COUNTRY CLUB VILLAGE, HAWAII

A CASE STUDY ON

DAEWOO’s MULTI-ROOM MODULAR CONSTRUCTION SYSTEM

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The five buildings in the Country Club Village development in Hawaii look like any other concrete buildings with plenty of architectural details, balconies, pitched roofs and pastel colors. Behind these crisp, cool comforting facades, however, lies a dramatic experiment with the radically new method of the multi-room modular construction system of Daewoo Corporation of Korea. Each of the individual dwelling units was prefabricated on site as a three-dimensional precast concrete structural module, and then lifted into position to assemble the buildings. It was this modular construction system that made the Country Club Village development financially feasible and gave Daewoo an entry to the USA construction market.

This case focuses on the use of Daewoo’s multi-room modular construction system (DWS) in the Hawaiian project, gives a background on previous uses of the system in Korea, and summarizes the areas that further research and development is needed.

Questions for Discussion

1. How would you prioritize the technical issues that need improvement, in terms of their importance for DWS’s viability in the future?
2. How would you improve the joints? Please evaluate the recommendations of Abam Engineers.
3. How could you transfer know-how to DWS from the modular shipbuilding construction system that has been used successfully for decades?
4. Do you agree with Dr. Shin’s recommendations regarding the total construction approach? What would be its limitations, if any?
5. How could you make DWS more flexible, so the final buildings can take more interesting shapes?
6. If Daewoo Corporation wanted to internationally expand the market for DWS, what should be the marketing strategy? Would it be advisable to first pursue markets in developing or developed countries, or should Daewoo expand in both simultaneously?
7. Please present a business plan for DWS for Daewoo Corp.

Professor Spiro N. Pollalis prepared this case with the assistance of doctoral student Kevin Rothroe as a basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation, a design and a construction process or a design itself. Additional research was provided by doctoral student Sanghyun Lee and Master in Design Studies student Sanghee Hwang.

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The authors acknowledge the assistance of Chulhong Lee and Junghyun Cho of Daewoo Corp., Pravin Desai of CSD International, Danny Shin of Shin Inc., and the construction team of Daewoo for the Shiheung Apartment project, Shiheung, Korea.

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The Country Club Village Development

In 1993, James K. Schuler, President of Schuler Homes, Inc., a NASDAQ traded company, perceived a market for a large-scale residential development of low-rise condominium buildings in Honolulu, Hawaii. At that time the real estate market was excellent in Hawaii with a strong demand for dwellings for both mid-range and luxurious units.

James Schuler carefully selected and then purchased fourteen acres of land adjacent to a picturesque eighteen-hole golf course, a stream and a park, a few miles from downtown Honolulu (Fig. 1). This site would be highly desirable to prospective residents, who would be able to enjoy expansive views of the vast open spaces as well as conveniently play golf. James Schuler named and marketed this development as Country Club Village to emphasize the amenities and lifestyle his condominium homes would offer. The planning of the individual condominium units was based on James Schuler's extensive knowledge of the Hawaiian housing market in general, as well as his familiarity with the features that attract buyers and increase sales. It is remarkable to note that the first 204 condominium units in the low-rise buildings sold in just two weekends, although it should be acknowledged that the housing market was very strong when the first units

Fig. 1. The location of the Country Club Village, in the outskirts of Honolulu.
in Country Club Village were offered for sale.

Schuler Homes, Inc. had a long history as a major developer of low-rise multi-family residential properties in Hawaii. While mid-rise luxury residential buildings, primarily on coastal sites, had often been constructed on the Hawaiian islands for thirty years, Schuler Homes, Inc. was primarily dominant in the lower and middle-priced segments of the housing market. In fact, prior to the Country Club Village project, buildings in most of their developments did not exceed four stories in height. These residential buildings often featured covered parking beneath two or three levels of condominium units, and, as is common for both single and multi-family residential structures throughout North America, they were primarily constructed using conventional wood or metal stick framing.

**Selection of the Architect - Feasibility Studies**

After he purchased the Country Club Village site in 1993, James Schuler carried an unpaid design competition to select the architect of the project. Two of the four architectural firms that participated were from Hawaii and the other two from the continental USA. The competition called for 4-storey high buildings. James Schuler was most satisfied with the design entry of CDS International and commissioned them to design the project. CDS International is a Honolulu based full service architectural firm that was founded forty years ago by George Hogan and Don Chapman, both of whom are now retired. Pravin Desai, AIA, CEO and President of CDS International assumed the leadership of the project. Mr. Desai had joined the firm in 1969, and has watched it grow significantly in size and develop a diverse client base. In the early years, the majority of the firm’s commissions were multi-family residential projects. By 1994, CDS International was designing major hotels, resorts and commercial developments in addition to residential projects, with the latter now accounting for twenty to thirty percent of their commissions.

Early design strategies for the Country Club Village followed the traditional low-rise “stick-built” approach. The winning entry of CDS International proposed 565 dwelling units, based on the requested low-rise building designs. However, the number of low-rise buildings required to achieve those 565 units would have densely covered the site and created uninspired living environments with insufficient views of the surrounding landscape. Such a solution would have, of course, defeated the fundamental advantages of the site and the marketing strategy of the project. Even more important, however, given the relatively high cost of the land and the fact that it was zoned for up to 1,300 units, such a development would have financially underutilized the site and probably not have been sufficiently profitable to be considered viable. Both Pravin Desai and James Schuler became convinced that a combination of low-, mid- and high-rise buildings was the necessary design approach for the Country Club Village project. The client and architect elected to design a complex that provided as many dwelling units as possible without diminishing the desirability of the individual condominiums and the site as a whole, and, hence, the ability to sell homes quickly.

This design approach, however, necessitated the use of concrete structures for the various buildings. James Schuler had never developed projects using concrete construction, and the cost of using this type of construction in a conventional way was prohibitive to his traditional clientele. Most of Schuler Homes Inc.’s developments were targeted at a low- to mid-priced segment of the
housing market, and the per dwelling unit cost of constructing traditional concrete buildings, estimated to be $130 to $150 per square foot, would have made the individual Country Club Village condominiums too expensive for the intended market. In an effort to provide a solution to this problem, Pravin Desai suggested to explore the multi-room modular construction system that had been developed by Daewoo Corporation in Korea.

