House me Tender

Total Precast Cell Systems for Mass Customized Housing in Hong Kong and China

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***Abstract*— Mass produced precast elements are increasingly favored by the housing sector in Hong Kong and China largely to minimize construction time and labor on site and to ensure greater building quality of industrialized components. These elements often consist of semi-precast slabs, partition walls and façade plug-ins that externally embellish a still rudimentary cast in place column-slab system. The aspirations for such vertical housing models are more aimed at maximizing real estate profits for developers and reducing the construction cost for affordable housing. They often fall short to internally offer better spatial and living qualities to its prospective residents and to generate a vibrant community structure from within. The scale of these current housing models directly address the large scale of the surrounding urban context while bypassing the human scale altogether. A relentless repetition of the same living units across great heights portrays these glazed monoliths as socially isolated on large commercial podiums.**

While remaining competitive and efficient against current models, the paper proposes new environmentally enhanced housing prototypes developed at incrementing scales that reassert the individual as the main protagonist for the making of their own living environment. This is achieved through mass customization of precast volumetric units. Prospective residents are able to choose from a catalogue of variants, customized units that conglomerate into unique three dimensional living entities that make up for the overall identity of the building. Choices for each type of units are based on the desired types of openings, amount of semi outdoor terraces, location of glass enclosure and shaded and well ventilated spaces.

To seek to implement mass customization in precast housing puts forward greater flexibility and adaptability over time in accommodating various types of living units for various social needs and ultimately challenges the supported tendency to segregate housing types for specific social groups.

***Keywords*— adaptive systems, catalogue of parts, mass customization, precast housing.**

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I. Introduction

The main objective of the project is to conceive housing models that offers its future inhabitants a range of choices in shaping the living units that is right for them (i.e. different scalar units) within a vertical housing complex “Fig. 1”. This is achieved primarily through the mass customization and standardization of concrete precast volumes and their possible assemblies into various types of living units from a catalogue of parts “Fig. 2”.

Fig. 1. *House me Tender* XL prototype.

Besides its social agenda, the project also aims to provide better solutions to some of the technical hurdles that have continuously challenged the rapid advancement of precast technologies, especially in regards to the overall structural integrity of a building. Only by implementing better developed connection details between various sizes of precast cells while remaining economically competitive towards current housing models, these new prototypes will have a chance to become more credible within the precast industry and ultimately perform throughout the life cycle of the building.

The added performance of the proposed prototypes is primarily environmental and consequently social. An aggregate of volumes discloses recesses and protrusions of elements presenting shaded and naturally ventilated spaces both internally and externally, resulting in greater quality of living within the spatial units.

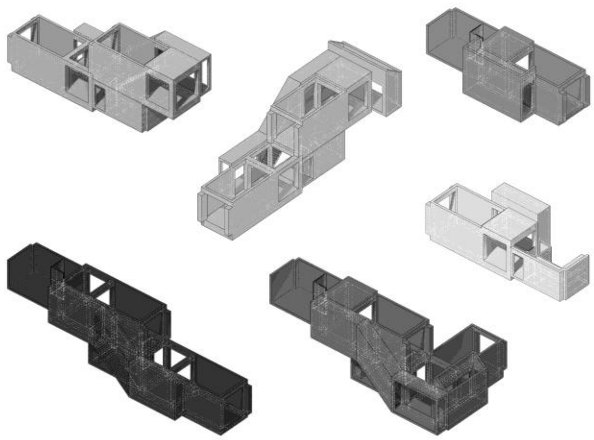

Fig. 2. Living units type for XL prototype.

II. Background of Research

Concrete precast is a relatively new method in the history of construction. It can be traced back to 1867 with the invention of iron mesh reinforced concrete by the French gardener Joseph Monier. Initially developed for watering troughs, a few years later, he quickly patented iron reinforced cement panels for building façades and reinforced concrete beams [1].]. The first industrial use of reinforced precast is attributed to the French businessman E.Coignet who in 1891 developed a system of components for the construction of a casino in Biarritz. In 1908, Thomas Edison experimented with a system of iron formworks for his single-pour housing prototype to mass produce homes for workers in New Jersey [2].

Yet, it is in Europe in the aftermath of the World War II that precast construction sharply rose from the large demand for cheap and fast housing after the war's destructions. A decade later, a first standardization and modularization of precast systems was formalized in various countries across Europe with widespread interests from America, Japan and Canada [3].

