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Expert Reviewed

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Light-Timber Frames for Transitional Disaster-Relief Housing

In the aftermath of a natural disaster such as a hurricane or earthquake, victims could get more than temporary help if the structures erected to provide immediate relief could be easily converted into permanent structures. These converted, repurposed buildings could become long-term housing, schools, and clinics—or farm and light-industrial buildings.

Canvas-covered, skeletal, light-timber frames meet this need, since they offer immediate, safe shelter. Afterwards, they can readily be modified to become permanent structures, or they can be disassembled, moved, and reconstructed at other permanent locations.

Relief Structure Basics for Timber Frames

Relief structures must be simple in concept, low-cost, and easily erected—yet provide adequate shelter from wind, rain, and sun. Certain basics are required. Each structure should have a floor. In cold climates, each structure also should have a heating source and insulation. Initial structures should require only ground anchors, which subsequently can be replaced with corner foundations that anchor and level the structure.

Ideally, frame members for the structure should be available as a ready-to-assemble kit with precut and engineered members so that only the simplest tools are required for erection without the need for heavy

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equipment. A simple drawing of the assembled structure should provide all the information needed for erection. Only limited construction skills should be needed, and the framework should be self-aligning. Also, the design should be such that during the transition from temporary to permanent housing, needed additional members can be processed from locally available materials by local cottage industry.

Frame size can vary; optimum width is 16 feet or less, although lengths of 8, 12, or 16 feet are satisfactory and can be expanded as needed. Recommended corner post size is a nominal 4 x 4 inches by 8 feet; recommended interior stud size is 2 x 4 inches by 8 feet.

It is extremely important to anchor the initial framework to the ground. This can be done with either steel or nylon strapping, which passes over the entire framework and is attached to ground anchors as shown in **Figure 1**. Steel or nylon strapping can also be used to reinforce the initial skeletal framework itself as is shown in **Figure 2**. As shown, the strapping can be threaded through preexisting holes in the wall and toe plate to provide effective resistance to strong horizontal winds. In addition, the straps can be attached to ground anchors to provide resistance to vertical lift.

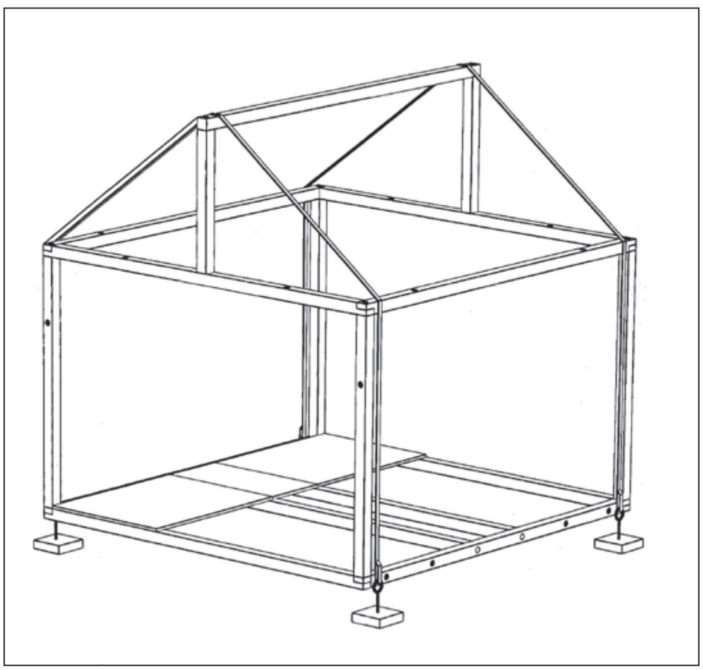

Figure 1. Use of steel or nylon strapping to anchor temporary framework in place.