The CDS’s branch office in Seoul, Korea had business connections with Daewoo Corporation. Through Jong Su Kim, in CDS’s Korean office, Pravin Desai was aware of the Daewoo Multi-Room Modular Construction System, a system of prefabricating entire dwelling units in concrete and stacking one on top of the other using cranes. He was also aware of the significant cost savings this system offered relative to conventional concrete building construction, and thought it may offer a solution to the Country Club Village project.

**Daewoo’s Multi-Room Construction System**

Daewoo Corporation is a division of the Daewoo Group, one of the vast multi-national Korean companies. These corporations have many divisions engaged in diverse and often completely vertically-integrated business activities. Fig. 2 shows the organization diagram of the Daewoo Group. Each division of the corporation has several subdivisions and each subdivision is structured as a separate organization.

The Daewoo Construction Company is a division of Daewoo Corporation, engaged in diverse design and construction activities throughout the world. The organizational structure of the Engineering Division of the Daewoo Corporation is also shown in Fig. 2. This division’s experience with concrete buildings with repetitive modules led it to seek ways to make the design and construction processes for these buildings more efficient and therefore more cost-effective. The company recognized that a means to produce buildings of higher quality in less time for significantly less money would be an enormous competitive advantage. At a time that construction becomes an international commodity, Daewoo’s Engineering Division put its efforts to develop proprietary technology to differentiate from its competitors and provide a better product to its clients. Such efforts were congruent with the Daewoo philosophy “to provide top value for Daewoo’s clients by achieving a quality revolution in fields of Daewoo’s activities from technology, production, marketing and procurement, as well as in the execution of all projects.”

In searching for innovation and for developing proprietary expertise, Daewoo purchased the patent rights from the Andersen Company of Nevada for prefabricating on site three-dimensional precast concrete dwelling units and assembling those units to make the buildings. The sale of the Andersen Company’s patent to Daewoo Corporation was coordinated by Danny Shin, P.E., owner of D.I. Shin International, Inc., Consulting Engineers in Honolulu.

Through CDS International’s Korean office, Pravin Desai became aware of Danny Shin’s firm and of his knowledge of Daewoo’s DWS system. He arranged a meeting with Danny Shin and James Schuler to discuss the applicability of Multi-Room Modular Construction to the Country Club Village project.

At the time of that meeting, Daewoo Corporation had already significantly modified and improved the earlier and less sophisticated Andersen System. The successive developments based
on research and field data were given the code numbers DWS 101, DWS 201, DWS 301, and DWS 401, and the “Daewoo System of Multi-Room Modular Construction” (DWS or MRMC) was already in its fourth generation development when Mr. Schuler expressed his interest in the system. DWS had been implemented quite successfully in 5 projects in Korea in the period 1989-1994, including both low-rise and high-rise buildings. The Country Club Village project would be Daewoo’s first project outside Korea and, at the same time, it would be the first construction project of Daewoo in the USA.

Fig. 2. The organizational structure of Daewoo Corporation’s Engineering Division.
Daewoo’s DWS projects in Korea are residential, although the system is suitable for hotels and schools. The Changwon Apartment complex, built in 1990-91, has 168 two-bedroom units in twelve-story structures. In this early DWS project, shown under construction in Fig. 3, the slab is located above the walls in the precast concrete dwelling unit, shown to be lifted into position. A major improvement in the system positioned the slab below the walls for each prefabricated unit for subsequent projects. The Suyongman Apartment complex in Pusan, built in 1992-94, is one of the largest applications is DWS and contains 600 dwelling units in seven fifteen-story buildings. Fig. 4 shows this project under construction and about half completed. The Kimhae Apartment development, 1994-96, has 504 three-bedroom units in eight fifteen-story buildings. The schedule for the Kimhae Apartment development includes 18 months for the construction of the multi-room modules and their assembly to make the buildings, and a total completion of the project in 24 months. The conduits for electrical work and the embedded plumbing are included in the construction of the modules. The actual wiring and the external plumbing is done in-situ, together with the rest of the finishing, after the buildings have been assembled. According to Daewoo Corp. “the DWS method of construction is transforming the entire concept of living environments. This system, developed by Daewoo, is capable of constructing high quality housing, hotels, or office buildings in an extremely reduced period of time. DWS makes effective use of technology, manpower, materials and equipment.”

Fig. 3. The Changwon apartment complex under construction, Changwon, Korea.
However, it is worth noting that the current Korean building code requires a minimum construction period for concrete buildings in an effort to assure safety by allowing the concrete to cure properly and reach its strength. The code requires inspections of the structural system every 5 floors that usually take more than 2 weeks to schedule while, using DWS, 2 floors can be assembled in 3 days. Furthermore, the total construction time period for each floor in a building should not be less than 2 months. Using DWS, it is technically feasible to construct 15 floors in 3 months, not counting the time to produce the modules. So, DWS can applied in the Korean construction market in large projects that their segmentation will allow the compliance of the overall project while some buildings will be available for occupancy much earlier. Nevertheless, DWS’s strength could be fully exploited in international markets that do not have time limitations and where labor is more expensive than Korea. Skilled labor cost in Korea in late 1996 was $100/person/day, less than half the US rate, and it is worth noticing that wet construction is cheaper in Korea than dry-wall partitions. Furthermore, residents prefer wet masonry construction for sound insulation as well as for its feeling of a sturdier home.

The construction of a building’s structure using DWS is based on 9 steps, shown schematically in Fig. 5, and can be compared to the process of building ships. In a similar manner to DWS, the modules that assemble the ship are prefabricated at the shipyard. Then, those modules are put together and welded in the dry-dock, to make the ship’s hull (Fig. 6). The ship’s main engines

Fig. 4. The Suyongman apartment complex in Pusan, Korea.
Fig. 5. Multi-room unit production and installation (continue).
Step 1: preparation of the slab casting deck.

Step 2: the positions of the walls are marked and block-outs are installed to allow the welding of the unit to the unit below.

Step 3: placement of reinforcement, electrical conduits and pouring of concrete, with steam-curing: the slab of the whole multi-room unit is completed. The thickness of the slab is 200 mm (approx. 8 inches), except for foundation slabs that the thickness is 700 mm (approx. 27.5 inches). Concrete strength is 270 kg/cm$^2$ (approx. 3,800 psi).

Step 4: the reinforcing steel bars of the walls are positioned and connected to the dowels of the slab, electrical conduits are tied to the reinforcing bars, the mold for the inner and outer surfaces of the walls are lowered by the plant’s crane.