A. Seminal precedents in precast housing

Habitat 67, designed by Canadian Architect Moshe Safdie is a ground breaking pilot project for affordable housing using modular concrete precast "Fig. 3". It was built for the Expo 67 in Montreal to showcase to the world a 'new model for urban living' that re-humanizes the mega scale by providing 'a garden for everyone' (Safdie's motto for the project).

Fig. 3. *Habitat 67* by Moshe Safdie, Montreal

Building the low cost model turned out to be a very expansive enterprise as mass producing, transporting and installing each module became more costly than anticipated even though the production line for the precast units was adjacent to the site. From its inception to this date, the residents have mainly comprised of affluent city dwellers. In justification for the high construction cost, the architect cited then that 'the technology was not yet in sync with the architectural approach' and that 'Habitat's day is yet to come' [4].

At this moment in time, social aspirations from diverse urban settlements joined with vivid technological advances made since 1967, plead for the implementation of improved living structures which are as progressive and as humanly generous as Habitat. However it still remains an isolated example in the history of prefabricated modular housing at large.

Similar ambitions towards new alternative models for urban living were experimented with in Japan at the time mainly by the Metabolist movement, in the names of Tange, Kikutake, Isozaki, Kurokawa, et al [5]. Most notably, the Nagakin Capsule Tower built in 1972 by Kisho Kurokawa became the icon of Metabolism "Fig. 4"; an aggregation around a circulation core of prefabricated capsules which could be individually replaced overtime to suit the needs and changes of its inhabitants.

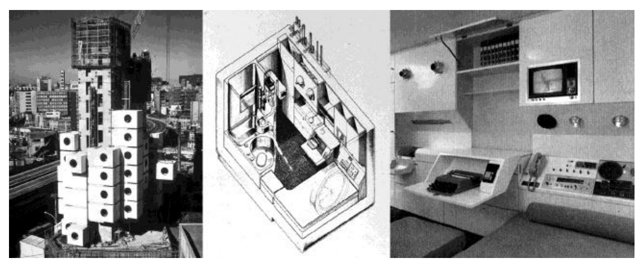

Fig. 4. *Capsule Tower* by Kishuo Kurokawa, Tokyo, 1972.

The project was the symbol of a new ideology for living where 'city workers could recover their individuality and independence' [6], while protected upwards from a hostile ground prone to natural disasters.

More significantly, the Capsule Tower also was a technological achievement in off-site mass production and moving architecture at the time. The 144 identical living units with fully integrated fixtures were plugged onto a cast in-situ concrete core to form an irregular aggregation of singular units for new urban professionals. Even if none of the capsules were ever substituted as originally planned due to high logistical costs, the idea remains innovative and unique to this present day.

In 1975, Kurokawa proposed an even more ambitious plug-in living model for a hotel in Iraq that put forward three successive construction systems integral to the design concept: a sliding and pile-up system for core and main structural elements, a jack-up system of these elements and a plug-in system for flexible and replaceable living capsules [6]. The metabolist notion of adaptability and flexibility in built architecture in Japan was instigated much earlier in1958 by Kiyonori Kikutake's project for his own house: the Sky House "Fig. 5".

Its main structural feature portrayed an elevated waffle slab surrounded by 4 large columns underneath which various units (i.e. playroom, bedrooms) were plugged in and out to accommodate the spatial and programmatic requirements of the family as its size increased and decreased over time.

Fig. 5. *Sky House* by Kiyonori Kikutake, Japan, 1958.

Similar ideas from the 60's onwards that combined structural frameworks with kits of plug-in cells were experimented with in Europe and America through the representation of highly speculative proposals (Cedric Price's Fun Palace, Archigram's Plug-In City, Yona Friedman's Ville Spatiale). These fictive yet influential projects had large social, political and cultural ramifications which resonated with many other practicing architects during this period. Such architect was the American Paul Rudolph who also sought in many of his projects to exploit methods of mass production for prefabricated housing [7]. His quest for flexible living models to adapt to the fast-paced changing society dates back to 1967 with his design proposal for the Graphic Arts Center in Lower Manhattan. The unrealized project advocated for the use of replaceable prefab units that could be rapidly mass produced and retrofitted at will into a fixed structural frame. He later claimed these prefab units to become 'the twentieth century bricks' [8].

