Technology Transfer and Interdisciplinary Collaboration Between Architects and Engineers for a Sustainable Future

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Abstract:

Technology transfer refers to the process whereby the techniques and materials developed in one creative field or industry is adapted to serve another field. It is a synergetic process through which to research and development effort of the donor field is exploited in order to lighten the cost-burden of the pre-production phase of the receptor field. Technology transfer and interdisciplinary collaboration are important for all fields of production industry. For instance, the technology transfer between tall buildings and aerodynamic design is appropriate, since aircrafts and super tall buildings are similar due to the objection of high wind speeds. This paper tends to reveal how technological improvements and in industries such as aerodynamics, automotive, chemistry, and aerospace have impacted or will impact the design and construction of sustainable buildings of our time, as well as of the future. Many of these advances have occurred in the aerospace industry, where development of new, smart materials, energy producing devices, intelligent systems, and analytical techniques has transformed the design of the new generation of sustainable buildings. Case study examples of built and futuristic sustainable buildings will also be presented to illustrate this process.

Keywords: Technology transfer, sustainable buildings, smart materials, aerodynamics, nano-technology, aeronautics.

1. Introduction

The word “technology” encompasses essentially three meanings: (i) tools and instruments to enhance human ability to shape nature and solve problems; (ii) knowledge of how to create things and how to solve problems, and (iii) culture to understand the world and value systems. Related to knowledge is the development of modern scientific information, based on empirical observations, hypotheses, and generalizations on the natural laws concerning the behavior of materials and the living environment [1].

The tools, instruments or techniques, which are developed in one creative field or industry, subsequently can be adapted to serve another field. This process is the transfer of technology, or Technology Transfer (TT), which is a synergetic process through which the research and development effort of the donor field is exploited in order to lighten the cost-burden of the pre-production phase of the receptor field. The practice of TT dates back over 5 000 years and has hastened the use of a multitude of materials that are now commonplace within the profession, including kiln-dried bricks, reinforced concrete and plywood. The method of firing bricks within a kiln was derived from the ancient process used in Mesopotamia to produce ceramic pottery [2]. Similarly, the invention of reinforced concrete can also be traced to the gardening industry. Beginning with the inclusion of a metal mesh to improve the strength of concrete flowerpots,

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Joseph Monier, a French gardener, is credited with the innovation ultimately leading to the development of reinforced concrete. Following soon thereafter, François Hennebique, an engineer and builder, extended this idea into buildings through the addition of bent reinforcement bars within floor slabs in the late nineteenth century. However, widespread use of this newly developed 'liquid stone' was not possible until the engineering methods to evaluate and predict the behavior of reinforced concrete systems was discovered in Germany in the early 1900s.

The aircraft and boating industries offered similar imported material technologies, including plywood and aluminum, both of which were produced in large quantities following the end of the Second World War. Modern plywood originated in The Havilland Mosquito, a British aircraft made entirely of wood that was used extensively in combat missions during the war. As the use of plywood in the Havilland was considered experimental, production of the plane was initially halted during the war in order to focus on existing and more conventional designs. Permission to build the planes was later reinstated owed to the fact that it utilized molded plywood, a "non-strategic" material that was available in sufficient quantity during the war [3]. The production of molded plywood monocoque shells utilized wood veneers alternatively laid with casein glue into a reinforced concrete mold. The molds were filled with an inflated rubber bag exerting pressure as the wood dried for 24 hours [4].

TT is a process, through which technical information and products developed by industries, such as automotive, aerospace, chemical, and etc., are provided to potential utilization and beneficial use of other industries in a manner that encourages and accelerates their evaluation, enhancement and/or use. It also refers to the transition of techniques and materials developed in one creative field, industry or culture to another by an adaptation [5]. It is a synergetic process, through which the research and development effort of the donor field is exploited in order to lighten the cost-burden of the pre-production phase of the receptor field [6]. For example, the pioneers of the Modern architecture adapted the ancient craft of building to the newer methodology of engineering, the techniques of mass production, and consequently to continuous technological improvements.