Step 5: concrete is poured to form the walls and the concrete is steam-cured. The thickness of the walls is 250 mm (approx. 10 inches) for exterior walls and 200 mm (approx. 8 inches) for interior walls. Concrete strength is 270 kg/cm$^2$ (approx. 3,800 psi).

Step 6: the mold is removed.

Step 7: the module is placed on a trailer to be transported for finishing, storage, and crane accessibility.

Step 8: the module is stacked on top of the module to be located below to level the surfaces using shims and grout and for storage.

Step 9: the installation crane installs the modules on the building.

Fig. 5. Multi-room unit production and installation.
and other large equipment are also put in that time as they are quite large in size and cannot be inserted after the modules are all welded in place. When the hull is ready to float, usually 2 to 3 months for a 50,000 tons ship, the hull leaves the dry-dock to be completed along the dock. Daewoo’s Shipbuilding Division, part of Daewoo’s Heavy Industries, is a pioneer in the modular ship construction system for several decades, and has perfected it through the years. In today’s shipbuilding it is economically essential a) to occupy the dry-dock, a high-investment facility, for as little time as possible, and b) to schedule the production of the ship’s parts in a production line rather than custom-building. It is worthy noting, however, that the Engineering Division conceived DWS independently from the Shipbuilding Division, although their headquarters are located a few floors apart in the same building.

According to Daewoo’s Engineering Division, DWS is financially attractive for building projects with more than 500 units. The major advantage of DWS is its speed of construction. It is estimated that a DWS project can be completed in half the time required to build the same project with conventional construction. Data regarding the cost of the structural skeleton show that the cost of the plant is 10% of the cost of the structural skeleton, 70% is the construction of the modules, and the remaining 20% is the cost of transportation and assembly. However, the actual cost of a project using DWS in absolute numbers is still about 5% more than if conventional construction were used. Given the speed of construction, however, DWS is financially more attractive than conventional construction, and its bigger advantage is the quick turnover which is quite important for speculative development. It is worth noting that the total labor required in a project using DWS is 70-80% of the labor required for a conventional construction and this could be lowered to 50%.

Before proceeding with the Country Club Village project, James Schuler and Pravin Desai decided to go to Korea and visit several of the housing projects that Daewoo was either building or had completed using DWS. Both developer and architect were impressed by the speed of construction and the quality of the finished buildings. They were also impressed by the efficient
Fig. 7. The site planning for the Country Club Village development that shows the location of the golf course, the 6 proposed buildings, their heights and the corresponding number of units.

process of designing DWS buildings that Daewoo had developed. What they learned made it immediately clear that the Daewoo system could offer Schuler Homes Inc. very significant cost savings, primarily because compressed construction schedules would allow James Schuler not only to sell the condominium units faster and capture the booming real estate market, but also reduce the period of time over which he would need to finance the project. These savings, in addition to the reduction in actual construction costs claimed by Daewoo, would more than offset the additional per dwelling unit cost he would incur in a mid-rise development.

The Design of Country Club Village

The Country Club Village development was re-designed to contain a total of 832 two- and three-bedroom dwelling units of various plan configurations, as shown in Fig. 7. The complete design includes six buildings of different heights, united by compatible aesthetic treatment of their exteriors. By the end of 1996, five buildings with 590 two- and three-bedroom dwelling units and two parking structures had been completed. The five residential buildings included three four-story buildings, one twenty-one story and one sixteen story building. By that time also, Hawaii’s real estate market was very weak. Federal cutbacks, reduced military spending, a reduced state budget,
and Honolulu’s own $500 million city budget deficit contributed to the situation. So, the last building of twenty-two stories was put on hold, to be erected when the local residential real estate market would become buoyant again.

The DWS construction required the buildings to be specifically designed to comply with the DWS process. The decision to use DWS was made after the architectural competition was awarded to CDS International but before the final design. So, the architect had the opportunity to design the buildings to be suitable for the proposed construction system. Daewoo’s involvement was crucial at the architectural design stage, as a consultant to the architect and as the designer of the DWS modules to comply with the architect’s design. Fig. 8 shows the required intermediate step that transforms the initial architectural design to a design suitable for DWS. Among the most important steps are the design of the modules so they can be as uniform as possible, the location and accessibility of the connections that should be strong, easy to inspect, and minimally visible in the completed building.

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**Fig. 8.** The interaction between the CDS International and Daewoo during design development in the DWS Country Club Village project.
Furthermore, the application of the DWS at Country Club Village required careful site planning, not only in the architectural and urban planning point of view, but especially in terms of accommodating the new construction process. The DWS requires significant open space for positioning the on-site precasting plant and the cranes that lift and stack the precast concrete modules (Fig. 9). Compliance with the building code as well as meeting the demands of the labor unions were additional concerns.

CDS accepted the challenge to produce high quality architecture within the added construction constraints and started working close with Daewoo’s experts to design the Country Club Village project. The modular construction system was seen as an opportunity for CDS to develop expertise that could be quite lucrative in the future, as the advantages of the DWS could make it a system of choice in the USA.

CDS designed each home to be spacious and open in plan, admitting abundant daylight while shading the interior from direct sun with recessed or projecting balconies. From these balconies, most owners have dramatic views of the golf course or the surrounding landscape. Fig. 10 shows a typical layout of a condominium unit. The external appearance of both the four story and high-
rise structures presents the image of a clean, comfortable and convenient place to live. The buildings are finished in soft pastel colors and accented with touches of aqua green in a manner popular in tropical resorts. In addition, the low-rise buildings have lushly landscaped courtyards and low hipped roofs with deep eaves. All of the buildings feature decorative pediments suggestive of home (Fig. 11 and 12). In recognition of its architectural quality, the project received an AIA Excellence award, and its innovative construction system won a Grand Award from the American Consulting Engineers Council in 1995 (Fig. 13 and 14).

Fig. 10. A typical three-bedroom, 1,117 ft² unit in the low-rise buildings.

Fig. 11. Completed low-rise courtyard building at Country Club Village in Hawaii.
DWS at the Country Club Village Project

Conventional Construction Methods

Conventional building construction methods for multi-family residences like those at Country Club Village consist of either steel frames with concrete slabs, or of poured in place concrete structures composed of floor slabs, columns, and shear walls. Often the concrete slab itself is made of prefabricated panels and beams are poured in place to make a concrete frame. Vertical plate concrete elements that act as shear walls are usually located between dwelling units, at the ends of buildings or as a part of core elements such as fire stairs and elevator shafts. The construction of a traditional concrete structure is normally sequentially staged. For each floor, formwork for the floor slab is erected, and, within this formwork, steel reinforcing bars are properly positioned. Concrete, specified for a certain strength and composition, is then poured in a carefully timed and uninterrupted process. Fig. 15 shows the construction of the structural skeleton of a typical floor, using Prof. Pollalis’s patented Visual Scheduling and Management System (VSMS) that displays the required labor in the vertical axis and time on the horizontal axis.