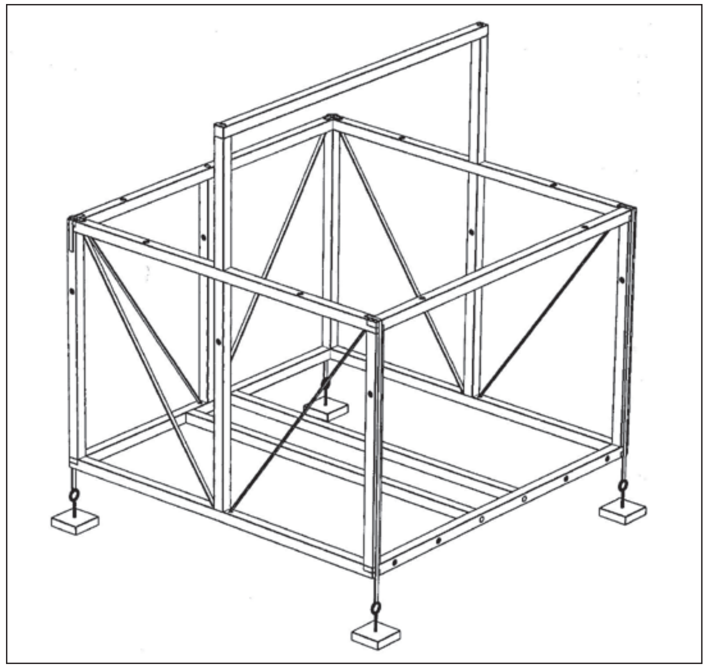

Figure 2. Use of steel or nylon strapping to brace and anchor temporary framework in place.

The Tinkertoy Approach

In addressing this serious and complex problem, we can learn from children's toys. With Tinkertoys©, for example, children can create relatively complex structures from standardized members using what are essentially round mortise and tenon joints. Importantly, no tools are needed for assembly.

A considerable body of research has already been conducted concerning light-timber frames constructed with round mortise and tenon joints (Eckelman, et al, 2002, 2006a). Additional research has assessed the performance characteristics of round mortise and tenon joints (Akcay, et all, 2005; Eckelman, et al, 2006b, 2007a, 2007b, 2008a). Two simple frameworks constructed with standardized members and round mortise-and-tenon joints are illustrated in **Figures 3a and 3b**.

In **Figure 3a**, a minimal structure is shown with the framework and members needed to support a canvas covering and a panel floor. This would be the minimum construction needed in a relief situation. Importantly, the initial basic structure provides above-ground flooring. Furthermore, if panel flooring is used as shown in **Figure 3a** and is superimposed on top of the floor plate, the holes drilled to receive the tenons on the ends of the studs form an L-shaped right angle and ensure the squareness of the frame. Also, as shown in **Figure 3a**, "runners" can be used

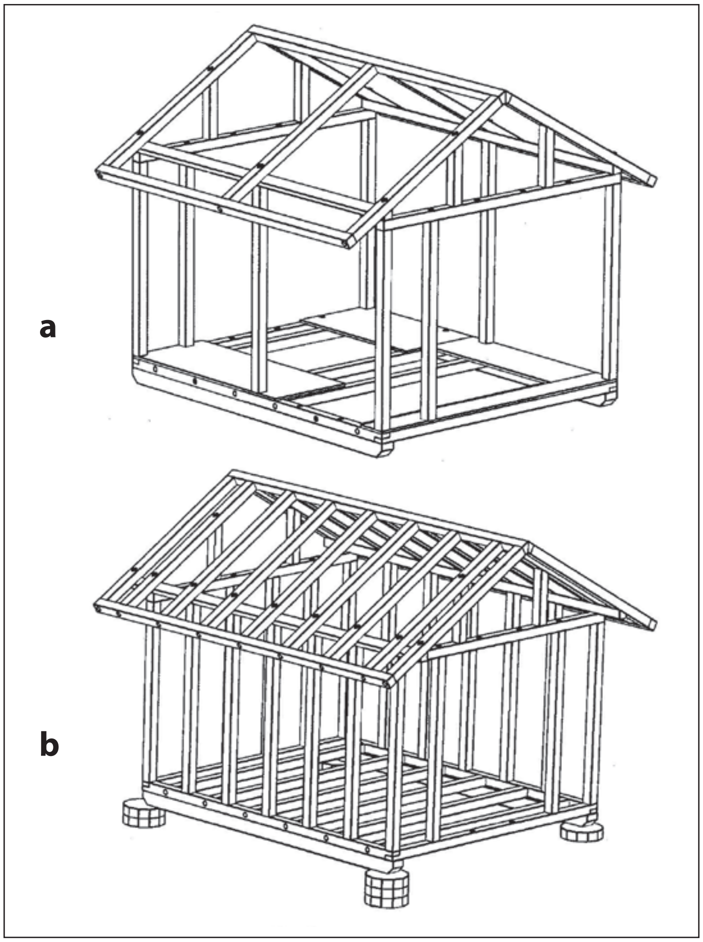

Figure 3. Transitional framework constructed with round mortise and tenon joints.

to provide an initial foundation; these runners in turn subsequently can be leveled and permanently supported at each corner.