The colonnade condominiums "Fig. 6", built in Singapore in 1972 by the same architect came close to fulfill the promises laid out in the Graphic Art Center project.

Fig. 6. *The Colonnade* by Paul Rudolph, Singapore, 1972.

Despite being conceived as a kit of precast units hoisted into a structural frame, the project at the end was entirely constructed with traditional methods of cast in place concrete [9]. The technical considerations (i.e. connection details) associated with precast construction were addressed too late in the design development of the project. This resulted in much higher financial demands to implement prefabricated units despite the need for large amount of formwork materials for the adopted cast in place construction. Yet, visual traces of the original concept can still be found in the realized project. At last, by virtue of working with volumetric systems, Paul Rudolph was able to incorporate setbacks and recesses for semi outdoor terraces providing shades and naturally well ventilated living spaces, essential in a tropical climate [10].

In this respect, it is the intention of prototypes presented in this paper to establish new sustainable and environmental models for total precast housing made of volumetric systems that are structurally self-supporting, independent of any super frame while addressing large scales able to be humanized once more.

B. *Precast in China*

Precast construction in China appeared in the 1970's with the introduction of a column-slab system for multi-storey buildings imported from Yugoslavia. Nonetheless, by being situated in an earthquake zone, precast technology in China saw a serious drawback from a succession of devastating earthquakes such as the one that hit Tangshan in 1976.

Poor connection details at the time provided precast structures with very little resistance against seismic loads [11]. Only after the 1990's, when the technology began to catch up with the technical requirements, the government started to consider again the benefits of such construction methods. Although till this present day, the potential development of mass produced precast building is largely limited to façade elements.

C. *Precast in Hong Kong*

One can learn much about the research and development of precast elements for residential construction in Hong Kong since its introduction in the mid 1980's [12]. The Housing Authority, in the public sector has long been a keen advocate of precast construction systems for the provision of affordable housing to Hong Kong residents. The evolution of their housing types from the Mark block, to the Trident block, to the Harmony block, to the Concord block went hand-in-hand with the incentive to reduce cycle time in construction (from 14, to 9 to 5 days today to complete a full structural frame for a floor) and to rationalize construction cost [13]. The integration of precast elements in the construction cycle of a building greatly accelerated these time and cost incentives by replacing previously long cast-in-place procedures with more efficient and better coordinated methods for lifting, installing and assembling precast components. In 1989, the Harmony type 1 block saw a first substantial adoption of precast elements comprising of semi-precast slabs, precast stairs and facade elements. At that stage precast elements accounted for 18% of the volume of concrete used for a high rise. In 2005, the Housing Authority presented a new pilot project for the redevelopment of two 41-storey Harmony blocks and one 36-storey Annex block [14] where precast elements occupied 65 % of the overall concrete in the building. This breakthrough project was called the Enhanced Precast and Prefabrication System [15]. Added to the previous models were precast structural shear walls and volumetric units for prefabricated bathrooms, bathroom-cum-kitchen units, lift cores and stair cores "Fig. 7".

Fig. 7. EPPS system by the Housing Authority, Hong Kong, 2005.

Fig. 9. Semi precast slab, precast façade, stairs, et al.

Upon further standardization of its parts and once contractors would become more familiar with the system, it was projected that the new EPPS model would reduce a typical 30 months construction period for a project to just 5 months. It is worth pointing that prior to this, the government initiated a bill in 2001 to promote use of renewable resources and green materials) for both the public and private sectors [16]. In a successive bill a year later, it regarded non-structural precast façade elements as green features which could be exempted from the Gross Floor Area and site coverage permitted for a given zoning [17]. Although the bill certainly motivated developers to make more use of precast technologies in residential projects by considerably boosting their sales profits and real estate in general, it did not necessarily ensure better quality of living spaces for its prospective residents.

The latest housing development by the Housing Authority is best portrayed by the Kai Tak housing estate, currently under construction “Fig. 8”. It consists of two clusters of towers of 40-storeys each. Each tower is made of a hybrid between cast in situ concrete and precast elements.

Fig. 8. Kai Tak housing estate project 1b by the Housing Authority, Hong Kong, 2013.