Once the poured concrete has gained a required strength, the formwork for the floor slab is carefully removed using manual labor. Next, pre-assembled column reinforcing bar “cages” are positioned and tied to rebars left projecting from the slabs. There also may be “blockouts” in the slab to key columns to the concrete floor structure. Around each of the column reinforcing assemblies, formwork is then manually positioned, and into these forms concrete is poured and then vibrated. Again, once the concrete on the next floor has set, the forms are removed by hand, cleaned as required and reused. Often the process requires the use of 2 to 3 sets of formwork so that more than one floors are supported by formwork, waiting to be set. Fig. 16
shows a graphic depiction of the construction of identical floors and the moving of the formwork. Fig. 16 was also prepared using the patented VSMS. The concrete for most of these slabs and columns (and any shear walls) is pumped from trucks through hoses mounted on hydraulically-maneuvered extension cranes. The uninterrupted or continuous flow of concrete deliveries to the construction site is critical to the visual and structural integrity of this type of conventional in-situ concrete work.

![High-rise building at Country Club Village under construction.](image)

*Fig. 13. High-rise building at Country Club Village under construction.*

The time constraints of the conventional in-situ concrete building process that imposes on a construction schedule are immediately apparent, as are potential quality control issues related to the manual placement of formwork and field dimensioning in general. The construction time for each floor’s component slabs, columns and walls is dictated by the amount of time it takes to erect formwork, place reinforcing bars, pour, vibrate and cure concrete and then remove formwork. In addition, this process is largely exposed to unpredictable weather conditions, and is, therefore, itself unpredictable. Especially in cold climates, such a process is severely handicapped during temperatures close to freezing and is often discarded in favor of steel construction. Furthermore, delays or unforeseen problems can be cumulative in that the construction of any given portion of this concrete structure is dependent on the successful and timely completion of that portion on which it bears. Other than pre-assembling selected reinforcing cages and prefabricating formwork, there is little opportunity to engage in the concurrent construction of various aspects of the design.
DWS Construction: a Manufacturing and Assembly Process

DWS greatly compresses the construction time necessary to erect a building like those in the Country Club Village development. By prefabricating the concrete superstructure of such a building on a per dwelling unit basis, the construction process is simplified and becomes essentially the assembly of a kit of large parts, parts manufactured on site in a temporary (relocated) precast concrete plant. It is estimated by Pravin Desai that had the Country Club Village project been constructed conventionally, it would have taken four years rather than two to complete, and
Fig. 15. Quantified bar chart for the construction of a typical floor, intensity personpower.

Fig. 16. Matrix-balanced chart for the construction of the structural frame, including the moving of the formwork and the scaffolding from floor to floor.
DWS saved approximately $11 million, almost 14% of the total construction cost of the project. The speed of construction realized by the application of Daewoo’s system, and the consequential speed of delivering homes to buyers is impressive and crucial to reach a strong real estate market.

Each of the modules contained, prior to being lifted into position, uninstalled and packaged window and door units, cabinetry and other prefabricated or pre-assembled interior components so that everything required for finishing the interior of a condominium unit was lifted into place at once. As the precast concrete condominium modules were stacked, they were fastened to each other by welding together exposed reinforcing bars and embedded steel plates from adjacent units at precise vertical and horizontal locations. The openings for these connections were then filled with grout. In this manner, the collective structural strength of the precast concrete modules was captured and eliminated the need for any type of conventional structural frame (Fig. 13).

Manufacturing of the precast concrete modules for the Country Club Village project was essentially a two-step process. First, a series of reinforced floor slabs were poured adjacent to each other on forms supported by a steel framework. This work was, reasonably in the Hawaiian climate, completed outside the precasting plant. In similar Korean projects, floor slabs had been manufactured in the plant and simultaneously stacked in a manner similar to traditional lift-slab technology. Embedded in these slabs, flush with the lower surface, were exposed steel plates, to which a welded connection was later made once the completed module had been positioned in a

![Fig. 17. Positioning of electrical conduit and junction boxes on reinforcing bar assembly.](image)
building. The upper surface of each slab had integral keys blocked out for positioning and tying concrete partitions and walls to the slab. The creation of this partition layout on top of the slab with hydraulically positioned and removed formwork constituted the second major step in constructing a multi-room modular precast concrete dwelling unit.

After a series of floor slabs were poured, finished and cured, usually six, reinforcing bars for the partitions and walls were set per the keys in the floor slab. In addition, conduit and junction boxes were positioned and connected to the reinforcing bars cage for the future distribution of electrical wiring (Fig. 17). Next, a module’s slab and partition reinforcing bar cage were transported using a gantry crane to the wall-casting area in the DWS manufacturing plant. Here, a partially completed module was positioned on a
Fig. 20. Opening of hydraulically-operated molds for making three-dimensional precast concrete dwelling units.

Fig. 21. A completed precast concrete dwelling unit or module being loaded on a 400-ton transporter by a 230-ton crawler crane for delivery to the erecting ringer crane.
dolly frame that transported the assembly through the remaining steps in the manufacturing process (Fig. 18).

The first step in this process was to position the hydraulically opened and closed formwork or molds for the partitions and walls. Once these molds had been positioned, the vertical connectors to be cast into the concrete walls were precisely positioned using guides attached directly to the formwork (Fig. 19). The hydraulic system for activating the opening and closing of formwork permitted the concrete to be poured with very tight tolerances. Concrete was poured into the molds using pump cars with hoses attached to hydraulically-operated pinned extension frames. This permitted flexible distribution of concrete over the full area of a module. Vibrators operated by compressed air lines ensured both proper distribution of the concrete within the forms as well as adequate structural performance by eliminating potential air pockets. After the pouring and vibrating of concrete had
Fig. 24. Floor slab reinforcing bars left exposed by block-out in precasting mold.

Fig. 25. Steel plates welded to exposed reinforcing bars form structural connections between adjacent floor slabs.
been completed, the partitions of a modular unit were then steam cured. The plant had an extensive steam distribution network whose pressure was carefully monitored.

