MODULAR AND MOBILE, SUSTAINABLE AND AFFORDABLE

Greenwich Millenium Village Sustainable Modular Building Design

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Introduction

The winning consortium of the competition to design and construct the new Greenwich Millennium Village set out to develop a landmark sustainable community. Their goal can be clearly seen in the stringent criteria they set for themselves. The completed village would show an 80 percent reduction in primary energy consumption with zero carbon dioxide emissions; the facilities would reduce water demand by 30 percent; buildings would be constructed from 80 percent recyclable materials, with off-site prefabrication and pre-made interiors that would cut construction costs by 30 percent; the construction period would be cut by 25 percent; there would be no defects at handover.[1]

The United Kingdom government redevelopment organization, English Partnerships, purchased the 120-hectare Greenwich peninsular site from British Gas in 1997. Their plan was to divide the site into three zones (see Fig. 1): the headland cap would contain the Millennium Dome; the middle zone would initially be developed for parking for the dome, which at a later date would be developed into 1600 to 2500 housing units; and, on the isthmus would be the site of Greenwich Millennium Village—a sustainable development of 1377 units.

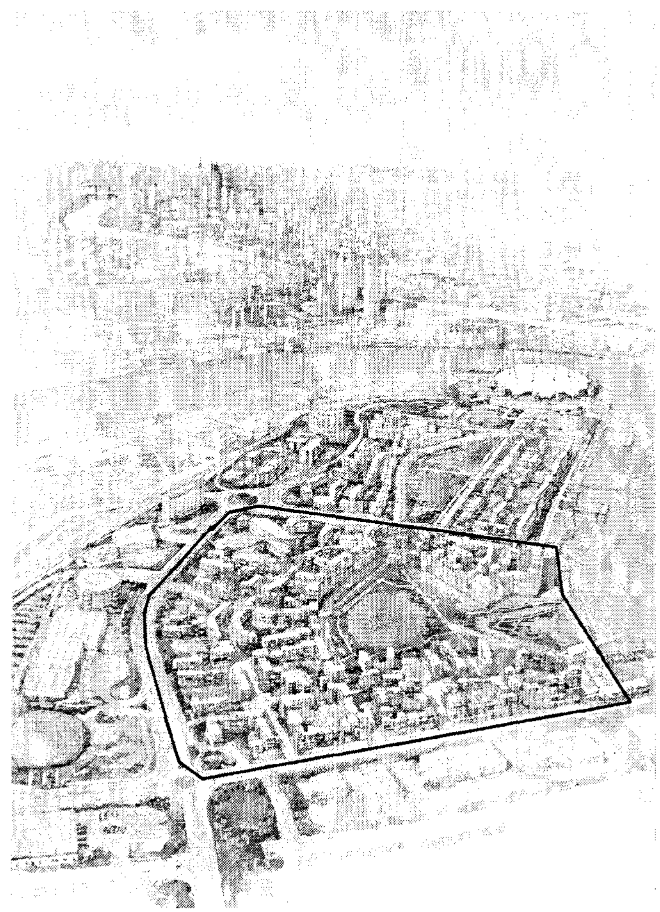

Fig. 1. Artist Impression of the completed Greenwich Peninsular Redevelopment with Greenwich Millennium Village in the foreground

A series of government institutions and other bodies, who, in the post competition phase would evaluate the proposed designs to ensure the claims made in the initial competition submissions were met, oversaw the competition.

The winning design consortium for the redevelopment of the lower 57-acre site was made up of several architectural firms, an engineering consultant, two housing associations, a developer who would finance the scheme, and a contractor. All competitors were required to submit a detailed proposal of what the team would do with the site, as well as a masterplan, basic details of buildings, and environmental goals. The aspirations of the competition were particularly high[2]. The government hoped that this development would be the first of many sustainable developments that would significantly address environmental issues, such as primary energy use and reducing car use—essentially producing an autonomous, self-supporting community. The village would foster community goals, with provisions for telecommuting, live workspace, low car use, communal space, a local school, and an urban ecology park.