TT can also result from coincidental curiosity of an individual researcher or a team, or it can originate from the effort of a company seeking to develop new products for their own market. The transfer occurs across industries where materials developed for one application benefits another. Knowledge exchange and interdisciplinary collaboration are of great importance. For example, the form design of a tall building is closely related with aeronautical design, since they are both complex and integrated systems and have self-contained environments with their own micro-climates [7]. Aerodynamic design is based on the physical laws of motion and aerodynamics, so such design methods are applicable to both aircrafts and super tall buildings in order to reduce the impact of lateral forces of wind. The innovations that come from different industries do not necessarily have to be high-tech. According to Ali and Armstrong [6], it can be simple in concept and incremental in development and execution.

For a successful TT these main steps must be followed:

- Establishment of collaborative partnership between key stakeholders, with the common purpose of enhancing technology transfer,
- Implementation of technology needs assessment,
- Participation in the processes of technology creation, development and adaptation,

- Design and implementation of technology transfer plans and specific actions,
- Evaluation and refinement of the actions and plan, and
- Dissemination of technology information.

In the following section of the study, past and current TT situations in building industry are presented. TT in building industry has been deliberately, and also coincidentially. In history, architectural design and construction have been influenced by production technologies and materials in other industries, as well as information technologies and biological processes, as will ve revealed in subjacent sections.

2. Past and Current Technology Transfer Situations in Building Industry

In the modern architecture era, the designers moved away from traditional practice to contemporary applications. These new fashions emphasized the functional side of the building environment. According to Le Corbusier (1976), the standard practice for the buildings must be their ability to provide natural light, thermal comfort, pure and clean air and a healthy indoor environment. Also, buildings should be economic and suitable for mass production. The most influential factors in TT were the massive building demands generated as a result of the industrial revolution and the advance of modern technology, especially the application of new production processes and new building materials.

The basic relationship between research and practice is that, research creates new knowledge, while practice makes use of the existing knowledge. According to Johnson [8], research and practice relationship includes correlative information flow. Research projects are defined based on the needs of practice, whereas the knowledge produced by research provides the solutions to the practical problems. Thus, there are two important aspects in the TT process. One is the time lag from technological development through its utilization, and the other is the extent of the technology dissemination and utilization. The essence of TT requires the dissemination of tools and techniques to the widest possibility with the shortest time delay and to an affordable cost as well.

The following sub-sections reveal the technological developments, which are transferred or transmitted successfully to the building industry in order to achieve environmentally conscious buildings.

2.1. Transfer from Production Technologies

With regard to building technology, a group of iron era pioneers created an initial symbol of the forthcoming revolutionary industrial process with the construction of Iron Bridge in Coalbrookdale (1775-79) in the Midlands in England. By means of dovetails, wedges and cogging adopted a familiar style of wood construction; it was the transfer of previous industrial techniques and practice into an iron bridge, as well as being an achievement of an interdisciplinary collaboration of architects and engineers. This bridge was the first sensational branding of industrial construction culture (Figure 1).

The automobile industry was a driving force in the mass production of consumer goods in the 19^{th} century. In 1855 Sir Henry Bessemer patented an affordable method of mass production of steel, and this innovation changed the building industry from the ground up. Detroit, from where the Bessemer process for the manufacture of steel took root in America, played an important role in the industrial development. Henry Ford invented the assembly line to produce more cars with a high speed, but low cost. While his system of production acted as an impetus for industrialization in general, it was further accelerated by Frederick Taylor's time and piece-rate model of scientific management, with both dimensions synthetically implemented in car factories, designed by the architect Albert Khan and his own 'industrial office' [9].

Ford and Taylor had an influence on developments in Europe, and parallel production plants were established such as the Bally shoe factory in Switzerland, and the FIAT Lingotto car factory in Turin. After the World War I, European Modernism developed a residential accommodation program of industrial dimensions. The acute shortage of accommodation after the war necessitated swift, efficient planning and construction. The new Frankfurt was an example of this approach of new industrial accommodation construction, and the Werkbund housing scheme at in Stuttgart was an experiment in new materials and building techniques. Since the advent of the Modern Movement, architects have been intrigued by the possibility of factory-built buildings, especially with regard to residential dwellings. In 1921, Le Corbusier introduced the Citrohan House, (or the Maison Citrohan), which was house designed for mass production by component pieces of tailored. Each house was based on a similar plan type, which could be modified according to the owner's needs. The Citrohan House embodied the conception of a machine for living in, a functional tool raised to the level of art through judicious proportions, fine spaces, and the stripping away of pointless decoration and purposeless habits (Figure 2) [10]. 50 years on from these first mass production developments, this horizontal advanced into vertical industrialization of the second-generation skyscraper technology, of which the 12-month construction time for the 88-story high Empire State Building in New York was a high-speed example.