Such elements are semi-precast slabs, volumetric toilet units, façade plugins, precast stairs, beams and partition walls “Fig. 9”. The main motivation behind the adoption of such efficient building method is to reduce as much as possible construction time on site as well as utilizing the land to its maximum capacity in order to guarantee low cost housing to future residents. City officials are pressured to cope with the large shortage for subsidized housing in Hong Kong, therefore fast and economical production of flats is the key agenda at this moment in time over better spatial and living quality.

The Integer pavilion at Admiralty in Hong Kong showcased in 2001 a proposal for a 40-storey residential tower that presented a new solution for an intelligent and green building (hence the name ‘Integer’) “Fig. 10”.

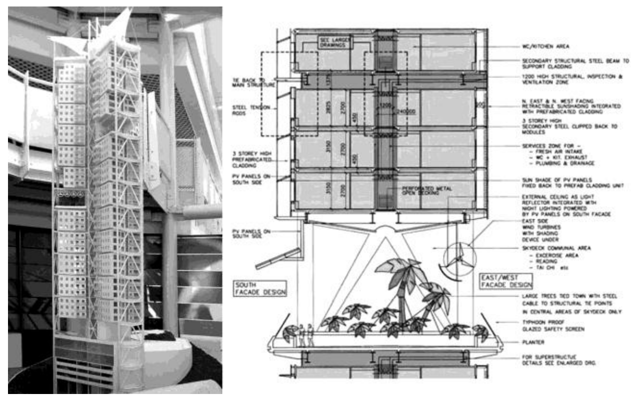

Fig. 10. *The Integer*, Hong Kong, 2001.

It consisted of a super frame steel structure inside which precast volumes were to be inserted. The pavilion offered the public ‘Flats of the Future’ which was demonstrated on-site by a full scale prototype for a modular flat [18]. Among various design features, the prototype promoted flexibility in design (flexible pods in superstructure), natural daylights, sky gardens and well ventilated living spaces. The integer was an initiative of the Hong Kong and British government with the participation and sponsorship of a private developer, a contractor and a UK based architecture firm specialized in green building, all advocating for innovation in green building technology . The tower project never was realized to this day mainly due to the added cost for the super frame structure.

Precast construction is still considered slightly more expansive than more traditional cast-in-place methods [19]. However, while bearing in mind the full life cycle of a building (i.e. maintenance, longevity, recycling and demolition), precast solutions becomes more competitive than generally perceived from short term estimates “Fig.11”.

III. Total Precast Proposal

There is a claim to be made today for residential housing in the region to comprise only of 100% precast (total precast system), as many advantages have begun and will continue to outweigh the early impediments of precast technologies. Cost remains a factor and indeed has obstructed over the years the realization of few innovative precast housing prototypes, discussed above.

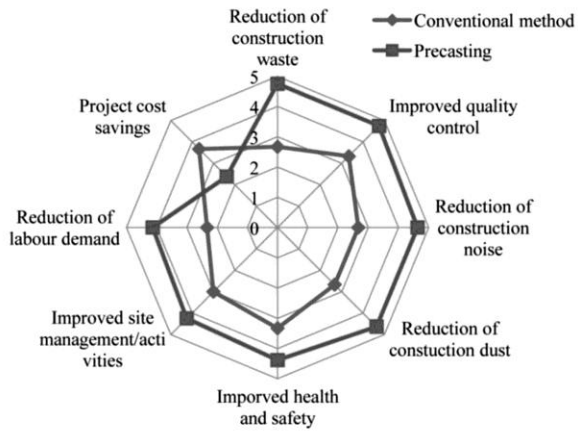

Fig. 5. Advantages when using precast or conventional methods, by Jaillon and Poon, 2008.

In response, the research project seeks at developing housing prototypes made solely of volumetric systems; new models that incorporate and are informed by innovative construction logic (assembly), technical detailing (connections between units) and technological integration (formwork design) at an early stage of the design process. Through the combinations of various size modules, living units of differentiated spatial qualities are presented “Fig. 12”. Each size module performs a specific programmatic role that belongs to a unique standardized precast family “Fig. 13”. From a catalogue of variants on precast types, prospective residents would be able to order straight from the factory the flat that is right for them, the motto for the project.