English Partnerships had spent £23 million ($33 million) of taxpayer's money cleaning up the lower site—formerly a gas storage facility—

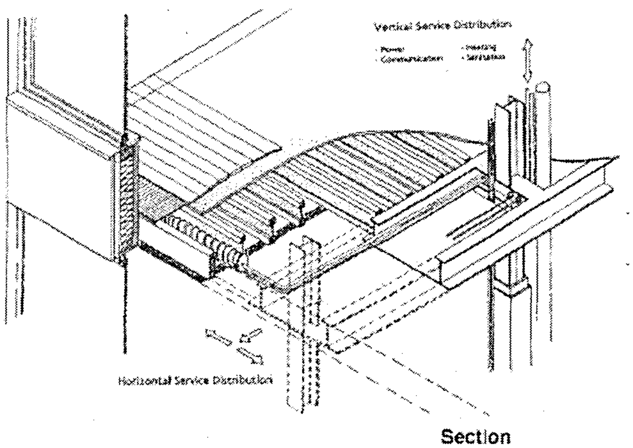

Fig. 2. Competition Proposal for the Modular Service Core. Note the service trench formed by the two beams and the construction of the floor cassette.

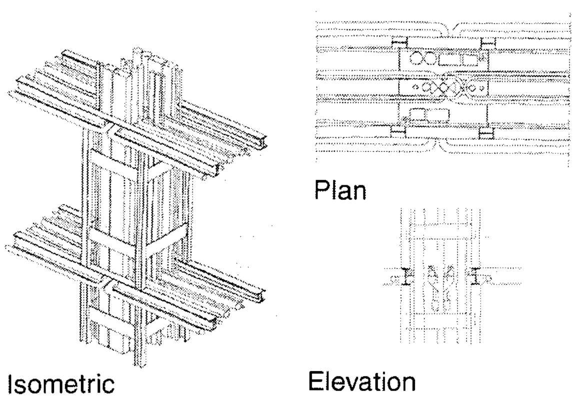

Fig. 3. Isometric, Plan and Elevation of the Scheme Design Core. With all services preinstalled. Prefabricated Cores.

in readiness for the competition.[3] However, the winning consortium was expected to form a joint venture with English Partnerships and would pay back the costs for cleanup.

The government considered time-to-completion as the most critical element of the project, since it wanted the first phase of the village occupied by late 1999—for the opening of the Millennium Dome in January 2000.[4]

Task Forces

When the competition winners were announced the legal details of the joint venture between the consortium and English Partnerships had yet to be settled. English Partnerships had already paid for the cleanup of the site and the initial remodeling. They also anticipated paying for major infrastructure systems, such as roads and services to the site boundary. The consortium would then fund the remaining development. English Partnerships, however, would be entitled to a percentage of the profits made by the scheme. This meant that the developers and their financiers were not guaranteed any return on their investment until the final agreements were finalized; consequently, they were reluctant to start the design process in earnest.

The consortium design team decided to divide up the work by creating a series of task forces. These task forces teams drew their members from the different groups within the consortium. The aim of these task forces was to identify specific issues that would affect significantly the overall design in terms of compliance with the sustainable criteria as set out in the competition submission, as well as the overall cost through date of completion. By keeping the design work to a minimum, the developers were able to keep their costs as low as possible until the final land deal was completed. The decision to create task forces, however, effectively broke the consortium's momentum.

Building Design

The consulting engineers were a multidisciplinary firm of engineers covering all the major disciplines including structures, electrical, mechanical and public health. In the initial post-competition phase of the building design, they aimed to fulfill the competition brief in full. As the scheme design developed it was continually measured against the competition criteria of 80 percent reduction in primary energy use; 80 percent recyclable buildings; and, project completion by the end of 1999.

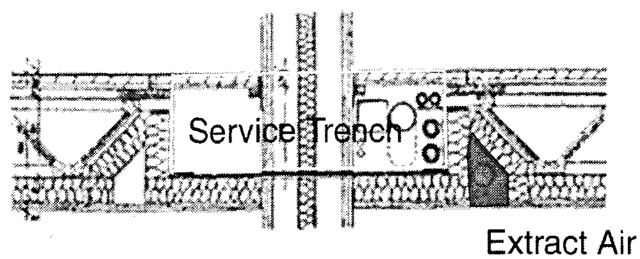

Fig. 4. Section through the service trench/floor cassette . The small area used for the ventilation ducting can be seen adjacent the steel W sections.