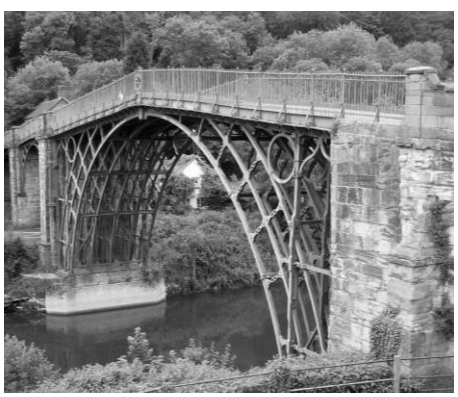

Figure 1. Coalbrookdale Bridge, Midlands, England.

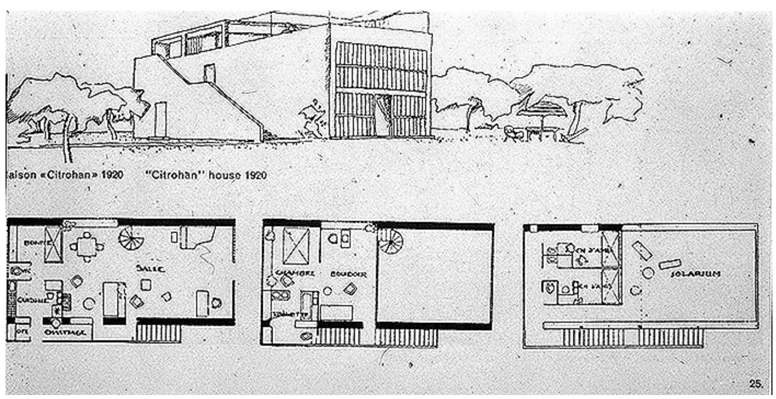

Figure 2. The Citrohan House designed by Le Corbusier in 1921.

Systematization of production led to increased standardization of parts, which also increased production efficiency. Along with these advances came the notion that labor and production processes could be scientifically evaluated to further increase in efficiency and production. Beyond the cost savings of the product as the fundamental benefit, components designed with common standards could be produced to high levels of tolerance and could be easily interchanged, as well as lowering amount of production and assembly wastes. Standardization of construction products and materials had a significant impact on the industry by reducing the waste and increasing the construction efficiency.

Buckminister Fuller's Dymaxion House was based on the low cost portable Dymaxion Deployment Unit (DDU) that he had developed in 1940. The DDU was based on standard circular agricultural storage bins [11]. It was a hexagonal metal house suspended by cables from a central mast (Figure 3). Although it was never produced, it served as the prototype for Fuller's aerodynamic Wichita House, which was manufactured by an aircraft company (Figure 4). Although its circular plan and shallow domed roof suggested a grain bin, wind tunnel tests confirmed that the form was aerodynamically up to ten times more efficient than a rectangular house.

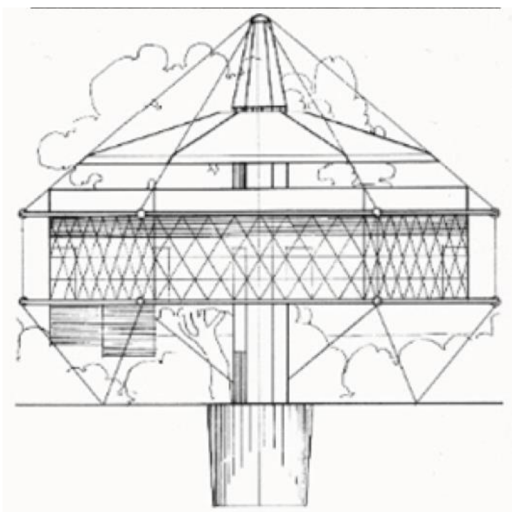

Figure 3. Dymaxion House designed by B. Fuller in 1940.

Figure 4. The Wichita House designed by B. Fuller and manufactured by an aircraft company.