In **Figure 3b** the structure is shown fully assembled—ready for the attachment of horizontal nailers or vertical siding that would make it a permanent structure.

Parts for these constructions can be mass-produced in factories and shipped where needed—tenons can either be turned on lathes or cut with large hole-saws, whereas mortises may be drilled with multiple head drill presses (or a single drill press). Parts can also be produced from locally available materials by cottage industries with equipment as simple as a modified concrete core cutter and appropriately sized hole-saws and drill bits.

This type of construction is not limited to round mortise and tenon joinery. Such structures can also be constructed with rectangular mortise and tenon joints using "built-up" member and joint construction. "Built-up" mortise and tenon joints with full-width tenons similar to those shown in **Figure 4** are well suited for the construction of ready-to-assemble frames, largely because they are simple to assemble without specialized tools. The ends of members such as studs are simply inserted into mortises in mating members such as sills and wall plates and pinned in place.

Mortise and tenon joints, in general, have a long history of use in house, barn, and bridge construction and are known and accepted in many areas of the world. Similarly, "built-up" sills and plates along with posts have a long history of use. "Built-up" sills, for example, are described in early textbooks of the 1900s (Townsend, 1907), and "built-up girders" are described by Anderson and Heyer (1955).

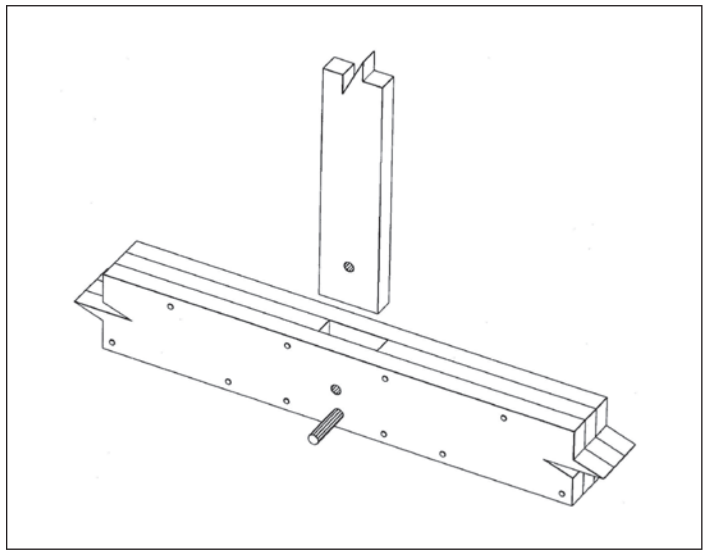

Figure 4. Built-up nail glued mortise and tenon joint construction.

The key elements of a ready-to-assemble, built-up mortise and tenon system are mortised sills, plates, or posts that are built-up (nail-glued, for example) from standard members into which studs, joists, or other members may be inserted (**Figure 5**). In a disaster situation, the skeleton structure shown in **Figure 5a** could be rapidly erected and covered with canvas. Subsequently, studs and rafters could be added along with horizontal nailers to create a more permanent structure. The resultant frame could be roofed and sided in a manner similar to that shown in **Figure 5b**. Other information on this type of construction and "partial width tenon" construction is given in Eckelman and Haviarova (2008b); Schmidt, et al (1997); and Miller (2004).