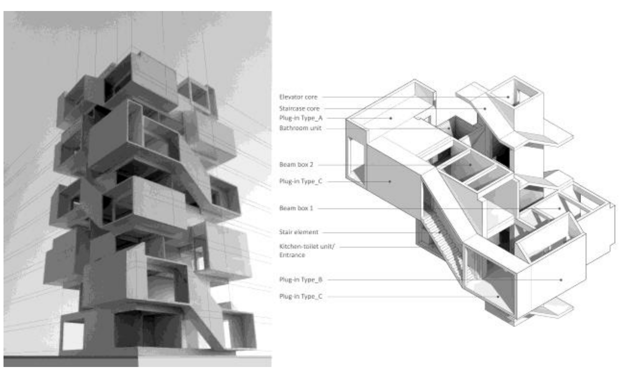

Fig. 12. *House me Tender* SML prototype and volumetric parts for a duplex unit.

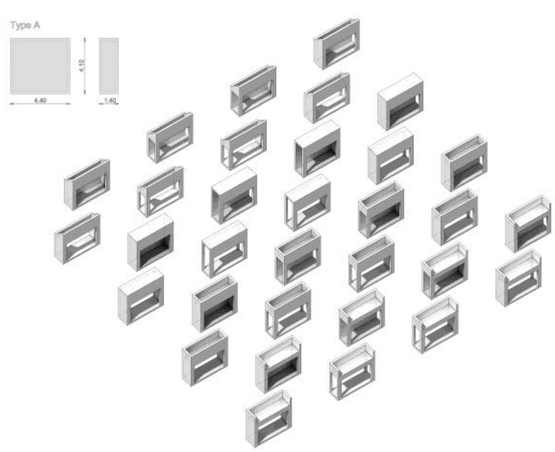

Fig. 13. Catalogue of precast variants from a single steel form.

A. On Mass Customization

Mass customization is not a new concept and can be found in many other fields such as in product design but as of today it never was executed in built architecture or in housing. The concept of producing variations from a type is often paired with the advancement of digital fabrication and therefore directly dependent on software communicating with machines. While Architecture relies more and more on industrialized parts to construct buildings, this new paradigm for housing seems not more than overdue.

Since most of the construction effort for the new prototypes relies on mass production in a controlled environment, the project offers a great opportunity to explore and implement strategies for mass customization. Through revisiting formwork design, a set of possible varied outputs from a precast type could be made largely available. Steel formworks based on existing technologies are cyclically being assembled, disassembled and reassembled on the production line daily “Fig. 14”. Reconfiguring them with supplementary interchangeable parts would not necessarily compromise the efficiency of production, but will further enlarge the pool of dissimilar precast outcomes.

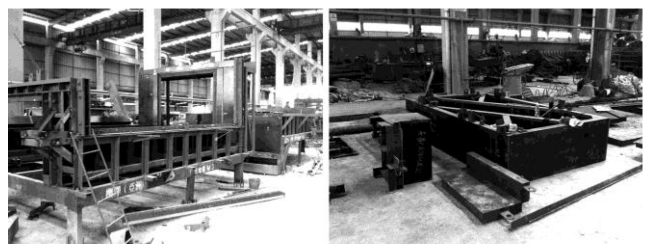

Fig. 14. Example of steel forms for mass production of precast façade elements

The quest for repetition of differences of precast units by means of formwork design is a main social ambition for the project. It offers the possibility for future residents to be given more individual choices in shaping their own living spaces [20]. The proposed work does not simply call for differentiation of precast (plug-in) units for variation sake’s. On the opposite, from sets of choices, residents will be able to decide on the type, direction and number of openings within a module, the desired ratio between interior and semi-outdoor spaces through setbacks and overhangs, the location of glass enclosure, the amount of natural light desired versus shaded spaces, et al.

At last, China, one of the intended contexts for this design research has seen relentless societal changes from the country’s economic reforms and growth since the 70’s. Poverty has diminished yet a larger social divide based on income continues to rise (a consequence from what is often referred to as dual track economy). On one end of the spectrum, a more dominant working class is demanding from government officials better living standards. On the other end, a growing urban middle class increasingly seeks more choices in shaping their own living environment and immediate communities. Rather than polarizing this social divide further by categorizing social classes with their specifically projected housing types (i.e. high end versus low cost housing), the prototypes aspire to project architectural strategies for high density housing that try to reconcile this segregation by offering a mix of socially different living units through mass customization.