In the steel-paneled Lustron kit house, which was introduced to the US market by the engineer and inventor Carl Strandlund in 1946 to meet the demands for the post-World War II housing, all components were packed into one large container and transported by truck [12]. Each house included a washing machine, an innovative built-in radiant heating system, a dishwasher and furniture. It had a steel skeletal frame to which wall sections were welded. The roof, as well as the exterior and interior walls, was made out of interlocking steel panels coated with a porcelain enamel finish sprayed on at the factory.

In 1957, when the 83.6 kg Russian satellite Sputnick I became the first artificial celestial body to circle the Earth in 95 minutes, it was interpreted as the east's technical and scientific superiority and attributed to deficiencies in the West's education and research system. Following this, school reform projects with a boom in education led to the mass production of all levels of classroom, the reconstruction of accommodation construction project of post-war Modernism, new methods in the production and distribution of mass produced consumer goods. All these represented the framework conditions that challenged numerous architects, engineers and constructers to come up with new inventions in technology.

The concept of using factory-made interchangeable modules, which can be plugged into mega structures was originally proposed by the Japanese Metabolisits in 1960s. Subsequently innovative architects such as Norman Foster and Richard Rogers exploited this technique during 1980s and applied it as prefabricated toilet pods on the outside of Lloyd's Building in London. According to Colin Davies [11] there is a practical side for assembling most of the service components of a building, such as saving time and improving the quality of product. By this production way, mechanical and electrical equipment can be installed more efficiently in a factor, where all systems can be easily accessed.

2.2. Transfer from Information Technologies

The impact of Information Technologies (IT) and computers on the society in just a few decades can match that made by the industrial revolution in a few centuries. During the last 50 years, computers have been changing the way people live and think, and today IT are playing an important role in many areas of our lives, i.e., transportation, commerce, agriculture, education, science, and the construction industry as well. Since the mid 1980s there has been a significant advance in IT, which open new opportunities for its wider application in architecture.

For design professionals, the initial surge of enthusiasm for computer application started in the early 1960s. It was generated by an optimistic view of the computer's potential as a design support tool and the time needed to develop this potential [13]. By the I970s and early 1980s, the initial excitement had been replaced by a greater realism about what the computer could offer. The change of opinion was caused by a combination of the high capital costs of computing hardware and the limitations of the existing design support software. On the performance aspect, the constraints were the small storage capacity, the slow processing speed and the facilities were inadequate.

Swiss Re Building in London is a very remarkable example of the architectural practice, which utilizes IT and Computer Aided Design (CAD). The greatest challenge in the construction of this unconventional-shaped building was to design and produce the elements of the cladding system, which was composed of panels with diamond-shape with different curves and angles. Scmidlin, the Swiss-based company, which produced the cladding for both London and other buildings in Europe, created their own detailed computer 3D model of the cladding system for the Swiss Re building, bridging spreadsheets and production line. Adapting existing software systems to the firm's needs, Schmidlin's computer staff built up a complete 3D model of the Swiss Re enabling both architects and cladding designers to examine every facet of the system for accuracy or any other problems in complete confidence, prior to actual production.

Nevertheless, the penetration of computer application in the architectural design profession continued to increase. Since the mid 1980s, the increase trend has been accelerating thanks to the rapid development in computer hardware and software. The cost of computing hardware is lowered while the performance, in term of memory size, processing speed, facilities and so on, is improving rapidly. Today computer drafting systems can free designers from distracting and unproductive activities allowing them to concentrate on the creative aspects of design. CAD can support decision making by enabling the designers to rapidly test and evaluate design alternatives in the search of the optimum solution. Computer information management systems can offer designers instant access to the accumulated knowledge in the building industry.

2.3. Transfer from Aerodynamic and Aeronautics

Aeronautics is the science involved with the design and manufacturing of airflight-capable machines, and the techniques of operating aircraft and rockets within the atmosphere. A significant part of this science is a branch of dynamics called aerodynamics, which deals with the motion of air and the way that it interacts with objects in motion, such as aircrafts. Formal aerodynamics study in the modern sense began in the 18^{th} century, although observations of fundamental concepts such as aerodynamic drag have been recorded much earlier. Most of the early efforts towards achieving heavier-than-air flight, which was first demonstrated by Wilbur and Orville Wright in 1903 [14]. Since then the use of aerodynamics through mathematical analysis, empirical approximations, wind tunnel experimentations, and computer simulations has formed the scientific basis for developments in other technologies, such as tall buildings.