The consortium won the competition with a design scheme for a standard modular, prefabricated housing unit that could be used for structures from 2 to 8 stories high, and that allowed for a variety of facade treatments. Facades and internal layout were designed to be changeable, to accommodate the needs of the owner. The aim was to enable residents to alter the size and look of their housing unit—allowing the owner to stay in the community as the family's needs changed, rather than having to move on as, say, the family grew.

It was anticipated that a purchaser would buy a unit approximately 20 x 43 x 10 ft. The unit would be either a shell that the purchaser fitted out or a finished unit with a standard fit out. The housing units were designed so that a buyer wanting a larger housing unit had the choice of purchasing an adjacent block above or next to the unit.

The preliminary scheme centered on a modular, prefabricated building that would be wholly manufactured under factory conditions. The design problem was to produce a repeatable module that could be used in a variety of ways.

A modular frame system, designed around a service core that could be easily accessed (see Fig. 2) was chosen as the design solution. The core, supported by the structural frame, would contain all the necessary services for each unit. Each modular frame would include systems for water, gray water (water from baths, showers that is reused to flush toilets), sewage, telecommunication, electricity, gas, and kitchen and bathroom ducting for ventilation, as well as ducting for air conditioning. The core frame also would be an integral part of the larger building frame. This system was ideal for lower scale buildings; however, as the height of the building increased, the amount of servicing required grew as more units were attached to each core.

The service core was designed to come to site pre-installed in the frames, thus reducing the amount of on-site work. This concept, together with the idea that the structural frame would come practically finished, would lead to a significant reduction in the construction period. Each frame unit was practically identical which would lead to scales of economy and would reduce the overall cost of construction.

Prefabricated Cores

The structural frames were designed with rigid connections in both the east-west and north-south directions to provide structural stability. Each frame would consist of a four-column core with two parallel beams attached to either side of the core (see Fig. 3). These beams would support the floor units and provide a "service trench" through which services could pass to any location within the unit. The service trench provided room for all the services that the unit would require apart from extract air. The depth of the trench, which determined the depth of the floor beams, was set to the minimum fall the main 4" sewage pipe would require if the owner wanted a faucet at the extreme end of the trench, i.e., along the building façade. A small space on the outside of the service trench, between the floor beams and the floor unit, would be used for the extract air ducting (see fig. 4) thus all the horizontal service runs for each unit were kept within the volume of that unit.

The front end of the service trench was supported on two columns, and each frame was typically 40 x 3 x 9 ft. (a single story), consisting of eight columns and four beams. This detail was an increase on the competition design both in terms of number of columns and physical dimensions. As the design team looked into the problem of servicing the units, it became clear the initial, proposed core sizes were too narrow. Eventually the core size was increased to approximately 3 ft square to enable the required number of services to be installed. The difficulty in accommodating the services was not due to the amount of space they filled in the riser, but due to the volume of the various bends necessary to get services from the core into the service trench.

At these dimensions the frame units were too large to be transported without special arrangements. It was therefore proposed to break each frame into a series of five sub-assemblies consisting of the 3 x 3 x 9 ft core frame, two pairs of perimeter columns and two pairs of service trench/floor beams. These sub-assemblies would then be reassembled on site to form the main frame. The factory-produced sub-assemblies would arrive at the site with all the required services pre-fixed—i.e., with a series of push fit connectors at each end to enable the adjoining sub-assemblies to be linked to its partners. This would require extensive tolerance control, but it was felt that the factory-produced items could provide this.

Frame Materials

The design team examined various material options for the different elements of the building. The plans submitted for the competition had outlined a range of options that would be considered; however, these guidelines were left suitably vague to allow for some reinterpretation in the scheme design phase. The design team's initial aim was to use timber for the floors, but no decision had been made about the material to be used for the main structural elements.

Concrete was considered for both the floors and the frame. It was subsequently rejected for the floors, as it is a wet trade that would slow progress on site—whether it was used either as part of an insitu frame or on precast units or permanent metal decking. Additionally, if it were used on permanent decking, there were concerns about the ease with which the building itself could be recycled. (The competition brief stated 80 percent of the building should be recyclable.)

Recycled precast concrete elements were considered for the frames. In recycled concrete the aggregate is made from crushed concrete. Work on this material [5] suggested that the concrete produced would be of a lower structural strength than normal concrete, because the recycled aggregate is not as strong as the original natural aggregate. This meant that the size of the structural member would have to be increased to support the same load. Increasing the space the frame would take within the building was deemed unacceptable.