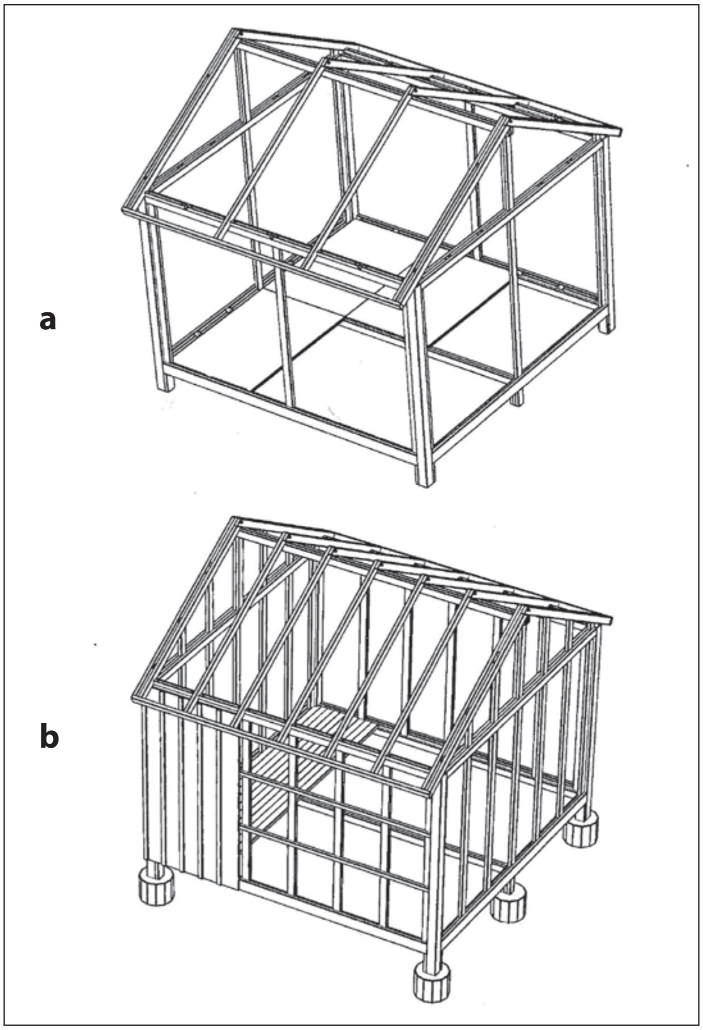

Figure 5. a) Initial transitional skeleton tent frame constructed with "built-up" mortise-and-tenon joints; b) drawing of structure after additional rafters, studs, and horizontal nailers have been added and partial vertical siding applied.

The Erector Set Approach

In contrast to the Tinkertoy© approach discussed above, another toy construction system—the Erector© set—is used by children to create complex constructions by simply bolting standardized members together. Only a screwdriver and wrench are required.

The Erector© set concept, as applied to disaster relief construction, uses a modified form of through-bolt with dowel-nut joinery to fasten pre-cut standardized members together. Through-bolt with dowel-nut fasteners were originally used in furniture construction, but they are also well-suited for timber frame construction (Eckelman, 2004). The dowel-nut itself consists of a length of steel rod with a threaded hole machined through it at mid-length perpendicular to the longitudinal axis of the rod. A less expensive, yet effective, modification of a dowel-nut is a cross-pipe with nut, hereafter referred to as pipe-nut, as shown in **Figure 6**.

In this construction, a hole is first drilled through a short length of pipe perpendicular to its longitudinal axis, and then a nut is slipped into the pipe and aligned with the hole. The key to a good connector is a close fit between the nut and the inside diameter of the cross pipe. A light "force fit" between the nut and the inside wall of the pipe is obtained with a 5/8-inch nut in a 1-inch diameter schedule 40 black pipe. Likewise, a close fit is obtained with a 3/8-inch nut in a 1/2-inch diameter schedule 40 black pipe. In this case, however the nut should be secured in place with a drop of adhesive.

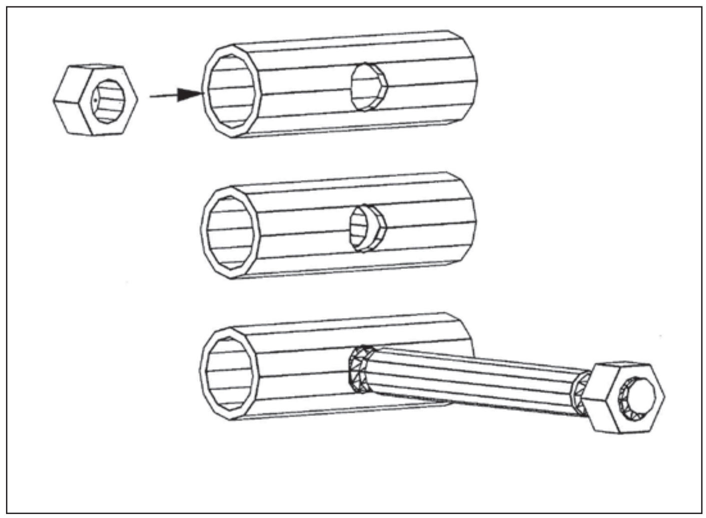

Figure 6. Through-bolt with pipe-nut fastener.