Structural engineers also use aerodynamics to calculate wind loads in the design of tall buildings and bridges. Urban aerodynamics seeks to help town planners and designers improve comfort in outdoor spaces, create urban microclimates and reduce the effects of urban pollution. The field of environmental aerodynamics studies the ways atmospheric circulation and flight mechanics affect ecosystems. People who do wind turbine design, and insert these turbines to their architectural designs use aerodynamics.

New developments in aeronautical engineering, production and assembly methods, and new materials often find their way to the building industry [15]. The design of a super tall building can be resembled with a jumbo jet in terms of integration of complex systems and intelligent technology, structural engineering to resist wind loads and create an aerodynamic design, and the development of light and durable materials. Aircrafts are self-containt environments with their own micro-climates as in the case of tall buildings. An aircraft's interior must be pressurized to withstand external air pressures and to maintain comfortable pressure levels for occupants at high altitudes. This is the same case for tall buildings.

Today, the shape and form of many super tall buildings are designed according to aerodynamic principles to withstand wind loads, as well as to maintain occupant comfort in upper floors. Swiss Re tower in London, as mentioned earlier in the study, is one of the excellent examples of tall buildings, which is designed according to aerodynamic principles. Environmentally, its aerodynamic form encourages wind to flow around the building, minimizing load on the cladding and structure, reduces the amount of wind deflected to the ground compared with a rectilinear tower of similar size, helping to maintain pedestrian comfort at street level, and creates external pressure differentials that are exploited to drive a unique system of natural ventilation. The building's appearance also reduces reflections and improves transparency and daylight penetration to the offices inside [16].

2.4. Transfer from Other Technologies and Industries

Building industry can transfer many technologies from other industries to utilize it in structures or as construction materials. For instance, teflon, or with the scientific name Polytetrafluoro-ethylene (PTFE), was invented by Roy J. Plunkett in 1938, who was assigned with Dupont to develop a non-toxic, non-flammable coolant to be used in refrigerators,. This slippery powder, now called Teflon was proved to be capable of withstanding extreme temperatures as cold as -

270°C and as warm as +270°C. During World War II, designers of the atomic bomb utilized Teflon to manufacture gaskets and linings that could resist the bomb's corrosive components. In 1954, two French engineers discovered that cookware coated in Teflon prevented food from sticking to the pots and pans. This discovery led to the first widespread commercial use of Teflon. Later in the twentieth century, scientists began to develop ways to utilize Teflon in the practice of medicine, as well as in numerous other industries. After World War II this material is used for a vast array of functions, including flexible impermeable membranes for building construction and ultimately, lifting surfaces for the first successful human-powered aircraft. Today it is used as a self-cleaning coating for architectural fabric roofs, as utilized in 511 000 m^2 Haj Terminal at Jeddah Airport in Saudi Arabia, designed by SOM (Figure 5).

Major industry effort in Japan resulted in a number of robotic technologies for building construction, including automated building construction systems designed and produced by many companies. Robotics applications in the construction industry have been researched, explored and prototyped for the last 20 years. As a result, automation of today are far different from those of the last two decades. For example, the Shimizu TRY 2004 Mega-City Pyramid, which is a hypothetical project can only be realized by using robotics technology, developed by Dante Bini. The structure is more than 14 times as high as the Great Pyramid at Giza, and 2000 metersabove mean sea level, including 5 stacked trusses, each with similar dimensions to that of the great pyramid of Giza. The proposed structure is so large that it cannot be built with currently available materials, due to their weight. The design relies on the future availability of super-strong lightweight materials based on carbon nanotubes. Large robots will assemble the truss structure, and air bladders would be used to elevate trusses above the first layer using a construction system proposed by Italian architect Dante Bini[17] [URL-6].

New developments in materials are also allowing architects and engineers to design huge and stronger structures using less material thereby reducing the costs and increasing overall efficiency and performance. The ductile concrete, for instance, developed by a French company, has many advantaged for tall buildings in earthquake and tsunami or high wind regions. Jacques Ferrier has developed the Phare and Hypergreen Towers utilizing this ductile concrete diagrid as the structural material [18].