After the concrete cured, the wall formwork was stripped by hydraulically opening the molds (Fig. 20). The forms were then immediately cleaned for and transported down the “assembly line” for the next module. This cleaning process was essential to ensure both quality control and that the molds could be used many times.

The next step was to prepare and refine the surface of the cured and stripped partitions for finishing. This was accomplished by applying a cement wash to the precast surface with hand trowels. Once this cement wash had dried, minor prefabricated metal-framed partitions were installed. These assemblies had gypsum wall board fastened to one side and included additional electrical conduit and junction boxes. In addition, at this time, various prefabricated or pre-assembled components necessary for completing the build-out of a condominium unit were placed in the precast concrete module. These components included pre-hung doors and frames, complete packaged window units, cabinetry, railings, plumbing trees and additional metal-framed partition units fabricated off site. As an example, the time it took to produce the dwelling unit modules for a typical floor in the twenty-one story building at Country Club Village averaged five or six days. The total module production, module erection, and connection welding and grouting time for each floor averaged fifteen days. Given the prefabricated nature of this building, production of a given floor’s modules occurred concurrently with the erection of a previous floor’s modules. Consequently, the time necessary to construct this twenty-one story building was approximately 130 days.

A completed DWS precast concrete dwelling unit containing the uninstalled component parts mentioned above was loaded onto a 400 ton transporter by a 230 ton low-rise crawler crane and delivered to the ringer crane (Fig. 21). This ringer crane then lifted the module into position on the building. Once positioned on a building, the module was leveled using neoprene shims before horizontal diaphragm and vertical shear connections were welded (Fig. 22). In order to expose sufficient steel for the welding itself as well as to provide sufficient space to maneuver a welding torch, small areas of concrete were chipped away from around the embedded steel plates and reinforcing bars that were to form the connections.

There were several distinct types of connections to be made. Mid-height wall connections consisted of a simple steel plate about eight inches long continuously welded to plates cast into the walls of adjacent units (Fig. 23). These connections permitted building shear loads to be resisted by the combined strength of walls from more than one module. In a similar way, the floor slabs of multiple units were connected together to create a single structural diaphragm at each level in a building. In order to prepare for these connections, small perimeter sections of a unit’s floor slab had been blocked out to expose the ends of two steel reinforcing bars (Fig. 24). Each pair of rebars (one from each unit) were then welded together using small 1/2-inch thick steel plates (Fig. 25). Vertical connections between units were accomplished by directly welding together (across the dimension of any neoprene shims) the steel plates embedded in the underside of the upper unit’s floor slab and in the top of the lower unit’s concrete walls. All of these various temporarily exposed connections were then grouted solid and in effect hidden within the overall concrete structure. Given the minimal temperature fluctuations to which the Country Club Village buildings are exposed, no expansion joints are required. Exterior joints between installed and finished units are filled with backer rod and sealant. Drawings of several typical vertical and horizontal connections are shown below in Fig. 26.
Fig. 26. Typical connection details between three-dimensional precast concrete modules: vertical and horizontal connections.
Fig. 27. Typical connection details between three-dimensional precast concrete modules vertical connections of the interior walls.
Fig. 28. Typical connection details between three-dimensional precast concrete modules: vertical connections of the exterior walls.
Contractual Relationships

After James Schuler decided to use DWS for the construction of the Country Club Village buildings, he contracted Daewoo Corporation, as shown in Fig. 29, to work together with CDS for developing the final design. CDS was carrying out the architectural design and Daewoo was consulting them on making the design suitable for DWS and economically feasible. After signing the contract in June 1993, Daewoo set up a local office under the direction of Mr. Junghyun Cho, a project manager experienced with DWS, with formal architectural education. In 1991, Mr. Cho had worked in the Changwon DWS project for finishing work; in 1992, he had prepared at Daewoo’s headquarters the design of forms for the DWS modules of the Suyongman Apartment complex in Pusan; and in 1993 he had worked in the same Pusan project for finishing work.

Fig. 29. The organization during design development.

Fig. 30. The organization during construction.
Daewoo had no experience with the US construction market and solicited a bid to hire a subcontractor with increased responsibilities. It is quite common for Korean or Japanese construction companies to hire US firms that usually perform the services of general contractors to work for them as subcontractors. Such subcontractors have the necessary local experience and hire most of the other subcontractors, while the foreign company has the opportunity of a very steep learning curve for subsequent projects.

A local contractor was selected as such subcontractor to provide the labor for the multi-room modules and to assemble the buildings. Daewoo would provide the technical expertise, the cranes, hydraulic formwork and all the necessary equipment. The organizational structure of the Country Club Village project is shown in Fig. 30. The subcontractor was selected through a bidding process and the contract was signed in early October 1994 for 204 units in the low-rise buildings. The first module was produced 6 months later, in March 1994. A separate bidding process was followed for the three high-rise buildings. The contract with the subcontractor was signed in early February 1995 for the fixed sum price of almost $20 million for 628 units, or 1,011 modules, composed of the 628 modules for the dwellings, 58 elevator modules, 3 modules for trash rooms, 167 modules for special wings, 36 modules for roof lids and 119 stairwell modules. The subcontractor would perform the following tasks:

a. cast in place concrete footings, grade walls and tie beams including installation only of embedded MRMC connections.
b. produce and erect the 1,1011 modules
c. grout the modules in place
d. cast in place concrete filler slabs, curbs and walls, elevator machine room structures, and installation of embeds furnished by others
e. include concrete corridor railing (excl. hoisting and scuppers)
f. include all reinforcing steel work
g. include all sealant and caulking work
h. exclude any supervision for Daewoo’s use

The first module for the high-rise buildings was produced in April 1995, utilizing the existing facilities. The construction of the structural skeleton of the two completed high-rise buildings with total of 386 units was completed in January 1996. However, while all of the concrete dwelling units were prefabricated, the stairs and stair wells, the elevator shafts and the hip roof assemblies were decided to be cast in-situ later in the process.

**The DWS in the Country Club Village project**

As the Country Club Village neared completion in September 1996, it was clear to the design participants and the contractors that DWS was a groundbreaking achievement and a success story. At that time, it was also known what features of the DWS worked well and what features presented problems in the previous 2 years. Reviewing a process for further improvements is a key element for Total Quality Management, a concept that is part of Daewoo’s corporate philosophy.