The use of through-bolts with pipe-nuts to attach a wall stud to a floor plate is shown in a "cut away" view in **Figure 7**. This type of connection is particularly useful in that it allows entire wall panels to be constructed and then joined at the corners to form a four-wall structure. A simple initial framework constructed with through-bolts and pipe-nuts suitable for supporting a canvas cover is shown in **Figure 8**.

Either two or three "runners" provide the foundation for this construction—the other members are attached to the runners with through-bolts and pipe-nuts. Initially, the framework may be squared through the use of a single diagonal member as shown in **Figure 9**—which also shows the foundation and anchor supports.

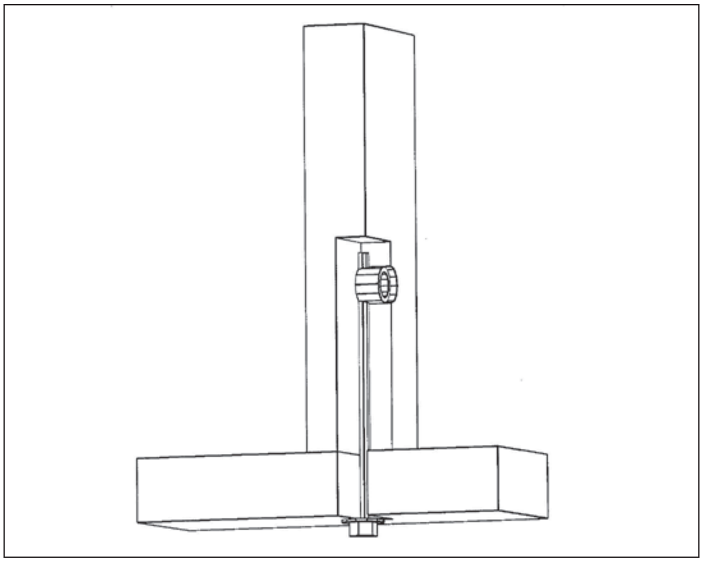

Figure 7. Through-bolt with pipe-nut fastener used to attach wall stud to floor plate.

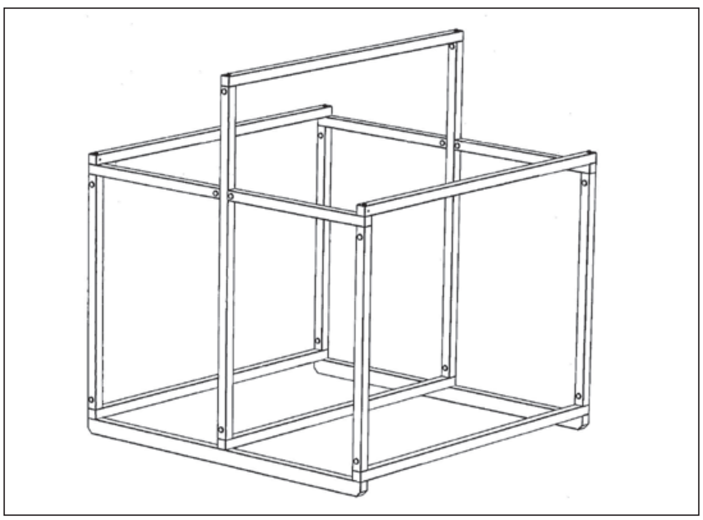

Figure 8. Through-bolt with cross-pipe and nut fastener used to attach wall stud to floor plate.