Carbon fiber is another innovative material, which has outstanding properties, such as high stiffness, high tensile strength, low weight, high chemical resistance, infinite shelf life, high temperature tolerance and low thermal expansion. These properties make carbon fibers very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. The manufacturing process of carbon fibers is very expensive since it involves nano-scale technology. These are highly customized in their product specifications, meticulously engineered and baked in autoclaves under high pressure at very high temperatures. These composites play a key role in specialized automobile industries, such as Formula-One automobile, bicycle, nautical and aeronautical design. They reduce operational energy demand with respect to kinetic energy by reducing weight and drag, as well as offering superior structural strength when compared with other materials. Carbon fiber is also used in large blades of wind generators. Super tall buildings subjected to high wind and earthquake loads can employ this innovative material using similar principles. A remarkable example is the 40-story Carbon Tower, designed by architect Peter Testa (Figure 6). The main structure of the tower is woven by carbon fibers together, rather assembling from a series of distinct parts. The building’s ultra light shell consists of 24 helical bands thousands of meters long winding in both directions around a cyclindrical volume. Instead of relying on a rigid internal core and a series of columns for stability, these thin bands of carbon fiber run continuously from the bottom to the top of the building and take the entire vertical compressive load [19].

Figure 5. Teflon coated fabric roof of Jeddah Airport, Haj Terminal, UAE.

Figure 6. Carbon Tower designed by Peter Testa.

The technology of Photovoltaics (PV), which is a device to generate electrical power by converting solar radiation into direct current electricity, as in the case of photosynthesis process, dates back over 160 years. The first commercial use of PVs were conducted by NASA for early satellites. Now there many research institutes working on this technology and its production expanded dramatically in recent years. Today the electricity generated by PV technology in buildings can marginally contribute to the energy efficiency. As PV panels can be manufactured in an affordable manner, it will be a very efficient way to utilize solar energy, especially for tall buildings, or buildings with large roof areas.

The development of fuel cells, another clean energy technology and widely employed in the aerospace industry, is also broadening in buildings, as an efficient energy production device. A fuel cell acts as a pollution-free energy source that uses hydrogen and oxygen to yield electrical output with only heat and water vapor as by-product, which can also be utilized for heating or cooling in the buildings [20]. The Conde Nast Building in New York, is one of the initial examples utilizing this technology. The two 200-kW fuel cells can generate the total night-time electricity of the tower without combustion.

Advances in physical sciences have also led to a new understanding of smart and changeable materials, which can be characterized by those that have enhanced physical properties and can be modified to provide better performances than ordinary materials. These materials, which are used in many industries, now can be adapted to buildings to regulate acoustical, luminous, and thermal building environments, generate electric energy, and contribute to the reliability of structural system elements for efficiency. Smart materials can be classified as piezoelectric, electrostrictive, magnetostrictive, electro-rheological, shape memory alloys, fiber optic sensors, etc. [21]. Additional future research will make these materials readily available and cost effective.

Conclusions

TT is not a new phenomenon. In fact, it has been occuring for a long time from automative, aerospace and textile industries to information technologies as well. Now it is increasingly widespread in all industries. The forces driving innovations in technologies may change in the future. In the past, military, space and medical technologies have been driving forces, with by-products to the green and sustainable building industry. In the future, the scarcity and high prices of non-renewable energy and natural resources, the pressure of environmental deterioration, and new threats of terrorism, may create new impulsive forces. In this context, while the combination of new technologies may have benign social applications, they could combine to undermine sustainability. The uncertainties provide the new context for re-visiting old questions about forecasting and assessments, decision-making and control of new technologies.

To be successful, TT requires more than moving any new high-tech inventions. Enhanced knowledge, management skills, technical and maintenance capabilities are needed, and integrating human skills, organizational development and information networks are also essential for an effective TT. Thus this is a complex and integrated process, if it is to contribute to a sustainable and productive environment. The recipient of the innovation must have the ability to use, replicate, improve and possibly to re-sell it. In the case of inadequate, unsustainable and unsafe technologies are transferred, the recipients will not be able to identify the technologies that are appropriate for their actual needs, circumstances and situations.

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