Other issues such as the quality of recycled aggregates were also a concern. At that time in the United Kingdom, the only means of guaranteeing the quality of the recycled aggregate was to take it from a known source. This meant finding a large concrete structure that was about to be demolished, with sufficient material of a sufficient quality and within a reasonable distance to the site.

The design team, in the end, chose steel as the material of choice, since it is stronger per unit area; it can be made up of to 90 percent recycled[6] material; and, steel can be easily recycled at the end of the project, building demolition.

Floor Cassettes

The floor was designed as a single, prefabricated unit so that it could be transported to the site and easily lifted into position. Timber was chosen for the flooring because of its green credentials and also to eliminate the need for the wet trade of concreting on site. The floor was to be a cassette manufactured from parallel-chorded timber trusses with a structural skin of plywood on each side (see fig. 2). The plywood would produce a stressed skin that would stiffen the floor (spanning 20 ft.), thereby reducing the overall floor depth when compared to loose trusses. The design team spent great deal of time on the issue of how to support the floors without losing the acoustic isolation required. Their solution allowed for the cassette to be seated on a continuous neoprene-bearing pad that would isolate the cassette from the frame.

By using the strategically positioned service trench, the number of services within the floor cassette units could be reduced—yet still maintain the acoustic and fire integrity of the unit. As previously mentioned, the parallel-chorded trusses could be hung on their top chord, creating a triangular-shaped void in the service trench area used to house extract air ducting for the unit below (see Fig. 4). This configuration did not bridge the acoustic isolation between the units.

Specialist Advice

A series of contracts with specialist manufacturers and consultants were set up to determine the best methods for the design and construction of these prefabricated parts.

The design team decided to take this step because of problems that arose on similar projects. For example, some companies, while capable of doing the required work, would not consider undertaking the contract because they felt it was outside their scope of experience. What was perhaps most difficult for companies willing to do the work was providing accurate cost estimates. These companies would invariably incorporate many extras into their estimates to ensure that they had covered all eventualities, making the prices uncompetitive with the more traditional types of construction.

Acoustics

In response to the aim of reducing the amount of raw material used in construction, the proposed building system was to be very "light." However, noise reduction using the wall and floor masses would have proved insufficient. Instead of utilizing mass to reduce noise transfer, the design used the principle of "a box within a box" to effectively isolate each unit from the next.

Working with an acoustic consultant, a system was developed whereby the floor cassette unit would provide the majority of the acoustic performance in the ceiling below. The ceiling would be hung from the floor above on fine suspension wires, which would both reduce impact noise and airborne noise transfer. Sheetrock insulation placed between the parallel-chorded trusses of the floor cassette would further enhance the noise reduction without producing a weight penalty.

The party walls were an altogether different problem, as they performed the three functions of:

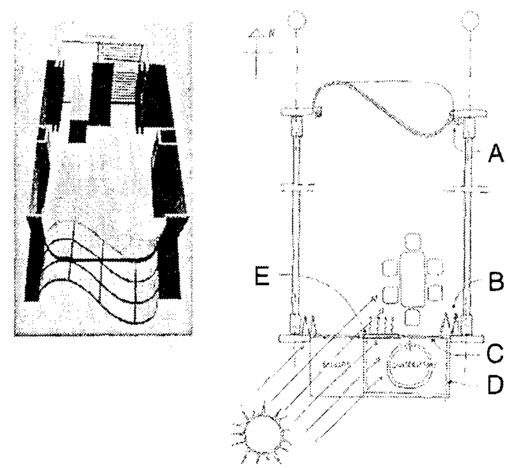

Fig. 5a. Winter Day.

A-Curtain Open. To allow good day lighting
B-Thermal Shutters Open. Allow passive solar heating
C-Low E IG unit
D-Single glazing
E-Thermal mass wall absorbs solar radiation

- physically separating the units;
- providing fire separation; and,
- providing sufficient acoustic isolation between the units.

The solution of providing two separate walls, one for each unit was identified as the best way to reduce the acoustic transmission between units. By staggering the position of the wall studs, the overall depth of the wall was kept to a minimum, so as to maximize internal space.