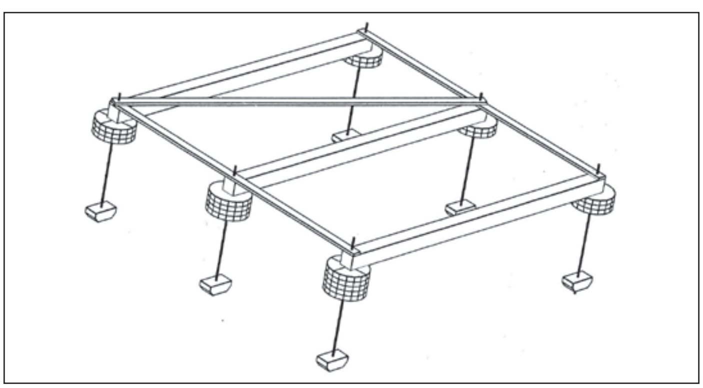

Figure 9. Use of runners to elevate floor above ground and provide temporary foundation. Also, simple method used to ensure "squareness of foundation."

Summary

Transitional disaster relief housing should be easy to erect without the need for complex tools or heavy equipment. Construction should be simple so that a drawing provides all of the information needed by untrained workers. Foundations for the frames should require only simple ground anchors that firmly fix the frame in place.

Light-timber frames can meet these requirements, whether constructed with a) round or rectangular mortise-and-tenon joints in which the tenons of one member fit into mortises cut into matching members, or b) mechanical joints, namely, through-bolt with pipe-nut joints, in which precut members are simply bolted together to form an basic skeletal frame to which additional members may be added to form a permanent structurestructure as shown in Figure 10.

The members used in initial frames should be easy to machine so that subsequent members can be produced by local cottage industries from native materials such as fast growing tree stems or other small diameter timber. In addition, the equipment used to shape members locally should also be simple in concept and inexpensive—a portable concrete core cutter or hole saw, for example, can be used to cut round tenons, and the same tool fitted with a Forstner bit can be used to bore mortises.

References

Akcay, H., C. Eckelman, E. Haviarova. 2005. Withdrawal, lateral shear, and bending moment capacities of round mortise and tenon joints. *Forest Products Journal* 55(6):60-67.

Anderson, L.O., and O.C. Heyer. 1955. *Wood-Frame House Construction*. Ag. Handbook No. 73. USGPO. Wash., DC. 235 pp.

Eckelman, C.A., H. Akcay, R. Leavitt, and E. Haviarova. 2002. Demonstration building constructed with round mortise and tenon joints and salvage material from small-diameter tree stems. *Forest Products Journal* 52(11/12):82-86.

Eckelman, C. 2004. Exploratory study of high-strength low-cost through-bolt with cross pipe and nut construction for roundwood and squared timber frame construction. *Forest Products Journal* 54(12): 29-37.

Eckelman, Carl A, Huseyin Akcay, and Eva Haviarova. 2006a. Performance tests of small barn frame constructed with round mortise and tenon joints. *Forest Products Journal* 56(4):41-47.

Eckelman, C., H. Akcay, and E.Haviarova. 2006b. Exploratory study of the withdrawal resistance of round mortise and tenon joints with steel pipe cross pins. *Forest Products Journal* 56(11/12):55-61.

Eckelman, C., E. Haviarova, and H. Akcay. 2007a. Parallel-to-grain end-load capacity of round mortises in round and rectangular timbers. *Forest Products Journal* 57(4):66-71.

Eckelman, C., H. Akcay, and E. Haviarova. 2007b. Exploratory study of truss heel joints constructed with round mortise and tenon joints. *Forest Products Journal* 57(9):1-5.

Eckelman, C., E. Haviarova, and H. Akcay. 2008a. Exploratory study of the moment capacity and semi-rigid moment-rotation behavior of round mortise and tenon joints. *Forest Products Journal* 58(7/8)56-61.

Eckelman, C., and E. Haviarova. 2008b. Rectangular mortise and tenon semi rigid joint connection factors. *Forest Products Journal* 58(12):49-55.

Miller, Joseph F. 2004. Capacity of pegged mortise and tenon joinery. MSc. Thesis. University of Wyoming.

Schmidt, R. J., and R. B. MacKay (1997). *Timber Frame Tension Joinery*. Univ. of Wyoming, Laramie. 87 pp.

Townsend, Gilbert. Carpentry and Joinery. 1907. *Technical World Magazine*. Chicago. 145 pp.

Figure 10 . Example of a potential permanent structure

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