James Schuler was particularly satisfied with the system, as well as Pravin Desai. As noted earlier, the major motivation for Schuler Homes, Inc. to adopt DWS for the Country Club Village
The project was the short construction period and the low price offered by Daewoo, taking advantage of the cost savings inherent in the DWS. The condensed construction schedule, made possible by DWS, offered the opportunity to deliver the project to the market in roughly half the time conventional construction would have required. This both reduced the cost of financing the development and accelerated the stream of revenues for Schuler Homes Inc. Furthermore, this ability to quickly provide finished products to buyers was both an easily marketed competitive advantage over other real estate developers and a means to capitalize on a very healthy market at its peak.

Pravin Desai was also very satisfied. He repeatedly mentions the tight control of the project as a plus, with intense team work, economy in modularity, and detailed book-keeping. The work was carried out with discipline and his firm got a “tremendous experience” with this advanced method of construction. Most important for Pravin Desai, however, was the opportunity to produce a high-quality architectural design that received numerous awards. It was only in the high-rise buildings that, due to budget cuts towards the end as a result of unsold units, their exterior was not completed as designed.

Most critical, in the positive sense, were Daewoo’s own people. They were all eager to see Daewoo use the system more in the future and they were seeing some technical drawbacks that needed to be overcome. Mr. Cho reported 5 problems that he faced repeatedly during construction in the Country Club Village project. Those problems were related to the quality of the exposed concrete and he was able to fix them to the satisfaction of the owner by using additional labor.

a. The slab steel formwork started curving after approximately 30 to 40 casts. Skim coats of up to a quarter of an inch concrete were applied by hand to level the slab surfaces.

b. The formwork for the walls developed minor curvatures after multiple casts. As with the slabs, skim coats were applied by hand to level the wall surfaces.

c. Quite often there were bad corners, especially at the connection of the wall with the slab that also needed treatment after the production of the units.

d. The concrete surface itself had often honey-combs, despite using the best oils available to cover the steel formwork. As with the other problems mentioned above, hand preparation was needed. The concrete surfaces were washed first and then a skim coating was applied by hand.

e. The alignment of the formwork using the hydraulic pumps was problematic for the required precision.

However, the biggest problem for Daewoo was that they did not make a profit on the project. With DWS being non-profitable, its future is questionable. Nevertheless, this may be attributed to the very low price they quoted to Schuler Homes Inc. By passing all the savings of DWS to the developer, Daewoo did not capitalize on the cost-savings of its unique product, and put itself in a position to work on slim profit margins under the uncertainty of the DWS technology in a foreign market.
Further Improvements of the DWS

Based on the Country Club Village project as well as the Korean projects, DWS is highly promising for the future. It adds a technological advantage to Daewoo that differentiates the company from its competitors, in an almost commodity market. However, DWS must be further improved to be a commercial success and must be accompanied by an appropriate marketing strategy. The target areas to concentrate on further improvements are:

a. improve the finishing quality of concrete
b. design the formwork for accurate dimension control
c. improve the design of the joints
d. transform DWS to a fully integrated construction system
e. allow for more variation of the modules to make the buildings more interesting architecturally
f. reduce the cost

Any of the first 3 target areas will reduce the cost of DWS, so they will satisfy by default the last objective. However, the cost could be reduced in other ways as well, i.e., by using a most efficient scheduling, closer to the scheduling of manufacturing processes (Pollalis, 1993).

Among the 6 areas for improvement, Daewoo has commissioned specific studies for the improvement of joints and for transforming the DWS to a fully integrated construction system. The following paragraphs provide a summary of those studies.

Suggestions for improving the joints in DWS

The joints in the DWS have been the biggest technical obstacle since the very beginning of the system. Special steel plates are exposed at several parts of the completed multi-room module and are subsequently welded in-situ and grouted. This process, however, is time consuming, requires manual labor on the site, and demands high precision. Furthermore, there is no scaffolding on site, so welding and grouting can be quite difficult in the parts of the modules that make the exterior walls of the building. Also, the module must be leveled using shims while the crane positions it on the building.

In addition to in-house research and development, Daewoo, through Dr. Shin, requested Abam Engineers to investigate how the joints could be improved as well as some additional technical questions. The Country Club Village project prompted that request in February of 1994 in order to utilize the best US technology in Daewoo’s first US project.

After examining several alternatives, Abam Engineers proposed a modification to the horizontal joint details for the wall connection: mortar grouting to carry vertical loads. They suggested to “erect the modules on neoprene pads and a continuous semiplastic grout mortar that will be squeezed to fill the gap as the mating module is set. Shortly after the box is set, workers trowel the excess mortar and flush the joints. A thick mortar does not require any special formwork during its application.” Furthermore, they recommended to use ½ inch thick joints instead of previously used ¾ ½ inch joints. Regarding the rebar connections for tension, Abam Engineers suggested to use small lap plates to eliminate the butt welds. This allows higher tolerances for the positioning of rebars in all directions but increases the welding metal.
In addition, they highly recommended to avoid any expansion joints in long building configurations, such as the high-rise buildings of the Country Club project. That was quite feasible in Hawaii given the constant weather temperature throughout the year. Finally they provided some additional comments on steam curing, the thermal expansion of the steel forms, the impact of the wall curing on the already cast slab, and the shrinkage in transverse walls.

**DWS as a Fully Integrated Construction System**

Danny Shin prepared an analysis of DWS, entitled *Principles of MRMC Project Planning*, in which he discussed the implications of applying such a system of prefabrication to the complete process of realizing a building project.

According to Dr. Shin, in order to optimize the economic efficiencies of DWS, the principles of the construction system need to be consistently applied to every aspect of a project. The three general and primary aspects of a Multi-Room Modular Construction project are as follows:

a. *Structure*. The structure consists of both the prefabricated three-dimensional concrete (dwelling) units as well as associated elements such as fire stairs, elevator shafts and individual or separate structural elements such as footings and columns.

b. *Interior System*. Interior system refers to the materials and assemblies necessary to complete the build-out and finishing of interior spaces and design requirements. This would include, for example, prefabricated partitions, pre-hung doors and frames, plumbing “trees”, cabinetry, railings, paint, carpet and even window units.

c. *Project Management*. In many ways, management requirements for the design and construction of a DWS project are more akin to those utilized in contemporary manufacturing enterprises than those necessary for conventional building construction. Project management must be adapted to capture and facilitate the efficiencies of DWS.