The contractor was particularly concerned with the steel frame proposal as he had never built a steel-framed apartment building and was concerned about noise transfer via the frame. Having studied many types of buildings, the acoustic consultant came to the conclusion that a concrete building was just as likely to transmit as

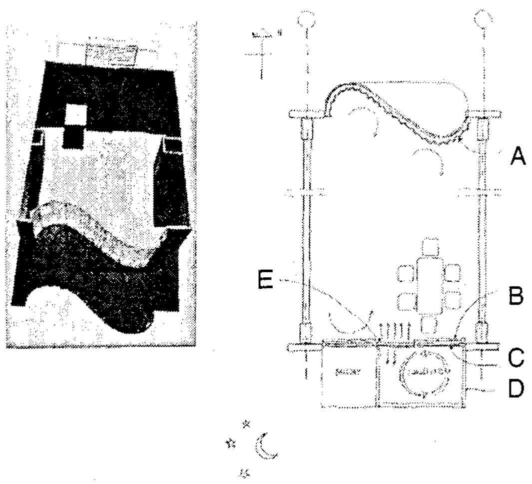

Fig. 5b. Winter Night.

A- Curtain closed. Reduce glazed area reduce heat loss
B- Thermal Shutters Closed. Reduce glazed area reduce heat loss
C- Low E IG unit
D- Single glazing
E- Thermal mass wall radiates heat into space

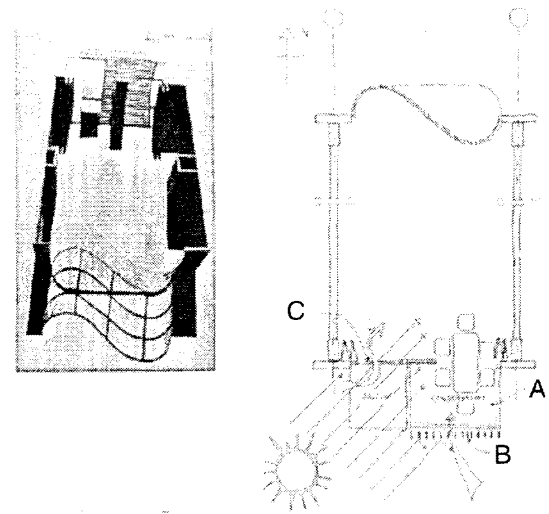

Fig. 5c. Spring/Autumn Day.

A- Conservatory provides pre-heated fresh air
B- Movable external shades control amount of heating
C- Controlled openings allow for natural ventilation

much sound as a steel a building. While the steel is denser than concrete, the steel frame is surrounded in fire protection that effectively isolates the steelwork from the noise source.

Façade

The facades were pivotal in reducing the energy use of the units. The main energy requirement would be in the winter months when the units would typically require heating to keep the occupant's comfortable. The facade would serve the dual purpose of allowing in as much natural light as possible, thus reducing the need for artificial lighting and giving the unit a light, airy feeling, and of providing a barrier to excessive heat loss or gain. The design solution was for a conservatory on the south-facing facades that would be externally screened with adjustable louvers. Behind the glazing, each unit would have a series of movable thermal shutters and a fixed thermal-mass wall panel. The facade was to be developed to form a "kit of modular parts," from which the residents could pick and choose. The aim was to provide alternatives and choices while still achieving an overall harmonious finish to the facade.

In the winter during daylight hours, the shutters would be opened to let in light. The thermal panel would heat up if there were any sunlight, while the conservatory would provide a buffer between the cool outside air and the warm air inside. The conservatory would not be used for habitation (see Fig. 5a). At night the thermal shutters would be closed and the thermal wall would provide the unit with any radiant heat it had collected over the course of the day, thus reducing the heating load (see Fig. 5b).

In the spring/autumn, the conservatory would be open to the unit and form additional habitation space, the glazing being used to warm the air before it entered the unit (see Fig. 5c). In the summer, the conservatory would be used for additional habitation space and the excessive heating of the conservatory would be controlled with

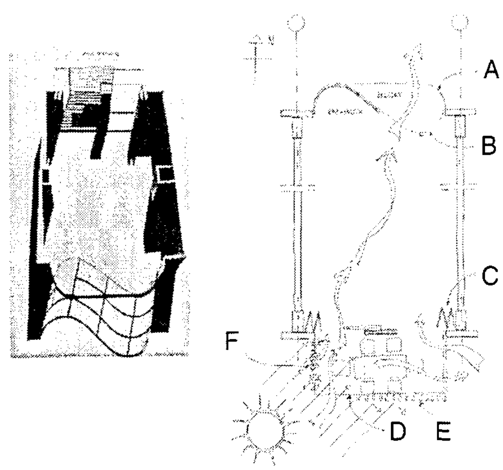

Fig. 5d. Summer Day.

