shows some progress, but also a deviation from the Dallas plan, making it quite clear that many problems remain unsolved.

The AEC model architecture foreseen in Dallas is no longer pursued. The AEC core model project never really started. The process plant people devel- oped a model based on their EPISTLE model, and integration of B–C and process-plant applications is more difficult than ever. Other sectors like civil engineering and offshore activities made limited progress while the shipbuilding industry pursued its own direction.

The STEP methodology itself has recently been heavily scrutinised. STEP requires its models to be 'interpreted', which means that they are brought into some common structure where certain restricted enti- ties and attributes have the same meaning in all the models, not only those belonging to the AEC indus- try. The problem is that after this interpretation process, the models look quite different and a great deal of the semantics have been removed, or at least have been obscured.

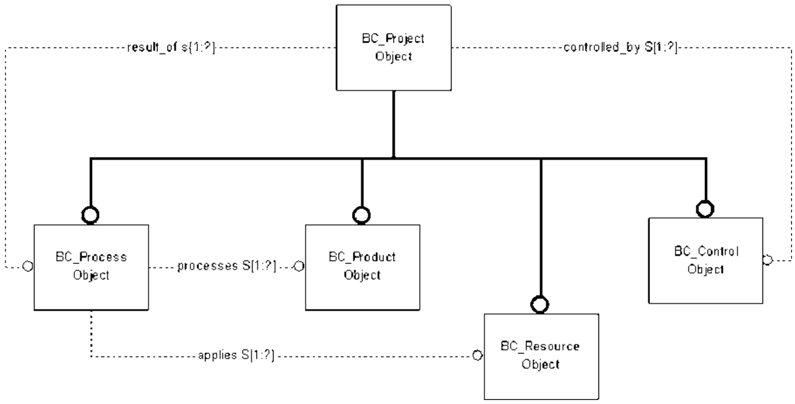


Fig. 4. Top of the BCCM. Four types of BC_ProjectObjects, following the IDEF-0 paradigm. BC_ProjectObject collects the attributes Žand in the future the methods· that are relevant for each objectclass Žentity·. Additional attributes are added to the specialised objectclasses. Every specialised object also inherits the relations shown in the model. As an example it is possible to say that a certain WallElement Žsubtype of BC_ProductObject· is processed by a certain Activity Žsubtype of BC_ProcessObject·, using a certain Crane Žsubtype of BC_ResourceObject·, controlled by a certain Schedule Žsubtype of BC_ControlObject·.

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Within the B–C area things are not going as planned. There is for instance no harmonization of developments of specific APs and the BCCM. Each group is working on its own goals with very limited funding.

The future of the IAI–IFC also does no longer look as bright as it did a year ago. Despite the industry drive and the limited scope of the IFCs Žbuildings only., resources are scarce and progress is

slow. Furthermore, the IAI–IFC is not really a stan- dard, it is an Application programming interface ŽAPI., providing product modeling functionality Žas a set of Cqq classes. to CAxx vendors that want to base their future software on these classes.

*Analysis of the current dẽ0elopments in semanti-cal standards*

The short history of product modeling standard- ization for the building and construction industry illustrates the following.

The mechanisms required for progress in the in- ternational standardization area are very weak to say the least. STEP is a very poor, administrative democ- racy. There are rules, committees, procedures and lots of paper, but money, workforce, management, mutual goals and progress are largely absent. Besides the editor and the project leader people only con- tribute at the periodic STEP meetings. The IAI is

also very weak. Many companies are taking an interest, but only with small amounts of their market-ing budgets.

What in fact is happening in STEP, is not stan- dardization, but prestandardization research. What- ever the leaders of the STEP initiative may claim, STEP for the building and construction industry is
not even in agreement about the way the standardŽs.
should be organized and structured. All the 'solu- tions', all the debates, all the small town politics have quite clearly shown that the building and con- struction industry still does not know how the inte- gration problem can be solved. For instance, the most important criterion, how to maintain semantical integrity in the project database, is not even ad- dressed.

Even if in the near future, STEP produces a more or less complete set of well-tested standards for AEC, we will have to wait for the vendors to imple- ment them. As most current CAxx systems are not product model based, support of STEP product mod- eling standards will be nearly impossible for most vendors.

If the expert guesses about the possible increase in effectiveness of the industry are correct, the indus- trialized part of the world is wasting large sums of capital on building and construction processes that result in designed products that are far from optimal.

Some countries, such as Singapore and Korea, have recently been noticing the lack of adequate stan- dards, and are currently attempting to increase the competitiveness of their national industries. Most noticeable is the realistic level of funding currently spent by the Singapore government in their Corenet project Žuntil 2000, about 50 MECU a year.. Also the European Commission is well aware of the prob- lem and is increasing its funding of AEC relatedproduct modeling projects.

Though this type of R& D helps to increase the awareness of the industry and administrators, it does not really help to solve the problem. National stan- dards are of limited value, because no single nation can do well in isolation anymore. The building and construction industry is a virtual multinational enter- prise that requires cooperation of companies of sev- eral nationalities in each large project. It is also important to note that the largest vendors of applica- tion software for AEC are based in the USA. It seems nearly impossible to expect that these soft- ware companies will support the development of national standards within each country where they sell their systems.

If STEP and the IAI are too weak, and national approaches are too restricted, what then are the perspectives for the future?

## 4. An agenda for the future

In my opinion the coming years will show that both STEP and the IAI are using outdated organiza- tional structures and outdated technologies that will prove to be ineffective for the building and construc- tion industry. A set of carefully designed standards for sharing, storing and exchanging AEC product models is not to be expected in this century. ISO is not the optimum organization to steer the pre- standardization process and there is not even consen- sus among the researchers that are carrying out the efforts. As there is also no strong management com- mitment and no funding, it is not realistic to expect that STEP will solve the industry's problems. More or less the same can be said about the IAI–IFC.

Clearly the solution will have to come from an- other source. Two alternatives are feasible. The first alternative assumes that we hold to the idea of a standard, but search for a much stronger organiza- tion. Candidates are the European Commission, the G7, or the UN. For such a development to be realized we need to involve politicians. Politicians might be willing to help if we can show them the profits: better AEC products at lower costs, healthier workforces, lesser environmental impact. If we can convince them that no single country, or even conti- nent can solve this problem on its own, we may find support among their ranks,

The second alternative is that we abandon the development of a standard, but solve the problem by providing a *ser̃ice*. Communication technology ŽWWW, Corba, Java. allows a service provider to assist the participants of a building and construction project in setting up a dedicated and distributed project database. The service can be extended to support product life cycle information management as well. If a service provider is able to support information transfer between the most popular subset of CAxx systems used in practice, there is a market that is willing to pay. This second alternative seems the most promising, because there the market mecha- nism will do its work. Several companies are already focusing their efforts in this direction. I am con- vinced that the first practical solution to the integra- tion problem will be realized along these lines rather than the unified development of standards.

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