IV. CONCLUSION

A. *Environmental impact*

In developing housing prototypes that further employ total concrete precast structures comprised of volumetric units or cells systems, a first long term impact is environmental.

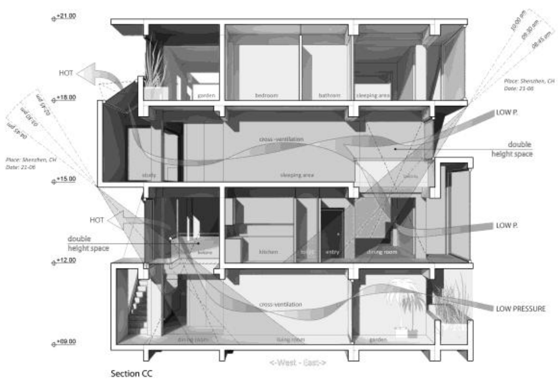

Fig. 15. SML prototype section showing environmental characteristics.

Some of the main benefits are:

-Naturally ventilated spaces shaded indoor and outdoor spaces "Fig. 15".

-A better outcome for the life cycle of a residential building; from installation to maintenance and to dis-assembly. Commonly, a residential building in Hong Kong has a life span of around 50 years after which it is likely to be replaced. Dismantling precast constructions to its original parts is safer and can be managed under better control than precarious urban demolition today [21].

-Since precast elements are mass produced in a controlled environment from reusable formworks, waste of large amount of formwork materials necessary for onsite construction are significantly reduced as well as its associated air and noise pollution.

Overall this will minimize the time and cost of construction in situ.

-In addition, a factory environment offers a higher quality control of its architectural finishes (more sophisticated formwork materials) and of its structural performances (prestressed capabilities). This will ensure a greater durability of its products which ultimately decreases the need for maintenance of a building during its life cycle.

B. *Technological impact*

The second long term impact is technological. By advancing the use of volumetric units systems in precast technologies, there is a greater potential to fully integrate fixtures (i.e. toilet / kitchen / bathroom), window enclosures, various materials for finishes and services (i.e. clear and black water, electricity) within the specific concrete units prior to installation on site. In doing so, the construction rate will once again increase. A few recent precedents already exist where integration of such elements (bathroom/kitchen) within precast units were tested. Another area for technological advance is in the conception and making of the concrete formworks for more complex architectural forms and structural innovations. Alternative formwork materials, other than traditional timber, can be better experimented with and implemented in a factory environment (i.e. steel, aluminum, fiberglass, geotextiles, et al.). Furthermore, improvement of details for moment connection of precast volumes greatly reduces the need for additional structural elements and facilitates continuous assembly on site "Fig. 16".

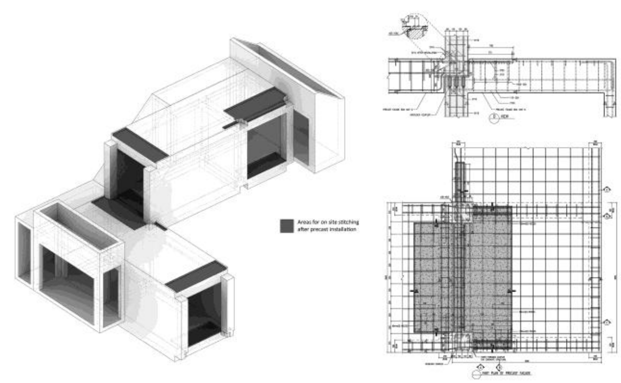

Fig. 16. Connection details between precast volumes.

C. *Social impact*

The third long term impact is of social values. From a construction perspective, the amount of labor necessary on site will become less yet more specialized, likely to improve health and safety standards and to incite workers to enhance their professional skills. In view of the building outcomes, innovation in mass customized precast cells systems and volumetric plug-ins units will bring forward more individual choices for the future dwellers in shaping their own living spaces with regard to their projected living standards. This will cause the current trend of relentless 'repetition of the same' seen in housing development today (regular and repeated layout) to hopefully sway towards more 'repetitions of differences', enhancing substantially the spatial quality of the units "Fig. 17" and as a result the wellbeing of its occupants. Overall, the development and implementation of this new precast model will influence the general opinions on precast technology in housing by remaining economically viable and efficient in regards to construction.

Fig. 17. Interior view of duplex unit.

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