A- Balcony receives morning / evening sun
B- North window open to allow cross ventilation
C- Shutters help prevent overheating in midsummer
D- Movable external shades
E- All glazing demountable to allow cross ventilation
F- Plants provide shade and evaporative cooling

the adjustable louvers. Much of the facade would be open and would be able to capture any breeze, thus aiding in cooling (see Fig. 5d).

The treatment of the northern facade was simpler as it was assumed most of the blocks would be orientated with the main living accommodation to the south to take advantage of passive solar gains.

Conclusion

The building whose design is outlined here was never built. The development team rejected the design proposal in the late summer of 1999.

The development arm of the consortium felt these targets had become too inflexible in the economic climate of the time. While the become prohibitively expensive.

Various conflicts emerged between the architect and the engineers over the orientation of the buildings. The architect favored the river views of the northern/eastern aspect while the engineers felt it imperative to utilize the southern aspect in order to meet the energy use targets. Ultimately, the bane of contention between the parties was about what issue was the most important to address in the final design: meeting the stringent environmental criteria or producing the most viable/saleable scheme. Sustainable design such as this project is about compromise; yet, it is impossible in most instances to accommodate both requirements equally.

Later the original competition targets were reduced, with the agreement of the overseeing committee.[7] This reversal enabled less ambitious designs to be considered and built.

The design team for the building element of the project was completely revised to include only one of the original winning firms. Working under the new targets a new design team with a different solution was ultimately accepted construction in late 2000; and, the new buildings were ready for occupation in the summer of 2001—well beyond the original time constraints for occupation in late 1999.

Interestingly some of the phases that have now been completed have included some of the original engineering consultant's ideas. The Phase 2a, designed by Proctor Matthews Architects, are steel-framed units that contain many prefabricated elements. However, the architect bemoaned the problems the firm encountered with prefabrication: "Every time we've gone to the market and said 'can you prefabricate this?' they've said 'yes, but it'll cost you twice as much as if we just get the scaffolding up and do it in the normal way."'[8] This mirrored the problems the original design team anticipated with prefabrication.

While the original concept was to find one solution that could accommodate every type of building likely to be built on the site, the new team split the buildings into similar groups and dealt with each design team felt that because of the government's insistence throughout the competition and design phase that this housing development should be the very best sustainable design to date—no less a benchmark on which future developments would be measured—the design concepts could not be altered, especially for purely economics reasons. This was a mistake, whilst the government wanted the best of sustainable design; it also expected a share of any profits—an unrealistic expectation on its first landmark scheme. The government's development arm, English Partnerships, caused the design phase to be delayed while this deal was thrashed out with the Developer.

Although the design complied with the initial competition targets, it was possibly too ambitious, and lead to the development arm of the consortiums' concerns over its feasibility. A reasonable amount of work was done in the time available to demonstrate the solution was practical; however, no actual prototyping was done to prove the feasibility. The design team had always requested that a full-size prototype be built, which they pointed out was a stipulation of the competition submission. In addition, obtaining accurate cost estimates for the project was difficult. The cost estimators struggled with the costs because of the unique requirements of the proposed system. As with most prefabricated structures, it is accepted that the initial setup cost to produce the units will be high; but, as more are built, the large volume of units being produced provides scales of economy. However, neither the design team nor the cost estimators were able to justify any figures. Potentially, the scheme could have typical housing, which is to be applauded. However, some elements of the competition criteria were simply lost. The gray water recycling system proposed in the competition submission was not installed; consequently, the buildings will not meet the target for a 30 percent reduction in water use.[9] Other targets that would have clearly demonstrated that the scheme was environmentally innovative were significantly reduced. A biomass-fuelled combined heat and power plant was proposed to produce a net zero emission of carbon dioxide for the entire development. The need for this plant is currently under review.

These two items, water use and carbon dioxide emissions are significant environmental concerns that should be addressed by any sustainable development.

Notes

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