All of the competitive advantages of the DWS result from the cost savings derived from shorter construction time. This is the central issue or goal that management decisions and strategies must constantly be measured against in a DWS project. Furthermore, management of the DWS process must always remain aware that the time-based efficiencies and economic benefits of prefabricated design and construction are the direct result of a system that permits design, manufacture, and assembly activities to occur concurrently. Therefore, the greater the percentage of a project’s “construction” that adheres to DWS principles, the more successful and profitable that project will be.

To maximize the benefits of DWS, on-site manufacture or prefabrication of the structural precast concrete three-dimensional units should be supplemented with concurrent off-site manufacture and pre-assembly of interior system components. Ideally, a central off-site plant will serve several different construction sites at a time, and permanently serve a given metropolitan area or geographic region. This plant will, in turn, be supported and supplied by various subcontracted or “out-sourced” manufacturing enterprises as well as businesses providing basic materials. The on-site precasting plant is, of course, disassembled, relocated and re-constructed as buildings are completed and new projects initiated. Just as the economic benefits of concurrent manufacture and assembly are based on the efficient management of time, successful management of an entire DWS project is based on design for and implementation of carefully-timed activities. In fact, it is completely appropriate to think of DWS as a system requiring the application of “Just-in-Time”
management, which has been so successful in the revolutionary streamlining of design and manufacturing processes in the automobile industry.

Just-in-Time (JIT) management of manufacturing enterprises was first developed by Toyota in Japan, and now permeates the automobile and many other manufacturing industries. It is based on the idea of a network of carefully selected suppliers delivering to a manufacturing process component parts and materials in the quantities needed just as they are required. No significant inventories of materials or parts are maintained, and, of course, the design and manufacture of many different components occurs concurrently. This reduces both manufacturing time and costs and, because of the greater pre-coordination of design such a system demands, also results in increased product quality.

In a DWS construction project, JIT management should operate at three different levels. The most conventional application of JIT management is at the off-site interior component manufacturing plant. In addition, it should be applied to the on-site plant producing precast concrete modules. However, it should also be applied to the final assembly of the buildings themselves, or, rather, to the construction process as a whole. It is critically important that the timing of deliveries of interior components to the building site be completely coordinated and synchronized with both the manufacture of the structural 3-D concrete modules and the final positioning of those units in a building. Components to be pre-installed in a just-completed concrete module, for example, must be delivered prior to materials and parts that simply require placing in a unit for installation after final positioning. With DWS, final assembly of a building “product” should not be thought of as fundamentally different from the final assembly of an automotive product. The only major difference is that final assembly of a building occurs outside of a manufacturing plant.

Utilizing JIT management also amplifies and enhances the inherent benefits of DWS. Traditional construction activities occur serially rather than simultaneously or in parallel with each other. While the manufacturing of components to be assembled is still a sequential activity, the wasted time or “down time” experienced in conventional construction when one trade is waiting for the completion of another trade’s work is largely eliminated with DWS. According to Danny Shin,

“The movement of workers, materials and equipment to and from a job site, in and out, up and down the building and between units is considered wasted time which consumes resources and adds no value to the final product. Material handling in conventional construction is a major part of the material and labor cost [of a project]. The waiting time of the work crews that commonly occurs at in-situ construction can be greatly reduced by having most of the work done in a manufacturing plant. …With ‘composite crews’ at each station, one trade need not wait for other trades to arrive and complete their work. …By performing work in the plant, logistical problems are reduced. Workers need not wait for materials and tools. …In conventional construction, a lot of labor time is wasted in layout of walls, dimensioning and positioning, fitting and cutting to each individual condition. In the plant, repetitive operations simplify and speed up the entire manufacturing and construction process.”

The notion of “composite crews” constructing or, rather, manufacturing and assembling buildings is key to understanding and appreciating the advantages of DWS. When construction activities occur in a manufacturing plant rather than on a building site, workers are able to be more productive because their activities are unrestricted by conventional labor and union arrangements.
Workers who traditionally would not work simultaneously are transformed into crews composed of members of different trades who work together to manufacture a given assembly. An example is the manufacturing of the prefabricated partition panels or soffit assemblies for a DWS modular unit. Conventional fabrication of these assemblies would involve carpentry (metal stud framing), sheetrock work, plumbing work and/or electrical conduit work all performed independently. When these components are manufactured, members of these distinct trades are transformed into members of an assembly line crew, or a “composite crew,” that works in a unified rather than a fragmented manner. At the Country Club Village project, Labor Union regulations permitted members to work in the manufacturing plants as participants in composite crews. This in turn led to very significant labor cost savings, since a manufacturing operation permits a much lower ratio of Journeymen to Apprentices, as opposed to a conventional job site construction process.

As is true for the design of any product to be manufactured, management of the design process must ensure that all components are carefully engineered and that assemblies and part interfaces are pre-coordinated. Conventional building construction permits loose coordination during design and field resolution and coordination of conflicts or problems. Prefabrication both pre-empts these issues by requiring careful coordination in advance of field assembly and depends on this advance coordination to ensure that a carefully-timed assembly operation is achieved. Any disruption of the assembly process can quickly diminish the time-based economic benefits of prefabricated design, and, therefore, reduce the competitive advantage such a system possesses.

One of the most critical issues in pre-coordinating the design of components is the management of dimensional tolerances. In DWS buildings, the most significant tolerance issues pertain to the manufacture of the concrete modules. This is true both for the relationships between installed units and, more importantly at present, dimensional variances that must be accommodated within concrete modules. Danny Shin concluded that, within dwelling units, most components should be able to accept tolerances of plus or minus an inch. While perhaps generous, reducing this tolerance will make the manufacture of the precast units prohibitively expensive. Furthermore, he states that standardizing the size, shape and specifications of components, or, in other words, limiting their variety and quantity, further facilitates the management of dimensional tolerances. The interior components he feels must be standardized in a DWS project in order to fully capture the potential benefits of the system are as follows:

a. Doors and Windows
b. Cabinets and Countertops
c. Moldings
d. Kitchen components with panelized partitions and soffit assemblies
e. Bathroom components with panelized partitions and ceiling assemblies
f. Stairs and Elevators
g. Vent and waste plumbing trees
h. Supply plumbing trees
i. Panelized shaft walls
j. Electrical conduit and trees

As Danny Shin points out, by not utilizing DWS for the stairs and elevator shafts in the Country Club Village, it may have impacted the project’s construction schedule, as the timing of the installation of prefabricated units became dependent on the conventionally construction of the
stairs and elevators shafts. And, any interruption or slowing of the construction schedule, or missed opportunity to fully capture the benefits of DWS directly reduces the system’s advantages over conventional construction.

**Daewoo’s Marketing Strategy for DWS**

The potential application of the Daewoo System of Multi-Room Modular Construction to a wide variety of building types in many diverse construction markets throughout the world is quite apparent from the Country Club Village and the Korean examples discussed in this study. Consideration of these potential markets for the Daewoo System immediately presents the question of whether the potential financial and constructive advantages of DWS are more applicable to conditions in developing or advanced countries. Should Daewoo promote the system in countries with less advanced infrastructure and construction industries, or should it attempt to compete, as it did in the Country Club Village project, with the established construction practices of the leading world economies?

As already presented earlier, the primary competitive advantage the Daewoo System possesses in advanced industrial countries lies in the financial benefits that are a consequence of compressed construction schedules. In addition, by reorganizing the construction process and redefining labor roles in a “manufacturing” context, the inefficiencies and costs of conventional labor organization in many advanced nations can be significantly reduced. Less-skilled and less expensive labor can be used to complete tasks that are arranged in an efficient “assembly line” fashion. Provided that buildings are designed to consistently take full advantage of DWS, the Daewoo System should be highly competitive in terms of reduced financing and labor costs and in terms of construction quality.

The major disadvantage of the Daewoo System in any market is the amount of land area required to set up and operate the on-site precasting plant. There are many urban and even suburban sites that could not accommodate the temporary staging and manufacturing space required by the system. Another disadvantage of DWS in developed countries is that while the system greatly simplifies the distribution of raw materials and component parts on a building site (i.e., from point of delivery to the building under construction) those materials and parts still have to be delivered to the site much as they would for conventional construction. At Country Club Village, for example, the delivery of concrete by truck to the on-site precasting plant was as carefully timed and sequenced an operation as it would have been for traditional in-situ concrete work. In this sense, prefabricating on site possesses little advantage over established methodology, except in terms of quality control.

In developing countries, however, which often possess both poor transportation infrastructure and high demand for standardized housing, the Daewoo System acquires additional advantages. In such locales, because distributing materials such as concrete over roads is not viable, it is established practice to set up material production plants on or adjacent to building construction sites. This practice would actually serve to amplify the efficiencies and product quality of Daewoo’s system of in-situ prefabrication. Furthermore, the abundance of inexpensive labor in developing countries’ construction markets dovetails very well with the labor requirements of DWS. And, of course, whether funded privately or publicly, construction projects in developing countries would,
as in advanced economies, benefit from the cost savings generated by the speed of Daewoo’s System of Multi-Room Modular Construction.

References

Personal Interviews
Interview with Mr. Junghyun Cho, in Hawaii, September 1996.
Interview with Dr. Danny Shin, in Hawaii, September 1996.
Interview with managers at the Shipbuilding Division, in Seoul, September 1996.
Interview with Mr. Pravin Desai, in Hawaii, September 1996.
Interview with Mr. Chulhong Lee and Mr. Sanghee Hwang, in Cambridge MA, March 1996.
Interview with Mr. Chulhong Lee, in Seoul, September 1996.
Interview with the Daewoo’s construction team at the Shiheung Apartment project, outside Seoul, Korea, September 1996.
Telephone conversations with Mr. Pravin Desai
Telephone conversations with Mr. Junghyun Cho

Book

Documents related to DWS
Numbering and organizational system:
XX-N, Sp, St, O, P,D/p, D/cd, or D/m-K,E, or K/E-Author
Where: XX=Document Number
N, Sp, St, O, P, D/p, D/cd, or D/m indicates the Document Type:
N=notes
Sp=Specification
St=Study
OW= Other Written Document
P=Photographs
D=Drawing (p=presentation, cd=construction document, m=marketing)
K,E, or K/E=Document is in Korean, English or Both

List of Documents:
01-D/cd-E-DHC (DHC=Daewoo Hawaii Corporation) Country Club Village, MRMC Drawings, January 13, 1994
02-D/cd-E-DHC Country Club Village, MRMC Drawings, Building #5, August 7, 1995
03-D/cd-E-DHC Country Club Village, MRMC Drawings, Building #5 Roof, October 9, 1995
04-D/cd-E-DHC Country Club Village, Buildings #2 and #3, Schuler Homes, January 21, 1994; Preliminary Architectural Working Drawings
05-D/cd-E-DHC Country Club Village, Building #4, June 8, 1995
Architectural, Structural, Mechanical, Electrical and Landscape Drawings.
06-D/cd-E-DHC Country Club Village, Building #5, Schuler Homes, June 5, 1995
Architectural, Structural, Mechanical, Electrical and Landscape Drawings.
07-D/cd-K-DW (DW = Daewoo, Korea) (needs translation)
Site, Building and Unit Plans and Elevations for a Korean DWS Project.


09-OW-E-DWH Subcontract Agreement, Country Club Hills Village-Phase II

10-St-K/E-Shin Cost Control and Analysis of DWS (Title needs translating) by D. I. Shin International, Inc. Consulting Engineers.

11-St-E-Shin Interior System Comparison


13-OW-E-Shin Principles of MRMC Project Planning

14-OW-E-? Daewoo MRMC System; Part II: Interior and Exterior System


17-Sp-K/E-DW DWS Plant Construction. Detail Drawings and specifications for the design of site-specific precast concrete plant.

18-Sp-E-Shin Specification for Precast Concrete - ASI and Daewoo Building Systems

19-OW-E-DW Introduction to DWS, Daewoo multi-room modular construction system.

20-OW-E-DW DWS, Daewoo multi-room modular Construction System. (3 copies)

21-OW-E-DW Daewoo Heavy Industries Ltd. Shipbuilding Division.

22-OW-E-Chung Korea’s Housing Industry of the 21st Century, by Hee-Soo Chung, Korean Housing Institute, April 26, 1996.

23-D/cd-E-DHC Project Schedules (Bar Charts), for the Country Club Village Project.


25-OW-E-DW Concept of Structure and System; SeeHeung Project, Korea.

26-D/m-E-CDS Color reproductions of perspective renderings and site plan (showing construction phasing) for Country Club Village, Schuler Homes. Intended to promote sales. Drawn by CDS International.

27-OW-E Sales sheet for model/unit DR at Country Club Village, 1117 square feet, from Parade of Homes literature.

28-OW-E Project Directory for Country Club Village (Participants), April 26, 1996.

29-OW-E-DW Meeting Minutes, June 27, 1996, by Daewoo on Hawaii Project.

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Fig. 29 and 30 were based on interviews.